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Original Article

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# Comparison of Single or Double Titanium Mesh Cage for Anterior Reconstruction After Total *En Bloc* Spondylectomy for Thoracic and Lumbar Spinal Tumors

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**Objective:** To compare the clinical efficacy of anterior column reconstruction using single or double titanium mesh cage (TMC) after total *en bloc* spondylectomy (TES) of thoracic and lumbar spinal tumors.
**Methods:** A retrospective cohort study was performed involving 39 patients with thoracic or lumbar spinal tumors. All patients underwent TES, followed by anterior reconstruction and screw-rod instrumentation via a posterior-only procedure. Twenty-two patients in group A were treated with a single TMC to reconstruct the anterior column, whereas 17 patients in group B were reconstructed with double TMCs.
**Results:** The overall follow-up is 20.5 ± 4.6 months. There is no significant difference between the 2 groups regarding age, sex, body mass index, tumor location, operative time, and intraoperative blood loss. The time for TMC placement was significantly shortened in the double TMCs group (5.2 ± 1.3 minutes vs. 15.6 ± 3.3 minutes, $p = 0.004$). Additionally, postoperative neural complications were significantly reduced with double TMCs (5/22 vs. 0/17, $p = 0.046$). The kyphotic Cobb angle and mean intervertebral height were significantly corrected in both groups ($p \leq 0.001$), without obvious loss of correction at the last follow-up in either group. The bone fusion rates for single TMC and double TMCs were 77.3% and 76.5%, respectively.
**Conclusion:** Using 2 smaller TMCs instead of a single large one eases the placement of TMC by shortening the time and avoiding nerve impingement. Anterior column reconstruction with double TMC is a clinically feasible, and safe alternative following TES for thoracic and lumbar tumors.

**Keywords:** Spinal neoplasms, Surgical decompression, Instrumentation, Titanium alloy

## INTRODUCTION

Vertebral tumors, though relatively rare, present a complex and challenging spectrum of conditions that significantly impact spinal health and overall well-being. These tumors, arising either within the spinal column (primary) or spreading from other parts of the body (metastatic), pose intricate clinical and therapeutic considerations owing to their potential for causing spinal instability, neurological compromise, and associated morbidity.[1,2] In general, spinal tumor treatment imposes a substantial economic burden on both patients and society. The average cost of the hospital admission was estimated to be $55,801, with a 90-day readmission rate reaching up to 11.6%.[3]

Total *en bloc* spondylectomy (TES) is intended to completely remove the tumor while preserving the integrity of the tumor border. It has been reported to decrease the local recurrence and prolong survival in appropriately selected patients.[4,5] The operation involves the complete removal of the vertebral body and surrounding ligament structure, resulting in severe instability of the spine. Rigid reconstruction is of vital importance after tumor resection. Titanium mesh cage (TMC) is most commonly used for anterior column reconstruction.[6] By filling the space left by the tumor, TMC restores vertebral height and helps maintain proper alignment, reducing the risk of spinal deformity or collapse. In the meanwhile, TMC serves as a container for bone graft material, promoting bone fusion and integration, aiding in the reconstruction of the affected vertebral segment.[7]

In order to achieve solid stability, a large TMC filled with allografts or autografts is typically used to reconstruct the anterior column. Studies suggest that the most suitable diameter of a TMC equals the diameter of the lower endplate of the adjacent cephalad vertebra.[8] However, the placement of a large TMC carries the risk of iatrogenic injury to the surrounding neural elements. Especially in the thoracic spine, this often requires significant traction or even ligation of unilateral nerve root to accommodate the TMC adequately.[9] In contrast, while a cage of smaller diameter is safer to insert, it provides insufficient bone graft contact area, which will increase the risk of nonfusion, subsidence, or endplate fracture.[10] Therefore, we adopted a different strategy, opting to use 2 smaller TMCs instead of a single large one for anterior reconstruction, aiming to minimize the risk of neural complications while ensuring adequate stability. The aim of this study is to evaluate the clinical efficacy and long-term safety of anterior reconstruction using double TMCs by comparing its outcomes with those associated with a single TMC.

## MATERIALS AND METHODS

### 1. Patient Data

Between 2012 and 2022, a retrospective review was conducted on 51 patients diagnosed with thoracic or lumbar spinal tumors who underwent TES and anterior column reconstruction using TMC, 45 (88.2%) were occupied with single-level TES. Prior to 2018, our center routinely utilized a single large TMC for anterior reconstruction following TES. Since 2019, we have adopted a different strategy, opting to use 2 smaller TMCs instead of a single large one for anterior reconstruction, aiming to minimize the risk of neural complications while ensuring adequate stability. The inclusion criteria of this study include: (1) pathologically confirmed single-segment thoracic or lumbar spinal tumors (primary or metastatic), (2) patients receiving TES and anterior reconstruction using single or double TMC, and (3) patients who were followed for at least a year. The exclusion criteria were: (1) tumors located in the cervical or sacral spine, (2) recurrent tumors, (3) patients undergoing subtotal corpectomy or total piecemeal spondylectomy, and (4) patients who were lost to follow-up. Patients were divided into 2 groups based on the implant used. After screening, 39 patients were included in this retrospective cohort study, with written informed consent obtained from all patients or their legal guardians.

Data regarding the patient's age, sex, body mass index (BMI), and preoperative symptoms were obtained from a review of clinical notes. The severity of back pain was evaluated using the visual analogue scale (VAS), while the American Spinal Injury Association (ASIA) impairment scale was assessed for motor function. Operative duration, estimated blood loss, instrumentation method, and any complications associated with the surgery were obtained from operative notes. Plain radiographs were examined to evaluate anterior body height compression, kyphotic Cobb angle, mean intervertebral height (MIH), TMC subsidence or dislocation, bony fusion, and the presence of instrumentation failure. The exposure distance was universally set at 100 cm, with a current of 630 mA and a voltage of 80 kv. The exposure time varies among different patients, depending on factors such as the thickness of the chest wall and the inflation of the lungs, ranging from 32 msec to 46 msec.

This study was approved by the Institutional Review Board of General Hospital of Northern Theater Command (Y(2022)180) where the experiment was performed. A written informed consent was obtained from all patients or their legal guardians.

### 2. Measurement of Radiographic Parameters

- *MIH* was defined as the average of anterior intervertebral height (AIH) and posterior intervertebral height (PIH) on the sagittal plain radiograph. Whereas AIH was the distance between the most anterior point of the inferior edge of the upper vertebra and the most anterior point of the superior edge of the lower vertebra, while PIH was the distance between the most posterior point of the inferior edge of the upper vertebra and the superior edge of the lower vertebra.[11] MIH was calculated before surgery, immediately after operation, and at 1-year follow-up (Fig. 1).
- *Kyphotic Cobb angle* was measured as the angle between the superior endplate of the vertebral body above the affected level and the inferior endplate of the vertebral body below the affected level (Fig. 1).

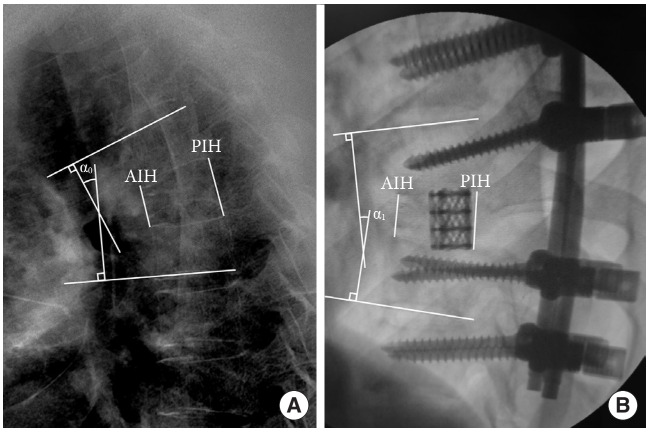


**Fig. 1.** Radiological measurement of mean intervertebral height (MIH) and Cobb angle (α0) in preoperative (A) and postoperative images (B). MIH was measured as the average of anterior intervertebral height (AIH) and posterior intervertebral height (PIH) on sagittal plain radiograph. Whereas AIH was the distance between the most anterior point of the inferior edge of the upper vertebra and the most anterior point of the superior edge of the lower vertebra, while PIH was the distance between the most posterior point of the inferior edge of the upper vertebra and the superior edge of the lower vertebra. Kyphotic Cobb angle (α1) was measured as the angle between the superior endplate of the vertebral body above the affected level and the inferior endplate of the vertebral body below the affected level.

- *Anterior body height compression* was calculated in patients with pathologic fracture according to the following formula: $b_0 = (1-2*A_0/[A_p+A_d])*100\%$, where $b_0$ was the percentage of anterior body height compression; $A_0$ was the anterior body height of the compromised vertebra; and $A_p$ and $A_d$ were the anterior body heights of the proximal and distal levels.[10]
- *Bone fusion* was evaluated according to the radiologic criteria of Bridwell et al.,[12] whereas Bridwell I and II were indicated as satisfied fusion whereas mature bony trabeculae that bridged across the cage between the adjacent upper and lower endplates without radiolucent line were observed.
- *TMC subsidence* was defined as the loss of the MIH more than 3 mm at each time point compared to the measurement taken preoperatively.[11]
- *TMC oblique* was defined as a mismatch of > 10° between the adjacent endplates (or osteotomy planes) on serial postoperative radiographs.[13]
- *Other internal fixation failures* include loosening, pulling out, or breakage of the screws and rods, as well as TMC dislodgement.

All measurements were independently performed by 2 authors (AL and JL). If there was no significant difference, the values were averaged. In cases of significant difference, a third author was consulted to perform additional measurements and make a final determination (Supplementary Table 1).

**3. Surgical Procedure**

All surgeries were performed by the same group of surgeons at our center. The patients were placed in the prone position following administration of general anesthesia. A posterior midline incision was made over the affected level, and the lamina, facet joints, and transverse processes were meticulously exposed and visualized. Poly-axial pedicle screws were placed in 2 segments above and below the index vertebra.[14] The diameter and length of pedicle screws were initially measured using preoperative radiographs and adjusted during surgery with the assistance of intraoperative fluoroscopy C-arm. A temporary rod was placed on the less affected side to stabilize the spine, reducing the risk of spinal cord injury due to instability during decompression. The surgical procedure involved blunt dissection to separate the vertebral body and anterior structures. Either a thread-wire saw or an ultrasonic osteotome was used to cut off bilateral vertebral pedicles, without sacrifice of the nerve root, followed by the extraction of posterior structures. Adjacent intervertebral discs and endplates were dissected before the vertebral body was rotated and removed in one piece. After tumor resection, a vernier caliper was used to measure the distance between the lower endplate of the superior vertebrae body and the upper endplate of the inferior vertebrae body. TMCs were then appropriately sized and packed with morselized artificial bone graft made of β-tricalcium phosphate, without the application of growth factors. Two TMCs were inserted obliquely into the corpectomy defect via bilateral corridors without traction of the nerve roots or the dural sac. Two rods of Ti6Al4V (diameter, 6.0 mm) were connected to each pedicle screw and the posterior instrumentation was adjusted to slightly compress the inserted cage. Distilled water was applied to the surgical site for 5 minutes before closure and the placement of drainage catheters. In all cases, a rigid spinal brace was used for a postoperative period of at least 3 months. Follow-up evaluation was performed at 3 months, 6 months, and 1 year postoperatively with plain radiographs, computed tomography (CT), ASIA classification, and complication assessment (Fig. 2).

**4. Statistical Analysis**

Statistical analyses were conducted using IBM SPSS Statistics


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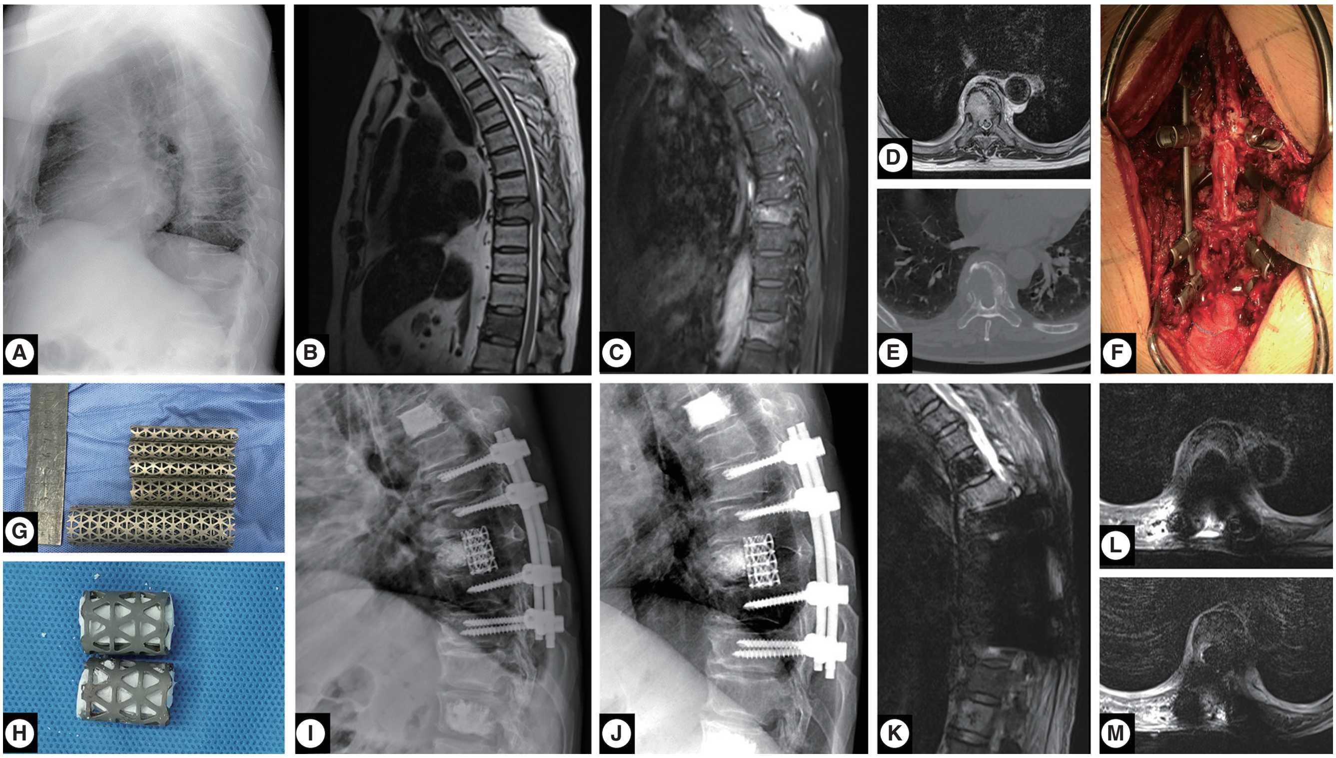


**Fig. 2.** A 67-year-old female patient (case #33) was admitted with motor dysfunction and mild back pain. (A) Preoperative plain radiographs reveal compression of the eighth thoracic vertebra. (B–D) To further clarify the cause of vertebral compression and observe any neurological involvement, an enhanced magnetic resonance imaging (MRI) was ordered for the patient. Through MRI, we noticed abnormal long T1 and long T2 signals in the eighth and twelfth thoracic vertebra, with significant enhancement on the contrasted sequence. Meanwhile, we noticed high signal intensity in corresponding thoracic spinal cord, and nodular high signals at the level of thoracic vertebrae 4–7, with significant enhancement on the contrasted sequence. (E) Through preoperative computed tomography, we noticed an eccentric lytic lesion without calcification inside the tumor. (F) A total *en bloc* spondylectomy was performed at the T8 level, while vertebroplasty was performed in T4 and T12. (G, H) Two appropriately sized titanium mech filled with morselized artificial bone graft were inserted via bilateral corridors without traction of the nerve roots or the dural sac. (I) Postoperative plain radiographs demonstrated satisfactory alignment and restoration of intervertebral height. (J–M) Follow-up evaluation at 1 year showed no instrumentation failure or local recurrence.

ver. 22.0 (IBM Co., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation. The normality of distribution was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene test. Pillai's Trace multivariate test was conducted following Mauchly test of sphericity. Categorical variables were presented as percentages. One-sided Fisher exact test was used to compare binary data between independent groups. Statistical significance is assumed at a p-value of $< 0.05$.

## RESULTS

### 1. Preoperative Information

Among the 39 patients enrolled in our study, there were 20 males and 19 females, with an average age of 52.1 ± 13.4 years and a range of 23 to 76 years. Of these, 14 received treatment for primary spinal tumors, consisting of 5 chondrosarcomas, 4 invasive hemangiomas, 3 synovial sarcomas, and 2 fibromas. The remaining 25 patients were admitted for metastatic spinal tumors, and the tumor histology was as follows: 9 lymphomas, 3 prostate cancers, 4 breast cancers, 3 renal cancers, 5 lung cancers, and 1 multiple myeloma. The average age for patients with primary or metastatic diseases was 50.7 ± 12.9 years and 52.8 ± 13.7 years, respectively. In 12 patients (31%), tumors were located in the lumbar spine, while 27 patients (69%) had tumors in the thoracic spine. Sixteen patients developed pathologic fractures, with an average anterior body height compression of 36.3%. Preoperative evaluation using VAS indicates an average score of 6.5 ± 1.0 and 6.1 ± 0.8, respectively, for each group. At the time of admission, 11 patients (28.2%) displayed normal

**Table 1.** General information of patients

| Variable | Single TMC (n = 22) | Double TMC (n = 17) | p-value |
|---|---|---|---|
| Age (yr) | | | 0.485 |
| Mean ± SD | 50.7 ± 14.2 | 53.8 ± 12.1 | |
| Range | 31–76 | 23–67 | |
| Sex | | | 0.517 |
| Male | 11 (50) | 11 (64.7) | |
| Female | 11 (50) | 6 (35.3) | |
| BMI (kg/m$^2$) | 24.4 ± 2.4 | 23.7 ± 2.2 | 0.358 |
| Tumor histology | | | 0.318 |
| Primary | 9 (40.9) | 4 (23.5) | |
| Metastatic | 13 (59.1) | 13 (76.5) | |
| Tumor location | | | 0.730 |
| Thoracic | 16 (72.7) | 11 (64.7) | |
| Lumbar | 6 (27.3) | 6 (35.3) | |
| Presence of pathologic fracture | 10 (45.5) | 5 (29.4) | 0.343 |
| Preoperative VAS score | 6.5 ± 1.0 | 6.1 ± 0.8 | 0.198 |
| Postoperative VAS score | 2.1 ± 1.0 | 2.4 ± 1.0 | 0.401 |
| Chemotherapy | 14 (63.6) | 14 (82.4) | 0.177 |
| Total operative time (min) | 299.6 ± 41.3 | 301.2 ± 48.7 | 0.913 |
| Time for TMC placement (min) | 15.6 ± 3.3 | 5.2 ± 1.3 | 0.004 |
| Estimated blood loss (mL) | 1,431.8 ± 552.4 | 1,647.1 ± 1,010.6 | 0.401 |
| Nerve disturbance | 5 (22.7) | 0 (0) | 0.046 |

Values are presented as mean ± standard deviation or number (%) unless otherwise indicated.
TMC, titanium mesh cage; SD, standard deviation; BMI, body mass index; VAS, visual analogue scale.

**Table 2.** Neurologic status evaluated by the ASIA impairment scale (AIS)

| AIS | Single TMC (n = 22) | | Double TMC (n = 17) | |
|---|---|---|---|---|
| | Preoperative | Final follow-up | Preoperative | Final follow-up |
| B | 3 | 1 | 1 | 0 |
| C | 2 | 2 | 3 | 1 |
| D | 11 | 5 | 8 | 5 |
| E | 6 | 14 | 5 | 11 |

ASIA, American Spinal Injury Association; TMC, titanium mech cage.

motor function, 24 patients retained partial motor function, and 5 patients were paralytic. There was no significant difference regarding the baseline information between the 2 groups (Tables 1 and 2).

## 2. Perioperative Findings

All patients underwent TES, anterior reconstruction with TMC, and posterior instrumentation. Pedicle screws were placed 2 levels above and below the excised vertebra. Only in 1 patient involving a tumor in the thoracolumbar junction area (L1) with severe osteoporosis, the instrumentation was extended to 6 segments. The average operation time and estimated blood loss showed no significant difference between the 2 groups. However, the time for TMC placement was significantly shortened in the double TMC group (5.2 ± 1.3 minutes vs. 15.6 ± 3.3 minutes, $p = 0.004$). Ten patients developed surgery-related complications, including wound infection in 2 patients, nerve root disturbance in 5 patients, pleural effusion in 2 patients, and dural tear in 1 patient. While none of the patients reconstructed with double TMC experienced nerve root disturbance, 5 out of 22 patients treated with single TMC experienced either transient numbness or a decline in muscle strength after surgery ($p = 0.046$). Symptomatic treatment including glucocorticoids, methylcobalamin, as well as physical rehabilitation were prescribed, and all patients achieved full recovery at last follow-up. For patients with localized primary disease, postoperative radiation therapy is not typically prescribed. In the meanwhile, all patients diagnosed with metastatic tumors underwent chemotherapy or targeted therapy as evaluated by an oncologist or a specialist.

## 3. Postoperative Evaluation

After a mean follow-up of 20.5 ± 4.6 months, all patients with motor impairment achieved complete or partial improvement, except for 1 patient with preoperative grade B who remained the same after surgery (Table 2). In the meanwhile, the average VAS score dropped significantly from 6.5 ± 1.0 to 2.1 ± 1.0, and 6.1 ± 0.8 to 2.4 ± 1.0 for patients reconstructed with single or double TMC, respectively. Although ASIA and VAS scores improved in the last follow-up in both groups compared with preoperative assessment, there was no significant difference between the 2 groups. The radiographic outcomes are summarized in Table 3. In patients with kyphosis secondary to pathological fractures, the average preoperative Cobb angle significantly improved from 19.1° ± 4.9° before surgery to 7.1° ± 2.0° immediately postoperatively ($p < 0.001$). This correction was sustained at 8.4° ± 2.0° during the final follow-up, with no evident loss of correction ($p = 0.291$). Notably, no significant difference was observed between the 2 groups ($p = 0.291$) (Supplementary Fig. 1A). Meanwhile, the MIH was 34.5 ± 11.5 mm preoperatively, showing a significant increase to 39.1 ± 8.3 mm immediately after surgery ($p = 0.001$), but decreased to 37.0 ± 8.5 mm at the


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**Table 3.** Postoperative evaluations on MIH and Cobb angle

| Variable | Preoperative | Postoperative | Follow-up | Repeated measures ANOVA | | |
|---|---|---|---|---|---|---|
| | | | | F-value | p-value | Partial eta squared |
| MIH | | | | | | |
| Single TMC | 33.4 ± 10.9 | 37.8 ± 7.3 | 35.8 ± 7.6 | | | |
| Double TMC | 35.8 ± 12.5 | 40.7 ± 9.4 | 38.7 ± 9.5 | | | |
| Time | | | | 11.8 | 0.001* | 0.241 |
| Group | | | | 0.9 | 0.351 | 0.024 |
| Time*group | | | | 0.1 | 0.830 | 0.001 |
| Cobb angle | | | | | | |
| Single TMC | 17.8 ± 5.3 | 6.9 ± 2.1 | 8.2 ± 2.3 | | | |
| Double TMC | 21.3 ± 3.5 | 7.6 ± 2.0 | 8.6 ± 1.8 | | | |
| Time | | | | 151.2 | < 0.001* | 0.915 |
| Group | | | | 1.2 | 0.291 | 0.079 |
| Time*group | | | | 2.4 | 0.144 | 0.145 |

Values are presented as mean ± standard deviation.
MIH, mean intervertebral height; TMC, titanium mesh cage; ANOVA, analysis of variance.
*p < 0.05, follow-up compared with preoperative.

**Table 4.** Postoperative evaluation on subsidence rate and bone fusion rate

| Rate | Single TMC (n = 22) | Double TMC (n = 17) | p-value |
|---|---|---|---|
| Subsidence rate | 4 (18.2) | 3 (17.6) | 0.650 |
| Bone fusion rate | 17 (77.3) | 13 (76.5) | 0.623 |

Values are presented as number (%).
TMC, titanium mesh cage.

last follow-up. Yet, there was no significant difference noted between the 2 groups (p = 0.351) (Supplementary Fig. 1B). Regarding subsidence, the average measured was 2.0 ± 1.5 mm, with a subsidence rate of 17.9% (n = 7) at the final follow-up (Table 4). No significant difference was found regarding subsidence between single TMC and double TMCs (p = 0.65). Meanwhile, the bone fusion rates for single TMC and double TMCs were 77.3% and 76.5%, respectively, showing no significant differences between the groups (p = 0.623). Notably, no hardware-related complication including loosening, pulling out, or breakage of the screws and rods, TMC dislodgement, or TMC oblique occurred in both groups.

## DISCUSSION

In spine surgery, vertebrectomy is a common procedure employed for addressing traumatic, infectious, or neoplastic conditions.[15] Subsequent to vertebrectomy, anterior column reconstruction becomes imperative to maintain stability and reinstate weight-bearing function. Various options have emerged for anterior reconstruction, including bone grafts, bone cement, TMC, carbon fiber stackable cage, artificial vertebral body, etc.[6,16] Among these, TMC is the most commonly used, since it offers superior stability and demonstrates better cost-effectiveness.[10,17] The advantages of the TMC are that it provides robust structural support, varies in diameter and height, allows for more space for mercerized bone grafts, and offers exceptional strength while being lightweight.[9] Additionally, the radiolucent property of titanium aids in postoperative imaging, enabling better visualization during follow-up assessments.[18]

Despite these advantages, inserting a large, fixed-height TMC between vertebrae poses technical challenges and risks of impinging on the neural structures. In some instances, nerve roots are even sacrificed to accommodate larger cages for better anterior reconstruction.[9] On the contrary, cages with smaller diameters may mitigate nerve injury but elevate the risk of postoperative subsidence.[19] Based on a finite element analysis, the diameter of the TMC is correlated with its future stability, and the most suitable diameter for reconstruction equals 1/1 the diameter of the lower endplate of the adjacent cephalad vertebra.[8] As a result, expandable cages have been developed and introduced to ease insertion. However, there remain some limitation. These include instrumentation failure related to overexpansion, especially in patients with osteopenia or osteoporosis. Moreover, they might induce stress-shielding and lack adequate space for bone grafting, potentially leading to pseudarthrosis. Furthermore, a significant drawback of expandable cages is its high cost.[19,20] Therefore, in this study, we adopted a different strategy, opting to use 2 smaller TMCs instead of a single large one for anterior reconstruction, aiming to minimize the risk of neural complications while ensuring adequate stability.

Overall, all patients in this study experienced partial or complete improvement after decompression, with a significant decrease in the mean VAS score. Meanwhile, the time for TMC placement was significantly shortened with double TMC (5.2 ± 1.3 minutes vs. 15.6 ± 3.3 minutes, $p = 0.004$). In addition, 5 of 22 patients who received a single TMC experienced iatrogenic nerve root disturbances, displaying numbness and motor dysfunction after surgery. Conversely, among patients who received double TMCs, no nerve complications were observed. In addition to symptom alleviation, a primary concern is whether the use of double TMC can offer rigid stability, since the main drawback of TMC is its susceptibility to subsidence. According to Van Jonbergen et al., a reduction in postoperative intervertebral height exceeding 3 mm constitutes TMC subsidence.[21,22] Based on their criteria, an incidence of 20%–40% has been reported in literature.[23-25] In our study, 17.9% of patients developed subsidence, with an average of 2.0 ± 1.5 mm. However, there was no significant difference in the subsidence rate between the 2 groups ($p = 0.65$). This demonstrates the safety and feasibility of applying double TMC of smaller size. According to the study by Hou and Luo,[26] the double TMC with off-center positions were closer to the cortical rim of the vertebral body, which was the strongest part of the endplate. Furthermore, even if subsidence does occur, its impact on bone fusion and clinical outcome remains controversial. The systematic review of Karikari et al.[27] concluded that subsidence did not significantly affect successful fusion or clinical outcomes. Similarly, Yan et al.[28] found no correlation between cage subsidence, clinical outcomes, sagittal alignment, or fusion rate. However, Matsumoto et al.[29] identified cage subsidence > 5 mm as a risk factor for instrumentation failure. In our study, 2 out of 7 patients with subsidence > 3 mm developed chronic back pain, without neural function deterioration. Symptom relief was achieved through nonsteroidal anti-inflammatory drugs, physical therapy, and bracelet protection.

Based on previous studies, some risk factors associated with TMC subsidence have been identified. Patient-related factors include a BMI > 28 $kg/m^2$, perioperative radiotherapy, and poor bone density.[13,30] Instrumentation-related risk factors involve selection of an excessively long TMC, overdistraction during insertion, aggressive correction of spinal curvature, and positioning the TMC obliquely.[13,30,31] Additionally, a finite analysis points out that a mismatch between TMC and adjacent endplates also affects the biomechanical properties and increases the risk of internal fixation failure.[32] Therefore, to potentially prevent postoperative subsidence, measures such as avoiding overexpanding the intervertebral height, optimizing TMC placement, and initiating antiosteoporosis treatments 6 months before surgery might be beneficial.[30] However, due to the limited number of patients with subsidence in our study, we were unable to conduct a comprehensive Logistic analysis for risk factors. Nonetheless, we observed that patients who experienced subsidence had a significantly higher average age compared to those without subsidence (63.4 ± 7.7 vs. 49.6 ± 13.0, $p = 0.01$).

Certain limitations should be acknowledged. In this study, we exclusively performed TMC reconstruction for a single-level spondylectomy, the assessment of multilevel reconstruction was not performed. Additionally, although we compared baseline information between the 2 groups and found no significant difference, the retrospective nature of our study inherently introduces some selection bias. Meanwhile, the small number of patients and relatively short follow-up period of minimum 1-year limit our ability to conduct extensive statistical analysis. Furthermore, despite the superior accuracy of CT in assessing bone fusion, we opted for plain radiographs considering radiation exposure and financial burden. Additionally, since dual-energy x-ray absorptiometry tests are not routinely conducted in our center, we were unable to provide bone mineral density data for each patient. To enhance our understanding of TMC reconstruction, finite element analysis for biomechanical insights and validating these findings with larger clinical sample sizes would be beneficial.

## CONCLUSION

Using 2 smaller TMCs instead of a single large one eases the placement of TMC by shortening the time and avoiding nerve impingement. Anterior column reconstruction with double TMC is a clinically feasible, and safe alternative treatment following TES for thoracic and lumbar tumors.

## NOTES

**Supplementary Materials:** Supplementary Table 1 and Fig. 1 can be found via https://doi.org/10.14245/ns.2448052.026.

**Conflict of Interest:** The authors have nothing to disclose.

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**Author Contribution:** Conceptualization: QW, AL; Formal analysis: AL, JL; Data curation: QW, JL; Methodology: YL, SS; Visualization: LM, MG; Project administration: HY, LX; Writing – original draft: AL; Writing – review & editing: HY, LX.

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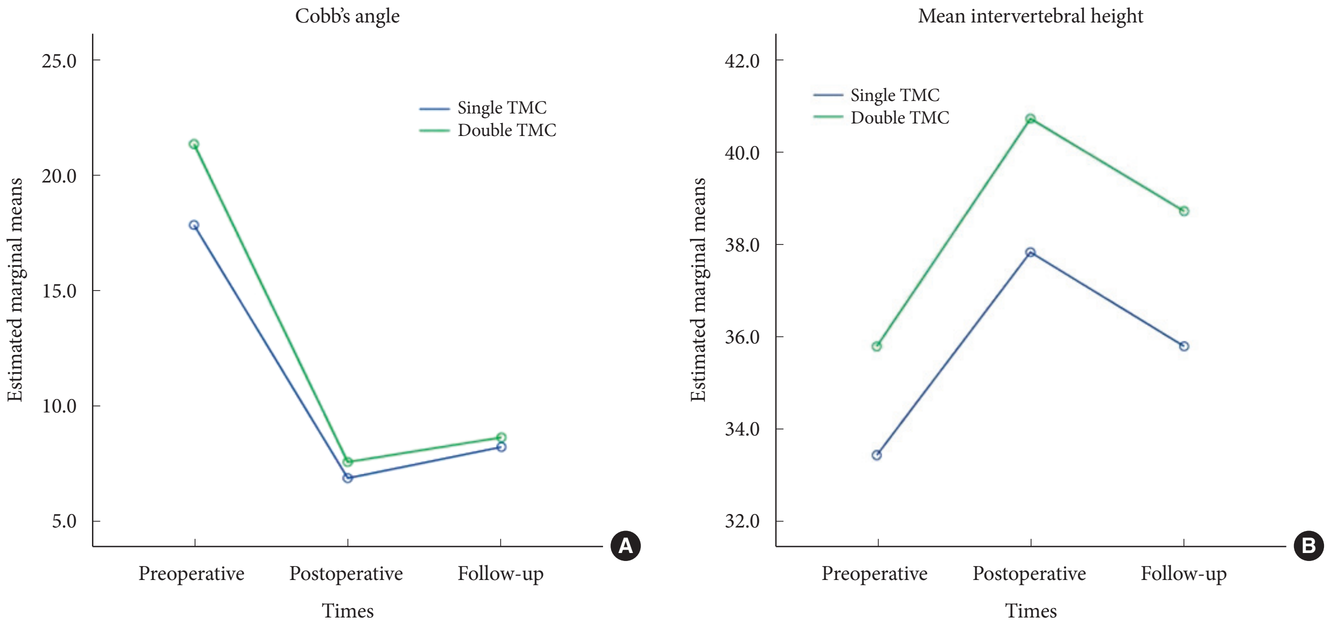
**Supplementary Table 1.** Radiologic measurement of mean intervertebral height, Kyphotic Cobb angle, and bone fusion

| Mean intervertebral height | | | | | | | | | Kyphotic Cobb angle | | | | | | | | | Bone fusion | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Preoperation | | | Postoperation | | | Follow-up | | | Preoperation | | | Postoperation | | | Follow-up | | | | | | |
| 1 | 2 | Final | 1 | 2 | Final | 1 | 2 | Final | 1 | 2 | Final | 1 | 2 | Final | 1 | 2 | Final | 1 | 2 | 3 | Final |
| 30.1 | 30.7 | 30.4 | 29.1 | 29.5 | 29.3 | 28.8 | 28.6 | 28.7 | | | | | | | | | | I | I | | I |
| 18.2 | 18.2 | 18.2 | 30.4 | 30.4 | 30.4 | 29.4 | 28.8 | 29.1 | | | | | | | | | | II | II | | II |
| 38.0 | 37.8 | 37.9 | 37.0 | 37.4 | 37.2 | 32.2 | 32.6 | 32.4 | 24.1 | 24.5 | 24.3 | 8.0 | 8.6 | 8.3 | 8.9 | 9.3 | 9.1 | III | IV | IV | IV |
| 50.2 | 49.4 | 49.8 | 48.6 | 48.8 | 48.7 | 46.0 | 46.0 | 46.0 | | | | | | | | | | II | II | | II |
| 15.5 | 15.5 | 15.5 | 30.2 | 30.2 | 30.2 | 27.7 | 25.3 | 27.5 | | | | | | | | | | II | II | | II |
| 32.3 | 32.3 | 32.3 | 29.0 | 29.4 | 29.2 | 27.6 | 27.8 | 27.7 | 27.5 | 26.9 | 27.2 | 9.5 | 9.5 | 9.5 | 11.0 | 10.4 | 10.7 | II | II | | II |
| 37.2 | 37.0 | 37.1 | 36.4 | 36.6 | 36.5 | 35.3 | 34.9 | 35.1 | | | | | | | | | | I | II | II | II |
| 35.6 | 35.6 | 35.6 | 34.9 | 34.9 | 34.9 | 30.8 | 30.8 | 30.8 | | | | | | | | | | II | II | | II |
| 52.6 | 53.2 | 52.9 | 52.1 | 52.1 | 52.1 | 48.4 | 48.2 | 48.3 | | | | | | | | | | III | III | | III |
| 24.3 | 24.3 | 24.3 | 30.2 | 30.4 | 30.3 | 28.5 | 28.5 | 28.5 | | | | | | | | | | I | I | | I |
| 48.6 | 49.0 | 48.8 | 49.5 | 49.9 | 49.7 | 48.3 | 48.9 | 48.6 | 13.1 | 13.5 | 13.3 | 7.2 | 7.8 | 7.5 | 7.7 | 7.9 | 7.8 | I | I | | I |
| 38.3 | 38.1 | 38.2 | 38.6 | 38.0 | 38.3 | 37.5 | 37.7 | 37.6 | | | | | | | | | | I | I | | I |
| 34.5 | 34.1 | 34.3 | 48.7 | 48.3 | 48.5 | 46.3 | 45.9 | 46.1 | | | | | | | | | | II | II | | II |
| 30.4 | 30.4 | 30.4 | 29.6 | 29.6 | 29.6 | 29.5 | 29.5 | 29.5 | 19.5 | 18.9 | 19.2 | 6.5 | 6.5 | 6.5 | 7.4 | 7.0 | 7.2 | II | II | | II |
| 23.4 | 23.4 | 23.4 | 29.6 | 30.0 | 29.8 | 28.8 | 28.2 | 28.5 | | | | | | | | | | III | III | | III |
| 22.3 | 23.2 | 22.8 | 28.8 | 29.0 | 28.9 | 28.9 | 28.9 | 28.9 | 16.8 | 16.6 | 16.7 | 6.6 | 6.0 | 6.3 | 7.5 | 7.1 | 7.3 | I | I | | I |
| 29.4 | 30.1 | 29.8 | 37.8 | 37.6 | 37.7 | 32.6 | 32.4 | 32.5 | 15.2 | 15.2 | 15.2 | 7.1 | 6.9 | 7.0 | 8.5 | 9.1 | 8.8 | IV | IV | | IV |
| 16.2 | 16.5 | 16.4 | 38.1 | 38.1 | 38.1 | 37.7 | 37.3 | 37.5 | 19.3 | 19.7 | 19.5 | 6.8 | 7.2 | 7.0 | 9.6 | 9.2 | 9.4 | I | I | | I |
| 21.6 | 22.1 | 21.9 | 45.5 | 44.9 | 45.2 | 40.6 | 40.6 | 40.6 | 27.2 | 26.6 | 26.9 | 9.1 | 9.7 | 9.4 | 10.0 | 10.6 | 10.3 | II | I | II | II |
| 45.0 | 45.0 | 45.0 | 46.8 | 46.8 | 46.8 | 46.3 | 46.3 | 46.3 | 22.4 | 22.4 | 22.4 | 5.5 | 5.3 | 5.4 | 7.3 | 7.1 | 7.2 | II | II | | II |
| 19.2 | 19.8 | 19.5 | 44.4 | 44 | 44.2 | 41.1 | 41.7 | 41.4 | | | | | | | | | | I | I | | I |
| 16.8 | 17.1 | 17.0 | 29.3 | 29.5 | 29.4 | 27.0 | 26.2 | 26.6 | 21.6 | 22.2 | 21.9 | 10.3 | 9.8 | 10.1 | 12.0 | 12.4 | 12.2 | I | I | | I |
| 24.2 | 24.2 | 24.2 | 30.5 | 30.5 | 30.5 | 25.0 | 25.4 | 25.2 | 20.2 | 20.2 | 20.2 | 10.9 | 10.1 | 10.5 | 11.6 | 11.0 | 11.3 | II | II | | II |
| 35.4 | 35.6 | 35.4 | 35.4 | 35.4 | 35.4 | 34.0 | 34.0 | 34.0 | 22.2 | 23.0 | 22.6 | 7.5 | 7.1 | 7.3 | 8.6 | 8.4 | 8.5 | I | I | | I |
| 30.3 | 30.5 | 30.4 | 37.7 | 38.3 | 38.0 | 36.5 | 35.9 | 36.2 | | | | | | | | | | I | I | | I |
| 54.4 | 53.8 | 54.1 | 59.1 | 59.1 | 59.1 | 57.7 | 57.1 | 57.4 | 12.4 | 12.4 | 12.4 | 5.0 | 5.2 | 5.1 | 7.0 | 6.4 | 6.7 | I | I | | I |
| 43.1 | 43.1 | 43.1 | 44.0 | 44.0 | 44.0 | 42.5 | 42.5 | 42.5 | | | | | | | | | | II | II | | II |
| 46.7 | 46.3 | 46.5 | 45.6 | 46.0 | 45.8 | 44.4 | 44.6 | 44.5 | | | | | | | | | | III | III | | III |
| 44.5 | 44.5 | 44.5 | 47.0 | 47.0 | 47.0 | 46.2 | 46.4 | 46.3 | | | | | | | | | | III | III | | III |
| 31.0 | 30.5 | 30.8 | 29.3 | 28.9 | 29.1 | 28.9 | 28.9 | 28.9 | 11.5 | 11.3 | 11.4 | 4.5 | 4.7 | 4.6 | 5.3 | 5.7 | 5.5 | I | I | | I |
| 39.1 | 39.3 | 39.2 | 40.4 | 40.6 | 40.5 | 37.7 | 37.9 | 37.8 | | | | | | | | | | III | II | III | III |
| 42.0 | 42.6 | 42.3 | 43.0 | 43.0 | 43.0 | 41.6 | 42.0 | 41.8 | | | | | | | | | | I | I | | I |
| 35.3 | 35.3 | 35.3 | 35.8 | 35.6 | 35.7 | 32.4 | 33.2 | 32.8 | | | | | | | | | | III | III | | III |
| 50.2 | 50.2 | 50.2 | 48.5 | 48.1 | 48.3 | 47.3 | 47.3 | 47.3 | | | | | | | | | | II | II | | II |
| 38.5 | 38.9 | 38.7 | 39.6 | 40.0 | 39.8 | 38.2 | 38.2 | 38.2 | | | | | | | | | | II | II | | II |
| 16.3 | 16.3 | 16.3 | 28.2 | 27.8 | 28.0 | 23.6 | 23.4 | 23.5 | | | | | | | | | | II | II | | II |
| 54.5 | 54.3 | 54.4 | 53.3 | 53.3 | 53.3 | 52.3 | 51.7 | 52.0 | 17.7 | 18.1 | 17.9 | 6.5 | 6.1 | 6.3 | 7.0 | 7.0 | 7.0 | II | II | | II |
| 32.0 | 32.6 | 32.3 | 37.3 | 37.9 | 37.6 | 35.2 | 35.2 | 35.2 | | | | | | | | | | II | III | III | III |
| 45.1 | 45.1 | 45.1 | 44.6 | 44.0 | 44.3 | 44.0 | 43.6 | 43.8 | 15.5 | 14.9 | 15.2 | 3.3 | 3.3 | 3.3 | 5.0 | 5.0 | 5.0 | I | I | | I |




**Supplementary Fig. 1.** Results of repeated measures analysis of variance. (A) The average preoperative Cobb angle significant improved from 19.1° ± 4.9° preoperatively to 7.1° ± 2.0° immediately postoperatively and was maintained at 8.4° ± 2.0° at the last follow-up, without obvious loss of correction ($p < 0.001$). No significant difference was observed between the 2 groups ($p = 0.291$). (B) The mean intervertebral height was 34.5 ± 11.5 mm preoperatively and significantly increased to 39.1 ± 8.3 mm immediately after surgery, but decreased to 37.0 ± 8.5 mm at the last follow-up ($p = 0.001$). However, no significant difference was noticed between the 2 groups ($p = 0.351$). TMC, titanium mesh cage.

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