**Expanded eggshell procedure combined with closing-opening technique (a modified vertebral column resection) for the treatment of thoracic and thoracolumbar angular kyphosis**

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**OBJECT** The purpose of this study was to determine the efficacy of a modified vertebral column resection for the treatment of thoracolumbar angular kyphosis.

**METHODS** A total of 13 patients (8 male, 5 female) with thoracolumbar kyphosis (kyphotic angle > 60°) were included in this study (Group A). There were 3 patients with failure of spinal formation (Type I deformity), 6 patients with old thoracic or lumbar compression fracture, and 4 patients with old spinal tuberculosis (including 1 case of T3–5 vertebral malunion). The average preoperative kyphotic angle was 67.3° (range 62°–75°). Each patient underwent an expanded eggshell procedure combined with the closing-opening technique for the treatment of thoracolumbar angular kyphosis. Sixteen patients who were previously treated with a closing-opening wedge osteotomy in the same spine classification group (kyphotic angle > 60°) were used as a control group (Group B).

**RESULTS** In Group A, the average (± SD) operative time was 400 ± 60 minutes, and the average blood loss was 960 ± 120 ml. There were no surgery-related complications observed during or after the operations. The average local kyphotic angle was 20.3° (range 18°–24.5°), and the average correction rate was 68.7%. In Group B, the average operative time was 470 ± 90 minutes, and the average blood loss was 2600 ± 1600 ml (range 1200–8200 ml). There were segmental vessels and spinal canal venous plexus injury in 1 case, spinal cord injury in 1 case, dural tearing in 2 cases, pleural rupture in 2 cases, and hemotherax and pneumotherax in 1 case. Each patient had more than 2 years of follow-up. At the latest follow-up examination, the average regional kyphotic angle was 19.9° ± 9.1° (range 19°–34°), and there was no significant loss of correction (p > 0.05). There was greater blood loss and a higher complication rate in Group B than in Group A (p < 0.05).

**CONCLUSIONS** An expanded eggshell procedure combined with the closing-opening technique for the treatment of thoracolumbar angular kyphosis resulted in significant reduction of the kyphotic angle, few complications, and good follow-up results. However, a larger series of patients and long-term follow-up results is still required to verify the effectiveness and safety of this method.

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**KEY WORDS** kyphosis; eggshell; closing-opening procedure; correction; technique; thoracic spine

**Thoracolumbar kyphosis** is a clinically common spinal deformity caused by hemivertebrae (Type I deformity), specific and nonspecific spine infection, trauma, and iatrogenic kyphosis, among other causes. Severe thoracic and thoracolumbar kyphosis is usually associated with severe low-back pain or severe neurological dysfunction. The main surgical methods for kyphosis correction include Smith-Petersen osteotomy (SPO), pedicle subtraction osteotomy (PSO), closing-opening wedge osteotomy (COWO), vertebral column resection (VCR), and vertebral column decancellation.

In 1945, Smith-Petersen et al. first reported the clini-
cal efficacy of the SPO for the treatment of ankylosing spondylitis, and subsequently, many scholars performed a multisegmental SPO for kyphosis treatment. The SPO is relatively safe and has a low level of technical difficulty, but it has a poor correction effect for sagittal deformity and cannot be performed to correct large kyphotic angles. In 1985, Thomasen first reported SPO. The previous year, Heining described an “eggshell” osteotomy—a transpedicular decancellation closed-wedge osteotomy—as a variant of the SPO. Compared with the SPO, the PSO can achieve the purpose of 3-column osteotomy, which not only promotes bone healing after shortening of the spine but also effectively avoids stretching the major vessels and visceralia anterior to the spine, which can be caused by opening of the vertebrae after SPO. Single-segment PSO can correct 30°–40° of kyphosis, but for a kyphotic angle of > 60°, it is difficult to achieve a good correction effect using a single-segment PSO. To effectively improve kyphosis correction effects, Kawahara et al. first reported the closing-opening technique. Based on the pedicle wedge osteotomy, opening in the front and closing at the back effectively improved the kyphosis correction rate. In their 7 cases of kyphosis, the average preoperative angle of 68° was reduced to a postoperative angle of 16° with a correction rate of 73.1%. The VCR is also an effective way to correct such malformations. In 1922, MacLennan first reported on VCR via both anterior and posterior approaches. In 2005, Suk et al. reported on a single posterior VCR (PVCR) technique. The technique can effectively correct lateral and rotational deformity of the spine. Hamzaoglu et al. reported that VCR resulted in a sagittal correction rate of 72%. Lenke et al. reported that VCR resulted in a correction rate of 58% for kyphosis. However, PVCR is usually associated with surgical trauma, huge blood loss, and spinal cord injury, which are the most serious complications. Suk et al. reported that PVCR had a surgical complication rate of 34.3% and neurological injury rate of 17.1%. Lenke et al. reported that the overall rate of complications was approximately 40%, and within that group, 11.4% of the patients had neurological damage. To further improve the efficacy of surgery and reduce the number of complications, Wang and Lenke used vertebral column decancellation to treat 45 cases of kyphosis and kyphoscoliosis; in 16 cases the average correction angle was 82.2° (range 61°–124°). The overall complication rate was 17.8%, 4% of which included neurological damage.

In this study, we report the clinical efficacy of an expanded eggshell procedure combined with the closing-opening technique for the treatment of thoracic and thoracolumbar kyphosis.

**Methods**

**Patient Population**

A total of 13 patients (8 male, 5 female; average age 33.5 years [range 15–47 years]) with thoracolumbar kyphosis (kyphotic angle > 60°) were included in this study (Group A). There were 3 patients with failure of spinal formation (Type 1 deformity), 6 patients with old thoracic or lumbar compression fracture, and 4 patients with old spinal tuberculosis (including 1 case of T3–5 vertebral malunion). The vertebral kyphosis was located in T3–5 (n = 1), T7–8 (n = 1), T8–9 (n = 1), T11–12 (n = 1), T12 (n = 4), or L-1 (n = 5).

A 10-cm visual analog scale (VAS) was used to assess back pain (0 indicates no pain/numbness, and 10 represents the worst pain/numbness). The mean (± SD) preoperative VAS score was 6.1 ± 2.3. Ten patients with a T11–1 L.1 lesion had severe back pain (VAS score ≥ 7). The remaining 3 patients, with chronic spinal tuberculosis kyphosis, had obvious associated neurological deficits, and their preoperative American Spinal Injury Association (ASIA) Impairment Scale grade was C in 1 case and D in 2 cases. The characteristics of the patients are summarized in Table 1. Each patient underwent an expanded eggshell procedure combined with the closing-opening technique for treatment.

Sixteen patients (6 male, 10 female; average age 26.5 years [range 13–34 years]) who were previously treated with the COWO in the same spine classification group (kyphotic angle > 60°) were used as a control group (Group B): 3 patients with failure of spinal formation (Type 1 deformity), 7 patients with old thoracic or lumbar compression fracture, and 6 patients with old spinal tuberculosis. The vertebral kyphosis was located at T-7 (n = 2), T-9 (n = 1), T-11 (n = 2), T-12 (n = 7), or L-1 (n = 4). The mean preoperative VAS score for back pain was 6.8 ± 1.4. Fourteen patients with a lesion located at T9–L1 had severe back pain (VAS score ≥ 7), and the remaining 2 patients (1 with Type 1 deformity and 1 with tuberculosis and kyphosis) had associated neurological disorders, with preoperative ASIA Impairment Scale grades of C in one patient and D in the other.

**Radiographic Measurements**

Each patient underwent full-length standing spine radiography that included a lateral view with visualization from at least the C-7 vertebral body to the pelvis. Radiographic measurements were made using a standard technique and included regional kyphotic angle (RKA), C7–S1 sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), sacral slope, lumbar lordosis (LL), and thoracic kyphosis (TK). Patients were classified as having positive global sagittal malalignment if their C7–S1 SVA was ≥ 5 cm. The correction rate was calculated as [(preoperative RKA – postoperative RKA)/preoperative RKA] × 100%.

CT scanning was used for preoperative deformity assessment and to evaluate bone fusion during follow-up. Preoperative MRI was used to exclude intraspinal canal diseases and to evaluate compression of the spinal cord.

**Surgical Procedure**

In Groups A and B, general anesthesia, neuromonitoring, and autologous blood transfusion were used during the operations.

For each patient in Group A, using the midline posterior approach, we detached the paravertebral muscles from the spinous processes and lamina to expose the surgical levels. Pedicle screws were inserted in the upper and lower 2–3 segments of the proposed osteotomy site. Then, the lamina transverse processes and the facet joint at the
resection level were removed. To reduce the spinal cord injury caused by shrinkage of the spinal cord, the laminae below and above the osteotomy level were also removed. Then, the left pedicle at the osteotomy level was identified and decancellated using a high-speed drill and a curette. After that, the cortical bone of the pedicle was removed, which enabled access to the vertebral body and protection of the dura and nerve roots. By using the eggshell technique, decancellation of the vertebral body was subsequently performed with a drill and a curette on the left side. The cortical bone on the left side of the vertebral body was burred away gradually, and part of the rib adjacent to the transverse process and vertebral body was also drilled away to create a sufficient space for placing titanium mesh. If the osteotomy site was at or above T-12, the nerve root at this level was ligated to facilitate the osteotomy. A temporary fixing rod was placed to maintain the stability of the spine. Similar procedures were performed on the right side. Because we planned to place titanium mesh from the left side, only decancellation of the vertebral body was performed. Cortical bone from the anterior and right side of the vertebral body and the rib were preserved (Fig. 1 upper). The discs and endplates above and below the osteotomy were then removed from both sides.

Finally, the portion of the vertebral body underlying the anterior spinal canal was removed using a bur and an L-shaped posterior wall impactor to collapse this bone into the cavity. The titanium mesh filled with autograft was placed through the left side. We preferred to place the mesh on one side, not at the midline of the coronal section, so that we could implant more autograft from the other side. The precurved rods, sized at an appropriate length, were placed and kyphosis was corrected using the closing-opening technique, which was first described by Kawahara et al. After deformity correction, a large amount of autograft and allograft bone was implanted from the right side (Fig. 2).

In Group B, each patient underwent a COWO for kyphosis correction. The exposure, insertion of pedicle screws, and laminectomy levels were identical to those in Group A. After that, ribs at the affected level were transected 3–4 cm lateral to the costotransverse joint, and the pleura was bluntly separated from the vertebra. The rib heads and the

<table>
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<th>Patient No.</th>
<th>Age (yrs), Sex</th>
<th>Preop Diagnosis</th>
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Modified VCR for thoracolumbar angular kyphosis correction

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transverse processes were excised. The pedicle for the osteotomy was identified, and blunt dissection was used anteriorly on both sides through the plane between the pleura and the vertebral body. The vertebral body was removed in a wedge shape, and the posterior vertebral cortex was drilled out. Subsequently, the disc was removed (Fig. 1 lower). Two short rods (correction rods) were positioned. The first 30°–35° of kyphosis was corrected using the closing-wedge technique with the hinge of the anterior longitudinal ligament. Next, the hinge was moved posteriorly to the spinal cord, and the remainder of the requisite angle of osteotomy was corrected using the opening-wedge technique to avoid spinal cord deformation.

Statistical Analysis

The SPSS version 12.0 software package (SPSS, Inc.) was used for statistical analysis. The Student t-test and the chi-square test were used to determine the statistical significance. The level of significance was set at a p value of < 0.05. Mean values are presented ± SD.

Results

Demographics of the patients in Group A are shown in Table 1. The preoperative and postoperative RKA, correction rate, LL, TK, SVA, PI, PT, back pain VAS score, operative time, blood loss, and complication rate are shown in Table 2.

In Group A, the RKA, LL, TK, SVA, PI, and back pain VAS score were significantly improved at the latest follow-up (p < 0.05). There were no segmental vessel or nerve injury, dural tearing, pleural rupture, hemothorax, or pneumothorax during or after the operation. Each patient underwent at least 2 years of follow-up (range 24–36 months, mean 29.6 months). At the latest follow-up, the mean RKA was 20.3° ± 2.5° (range 19°–23.3°), and there was no significant loss of correction (p > 0.05). The condition of the 3 patients with a neurological deficit improved from ASIA Impairment Scale Grade C to D in 1 case or from D to E in 2 cases. Mean back pain VAS scores improved from 6.1 ± 2.3 to 2.1 ± 1.9 (p < 0.05). There was no loss of correction, loosening of internal fixation, or pseudarthrosis during the follow-up period (Fig. 3).

In Group B, the RKA, LL, TK, SVA, PI, and back pain VAS scores were significantly improved at the latest follow-up (p < 0.05). One or two complications occurred in 6 cases (37.5%). There were segmental vessels and spinal canal venous plexus injury in 1 case, spinal cord injury in
1 case (ASIA Impairment Scale grade from E to C), dural tearing in 2 cases, pleural rupture in 2 cases, and hemothorax and pneumothorax in 1 case. Each patient had un-


malunion). Three-column osteotomy at the thoracic and


thoracolumbar levels includes mainly the following steps:
1) removal of 3–5 cm of the medial rib; 2) wide laminac-


\[\text{Correction rate, } \% \quad 68.7 \pm 70.2 \quad 0.47\]

\* Values are expressed as the mean ± SD or percentage (number).

† \( p < 0.05 \).

Discussion

According to the spinal osteotomy classification re-

ported by Schwab et al.,\(^7\) the osteotomy performed in our
technique is classified as complete vertebral and disc re-
sction (Grade 5) in 12 cases and multiple adjacent verte-
bral and disc resection (Grade 6) in 1 case (T3–5 vertebral


malunion). Three-column osteotomy at the thoracic and
thoracolumbar levels includes mainly the following steps:
1) removal of 3–5 cm of the medial rib; 2) wide laminec-
tomy; 3) dissection above the periosteum and around the


The condition of 3


patients with a neurological deficit improved from ASIA


Impairment Scale grade C to D in 2 cases (including 1


case caused by osteotomy) and from D to E in 1 case.


There were no significant differences in preoperative
and postoperative RKA, PI, PT, LL, TK, SVA, surgical
time, and correction rate between Groups A and B (\( p > 0.05 \)).
There was greater blood loss and a higher complica-
tion rate in Group B (\( p < 0.05 \)). A solid fusion was
achieved in 11 and 13 patients by the 6-month follow-up
in Groups A and B, respectively, whereas in the other
patients in Groups A and B fusion was achieved by the
1-year follow-up.
pcedures we performed. The nerve root at the osteotomy level can affect disc resection and titanium mesh placement. Therefore, the nerves at or above T-12 can be ligated to facilitate the operation and avoid spinal cord injury caused by excessive retraction of the dura and roots. After completion of the osteotomy on one side, a temporary rod should be installed before performing osteotomy on the contralateral side. Moreover, electrophysiological monitoring and wake-up tests should both be conducted during the operation to avoid spinal cord injury.

Second, in patients with old tuberculosis or an old fracture, there was less blood loss when the cancellous bone was removed by bur. For congenital hemivertebra decancellation, a diamond-bit drill and bone wax were used to control blood loss; no other agents were used in this series. Moreover, there is always some venous plexus within the spinal canal close to the medial wall of the pedicles. Therefore, bipolar coagulation should be performed before removing the medial wall of the pedicles to reduce blood loss. Every patient in this study received an autologous blood transfusion, which can effectively reduce blood transfusion complications and the cost of surgery.

Third, it is not necessary to install titanium mesh in the center of the coronal vertebral plane. Placement of the titanium mesh on one side enabled us to put more autograft on the other side to facilitate bone fusion and also to avoid spinal cord injury during installation (Fig. 3F).

Conclusions

In this small series, an expanded eggshell procedure combined with the closing-opening technique for the treatment of thoracolumbar angular kyphosis resulted in significant reduction of the kyphotic angle, few complications, and good follow-up results. Our primary results show that this technique can be used for thoracic and thoracolumbar angular kyphosis associated with severe back pain and/or neurological deficits. However, a larger series of patients and long-term follow-up are still needed to verify the effectiveness and safety of this method.


References


Author Contributions
Conception and design: Liu. Acquisition of data: Liu, Yuan, Tian, Lianlei. Analysis and interpretation of data: Liu. Drafting the article: Liu. Critically revising the article: Zheng. Reviewed submitted version of manuscript: Li. Statistical analysis: Tian.

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