Original Article

Type 3 bone-disc-bone osteotomy (grade 4+ osteotomy) combined with presurgical halo-pelvic traction: a safe and effective solution to correct severe angular-like kyphoscoliosis

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Background: Treatment of severe angular-like kyphoscoliosis is a technically demanding surgical challenge and requires high-risk spinal osteotomy, such as vertebral column resection. Preoperative halo-pelvic traction is commonly used to decrease the curve magnitude. However, few studies have utilized the potent method of bone-disc-bone osteotomy, which could theoretically provide correction up to 60°. This study aimed to evaluate the safety and effectiveness of type 3 bone-disc-bone osteotomy combined with presurgical halo-pelvic traction to correct severe angular-like kyphoscoliosis.

Methods: This was a retrospective cohort study. Patients with severe angular-like kyphoscoliosis who underwent presurgical halo-pelvic traction and type 3 bone-disc-bone osteotomy from January 2017 to December 2019 were consecutively reviewed. Patient demographics and clinical data were recorded. The coronal and sagittal Cobb angles were measured preoperation, post-traction, post-operation, and at the final follow-up. Complications were also recorded. Patients' health-related quality of life was evaluated by the Scoliosis Research Society 22 (SRS-22) questionnaire. Paired Student's t test and one-way analysis of variance were used for comparisons among different groups.

Results: Thirty patients (18 females and 12 males) with an average age of 20.2 years (range, 13–33 years) were included. The mean preoperative coronal and sagittal Cobb angles were 123.1°±16.4° (range, 90°–155°) and 120.3°±19.9° (range, 90°–156°), respectively. After 2.9±0.7 months (range, 2–4 months) of halo-pelvic traction, the coronal and sagittal Cobb angles decreased significantly to 81.9°±13.2° and 76.0°±12.6°, respectively. Postoperatively, the scoliotic and kyphotic angles further decreased to 42.4°±12.2° and 33.9°±8.8°, respectively. After a mean follow-up of 2.93±1.05 years, the correction rates were maintained at 64.3%±10.6% and 70.5%±6.3%, respectively. Nine patients experienced positive evoked potential events during surgery. Common complications after surgery included transient lower extremity weakness, pneumonia, and pleural effusion. The self-image scores were significantly improved from 2.66±0.27 to 3.36±0.23 compared to preoperation.

Conclusions: This study proposes a novel strategy to correct severe angular-like spinal deformities. The combination of presurgical halo-pelvic traction and type 3 bone-disc-bone osteotomy (grade 4+ osteotomy)

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achieves substantial correction and satisfactory aesthetic outcomes without serious complications.

Keywords: Bone-disc-bone osteotomy; halo-pelvic traction; severe kyphoscoliosis; vertebral column resection; deformity angular ratio

Submitted Sep 13, 2022. Accepted for publication Apr 18, 2023. Published online May 09, 2023.
doi: 10.21037/qims-22-964
View this article at: https://dx.doi.org/10.21037/qims-22-964

Introduction

Treatment of severe spinal deformities is a technically demanding surgical challenge and requires the use of osteotomy techniques. Currently, vertebral column resection (VCR) is often recommended to address serious and complex deformities (1). However, it involves increased operative time, larger blood loss and higher risks of neurologic injuries and other complications (2,3). A recent multicenter analysis of 147 cases conducted by Lenke *et al.* showed that this complex procedure was associated with a 59% complication rate (4). The deformity angular ratio (DAR, Cobb's angle divided by the number of vertebral levels involved) was first proposed by Harrington to evaluate curve progression (5). Wang *et al.* used it to quantify the angularity of severe spinal deformities and found that a sharper curve (total DAR >25) correlated with a significantly higher risk (41.1%) of neurologic deficits following VCR (6). Furthermore, Huang *et al.* reported that a total DAR >28 or sagittal DAR >20 was an important indicator for high-grade osteotomy (7). Thus, high-risk VCR should be considered as the last resort for severe spinal deformities with different DARs (*Figure 1*), and other alternative solutions need to be explored urgently.

Halo-pelvic traction (HPT) is a common tool for presurgical correction of severe and rigid spinal deformities. The gradual distraction can not only increase curve flexibility but also reduce neurologic risks (8). With appropriate management and substantial correction, other types of osteotomies, such as pedicle subtraction osteotomy (PSO) and bone-disc-bone osteotomy (BDBO), could be performed in place of VCR after HPT. Yu *et al.* reported a patient with tuberculous angular kyphosis of 180° who underwent PSO after 10 months of presurgical HPT and achieved excellent outcomes (9). Wang *et al.* showed satisfactory correction rates (64.1%±4.2% in coronal and 49.6%±5.2% in sagittal) of 32 extreme rigid scoliosis (Cobb angle >120°) patients without VCR following HPT (10). Therefore, HPT offers a powerful corrective force for severe spinal deformities, and lower grades of osteotomy may be possible following HPT.

BDBO is an osteotomy procedure performed both above and below a disc level, and the resection includes the disc with its adjacent endplates (11). It is divided into 3 different types according to the anatomical range of resection and typically provides correction rates from 35° to 60° (12). It is often considered equivalent to a grade 4 osteotomy according to the classical osteotomy classification proposed by Schwab *et al.* (13). According to the classification, grade 4 osteotomy involves the resection of the posterior elements, partial vertebral body, and superior adjacent disc, which is similar to type 2 BDBO. Type 3 BDBO has a larger range of resection than grade 4 osteotomy and theoretically could offer correction up to 60° (12,14). Therefore, type 3 BDBO should be classified as grade 4+ osteotomy to distinguish it from grade 4 osteotomy. Few studies have discussed the use of this specific type of osteotomy in severe spinal deformities. In this study, for the first time, we reported the radiographic and clinical outcomes of type 3 BDBO (grade 4+ osteotomy) combined with presurgical HPT to evaluate whether it was a safe and effective solution for severe angular-like spinal deformities. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-964/rc).

Methods

Cohorts

This is a retrospective study from our prospectively collected clinical database. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). It was approved by the Ethics Committee of Xinhua Hospital Affiliated with Shanghai Jiaotong University School of Medicine, and all patients signed informed consent forms for the study and the use of clinical information. Patients with severe angular-like

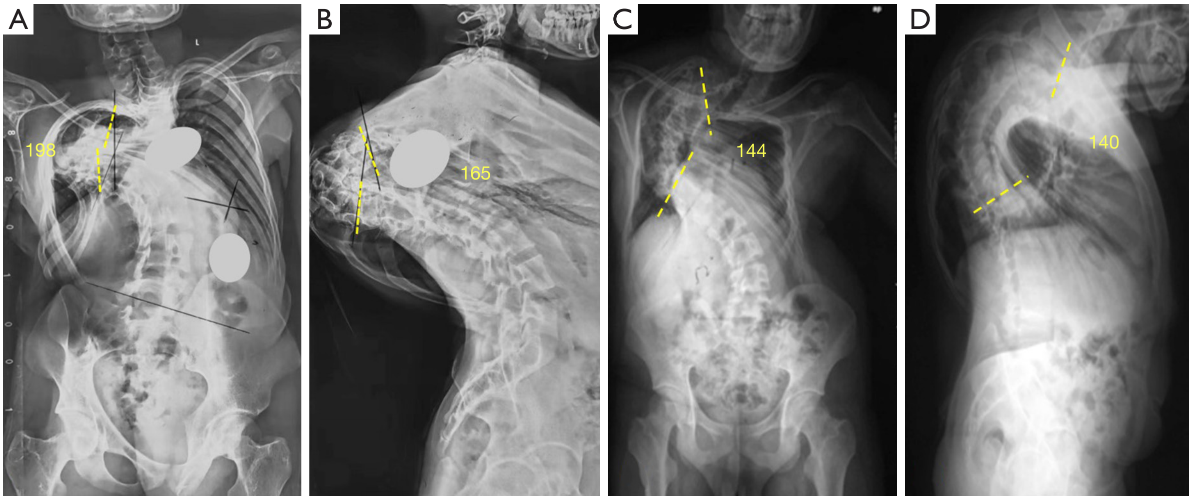

Figure 1 Representative pictures of patients with sharp angular and angular-like severe spinal deformities. The yellow dotted lines indicate the measurement of the Cobb angle. A sharp angular curve with scoliosis of 198 degrees and kyphosis of 165 degrees (A,B). An angular-like curve with scoliosis of 144 degrees and kyphosis of 140 degrees (C,D).

kyphoscoliosis who were surgically treated between January 2017 and December 2019 in our center were consecutively reviewed. The inclusion criteria were as follows: (I) both scoliotic and kyphotic curves greater than 90°; (II) angular-like curves with large DAR [total DAR >28 necessitating the use of at least grade 4 osteotomy (7)]; (III) undergoing presurgical HPT for more than 2 months; (IV) undergoing one-stage posterior type 3 BDBO (grade 4+ osteotomy) and correction surgery; and (V) at least 2 years of follow-up. The following exclusion criteria were applied: (I) patients with sharp angular curves (focally severe deformities that only contain a few vertebrae); (II) patients undergoing a combined anterior approach; (III) patients with prior history of spinal surgery; (IV) patients with preoperative neurological deficits; and (V) patients with incomplete clinical or radiographic data.

HPT protocols and BDBO indications

The HPT apparatus has skull and pelvic rings that are fastened to the cranial and iliac bones, respectively, and four correcting rods that align the two rings to allow spinal distraction. Local anesthesia is essential to install the device. The cranial ring pins are placed as in halo-gravity traction (15). The pelvic ring pins are placed on the iliac crest and the posterior superior iliac spine. After construction of the frame, distraction begins at a speed of 3–5 mm/day. As the distraction continues, the rate is gradually decreased depending on the curve's flexibility and patient's tolerance. Generally, 2–4 months of HPT is performed to provide enough correction at a cooperative rehabilitation hospital before definitive surgery.

The best indication for BDBO is a deformity with the intervertebral disc as the apex or center of the rotational axis. In this study, we also extended it to deformities that met the DAR criteria and had substantial improvement after HPT while still exceeding the correction that a single-level PSO can provide. The resection range in grade 4+ osteotomy contains three parts: (I) partial vertebral body (including pedicles); (II) superior intervertebral disc; and (III) superior partial vertebral body (not including pedicles).

Surgical procedure

Under general anesthesia, the patient was placed in a prone position on a special bed to allow the abdomen to be free from long-term pressure. After precise dissection, pedicle screws were inserted into the preselected vertebrae. The concave laminae at the apical region were first resected to provide enough space for the medial-shifted spinal cord, and a temporary rod was installed. Then, posterior elements on the convex side were removed. Resection of the rib heads was also needed if the apex was in the thoracic region. The upper part of the inferior vertebral body, disc and lower part of the superior vertebral body were resected based on the planned range consecutively from the convex side to the concave side. Asymmetry coronal osteotomy was also performed to achieve coronal balance. The nerve roots included in the osteotomy region were carefully isolated and protected. Then, the osteotomy gap was gradually compressed from the convex side after a relatively long temporary rod was installed on the convex side to prevent sagittal translation. The direction of the compression procedure was from the proximal vertebra to the distal vertebra. Additional laminectomy was needed if suspicious compression of the nerve roots and dura was observed. Finally, the precontoured long rods were fixed on both sides spanning all screws to stabilize the corrected spine. In situ rod bending was further applied for better deformity correction.

Multimodal intraoperative neuromonitoring (IONM), including somatosensory evoked potentials (SEPs), transcranial motor evoked potentials (MEPs) and descending neurogenic evoked potentials (DNEPs), was applied for all cases (16). The warning criteria of IONM were as follows: (I) MEP: the amplitude disappeared in unilateral or bilateral lower extremities and was not restored within 10 min; (II) SEP: the amplitude was reduced by >50% and/or the latency increased by >10% compared with baseline values; and (III) DNEP: the amplitude decreased by >80% and/or the latency was prolonged by >10% compared with baseline values. If a positive neuromonitoring event occurred, we first checked the current anesthetic and physiological parameters, including anesthesia potency, muscle relaxants, inhalation gas and blood pressure, and properly increased the blood pressure and reduced the anesthesia depth. Then, the accuracy of screw insertion and range of osteotomy were checked to ensure that there was no spinal cord injury. After that, surgery was quickly completed with relatively reduced correction. A routine wake-up test was performed immediately after the operation.

Radiographic and clinical outcomes

Patients were required to follow up three months, six months, one year, and two years after surgery and every two years thereafter. On the full spinal posteroanterior and lateral X-rays, the maximum coronal scoliotic angle and sagittal kyphotic angle were measured by Cobb's methods preoperation, post-traction, post-operation and at the 2-year follow-up. The coronal deformity angular ratio (C-DAR) was calculated as the maximum scoliotic angle divided by the number of vertebral levels involved. The sagittal deformity angular ratio (S-DAR) was calculated as the maximum kyphotic angle divided by the number of vertebral levels involved. The total deformity angular ratio (T-DAR) was the sum of the C-DAR and S-DAR scores. Radiographic parameters were measured twice by different physicians, and the mean values were calculated to eliminate potential measurement bias. The clinical data, including HPT time, operative time, estimated blood loss and perioperative complications, were reviewed from medical records. Complications that occurred during follow-up were also recorded. The patient's health-related quality of life was evaluated preoperatively and at the last follow-up by the Scoliosis Research Society 22 (SRS-22) questionnaire (17).

Statistical analysis

All statistical analyses were performed using SPSS 22.0 software (IBM Corp.). The results are expressed as the mean ± standard deviation. The paired Student's *t* test was used for comparison of two different groups. One-way analysis of variance (ANOVA) was used to determine the significance of differences in the scoliosis and kyphosis curves among the four different time points (preoperation, post-traction, post-operation and follow-up). A post hoc LSD test was used to identify where the differences occurred. A P value less than 0.05 was considered statistically significant.

Results

Thirty patients were consecutively enrolled in this study, and no patients were excluded according to the exclusion criteria (*Table 1*). There were 18 females and 12 males, with an average age of 20.2 years (range, 13–33 years). The etiologies were as follows: 15 patients with idiopathic scoliosis, 9 patients with congenital scoliosis, 4 patients with Marfan syndrome and 2 patients with neurofibromatosis. The locations of the apex were thoracic in 18 cases and thoracolumbar/lumbar in 12 cases. The average preoperative maximum coronal Cobb angle was 123.1°±16.4° (range, 90°–155°), and the average maximum sagittal kyphotic angle was 120.3°±19.9° (range, 90°–156°). The mean total DAR, coronal DAR, and sagittal DAR were 34.8±5.5, 17.3±3.1, and 17.5±4.2 per level, respectively. The severity and angulation ratio indicated that they were angular-like curves. The mean operative time was 410.8±126.2 minutes (range, 220–660 min), and the average estimated blood loss was 1,364.2±619.8 mL (range, 600–3,000 mL). Twenty-three patients used two rods for fixation, while the other seven patients used multirod constructs to increase the fusion rates.

Table 1 Baseline characteristics and clinical data of all patients.

Parameter	Values
Number	30
Age (years)	20.2±6.2
Gender	18 F, 12 M
Etiology	15 IS, 9 CS, 4 MS, 2 NF
Apex location	18 T, 12 TL/L
Scoliosis (°)	123.1±16.4
Coronal DAR	17.3±3.1
Kyphosis (°)	120.3±19.9
Sagittal DAR	17.5±4.2
Total DAR	34.8±5.5
Traction time (months)	2.9±0.7
No. of instrumented vertebra	12.3±0.8
Operative time (minutes)	410.8±126.2
Estimated blood loss (mL)	1,364.2±619.8

Values are presented as the mean ± standard deviation. F, female; M, male; IS, idiopathic scoliosis; CS, congenital scoliosis; MS, Marfan syndrome; NF, neurofibromatosis; T, thoracic; TL/L, thoracolumbar/lumbar; DAR, deformity angular ratio.

Table 2 Radiographic parameters at different time points

Curve magnitude	Scoliosis (°)	Kyphosis (°)
Preoperation	123.1±16.4	120.3±19.9
Post-traction	81.9±13.2	76.0±12.6
Post-operation	42.4±12.2	33.9±8.8
Follow-up	43.6±12.3	35.2±8.2
Total correction rate	64.3%±10.6%	70.5%±6.3%
F*	235.6	288.2
P value	<0.001	<0.001

Values are presented as the mean ± standard deviation. *, indicates one-way analysis of variance (ANOVA).

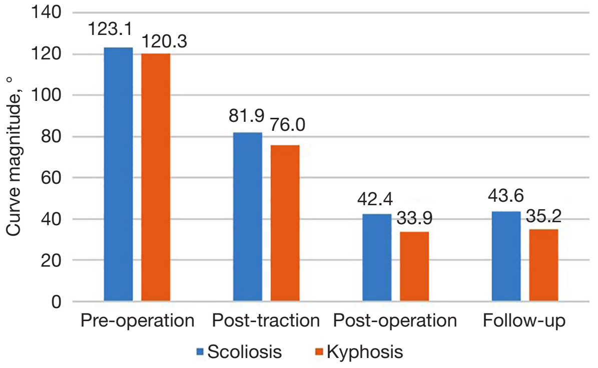

Figure 2 Change in scoliosis and kyphosis curve magnitude at different time points.

After an average 2.9±0.7 months (range, 2–4 months) of HPT, the coronal scoliotic angle and sagittal kyphotic angle decreased significantly to 81.9°±13.2° and 76.0°±12.6°, respectively (*Table 2*). After surgery, the scoliotic angle further decreased to 42.4°±12.2°. The kyphotic angle was 33.9°±8.8° post-operatively. At the mean follow-up of 2.93±1.05 years, the mean scoliotic angle was 43.6°±12.3°, and the mean kyphotic angle was 35.2°±8.3° (*Figure 2*). The overall correction rates were 64.3% and 70.5% in the coronal and sagittal planes, respectively. One-way ANOVA showed significant improvement for scoliosis and kyphosis curves (both P<0.001), while a post hoc analysis indicated that no obvious change occurred between post-operation and follow-up (P=0.734 and =0.718).

During surgery, positive evoked potential events occurred in 30% (9/30) of patients. One positive event occurred in the screw insertion procedure, five occurred in the osteotomy procedure and three occurred in the correction procedure. Seven patients recovered after we took steps to exclude interference factors intraoperatively, and all patients recovered post-operatively. After surgery, five patients demonstrated different degrees of transient neurological deficits, including two with lower limb numbness and three with lower limb weakness. All of them recovered within 1 to 6 months of rehabilitation. No permanent neurological deficits occurred. Respiratory complications were common in our cohorts, including 4 cases of pneumonia, 1 case of pneumonedema, 6 cases of pleural effusion and 2 cases of atelectasis. One patient had a surgical site infection post-operatively, and we performed irrigation and debridement. One patient experienced leakage of cerebrospinal fluid, and we performed dural repair. During follow-up, two patients with two-rod constructs had unilateral rod fractures but no obvious correction loss (one at six months, another at approximately nine months), so revision surgery was not performed (*Table 3*). No implant-related complications occurred in patients with multirod constructs. The SRS-22 scores were calculated and compared between preoperation and last follow-up. The self-image scores were significantly improved from 2.66±0.27 to 3.36±0.23 (P<0.001). The differences in other scores showed no statistical significance (*Table 4*).

Discussion

The correction of severe spinal deformities remains a challenging issue for most spinal surgeons. For severe curves with a large DAR, VCR was always recommended in the past to achieve sufficient correction. However, many unexpected complications can occur and influence the clinical outcomes following this high-risk technique. Thus, determining a more secure strategy to correct severe spinal deformities has attracted increasing attention. Recently, Hengwei *et al.* compared the outcomes and complications between grade 4 and grade 5 osteotomies in patients with severe and stiff thoracic kyphoscoliosis (18). They found that similar radiologic and clinical outcomes were achieved between the two groups, while the operative time and blood loss of grade 5 osteotomy were greater than those of grade 4 osteotomy. In this study, we proposed an effective but less invasive solution to correct angular-like deformities with an average scoliosis angle of 123.1°±16.4° and an average kyphosis angle of 120.3°±19.9°. The combined application of type 3 BDBO (grade 4+ osteotomy) and preoperative HPT achieved promising results with satisfactory correction and few complications (*Figure 3*).

Table 3 Perioperative and postoperative complications.

Complications	Numbers
Pneumonia	4
Pneumonedema	1
Pleural effusion	6
Atelectasis	2
Surgical site infection	1
Transient lower extremity weakness	5
Leakage of cerebrospinal fluid	1
Rod fracture	2

BDBO is a closing-wedge posterior osteotomy performed above and below a disc level. In 1994, Lehmer *et al.* developed a new technique of transvertebral osteotomy termed "Steffee" osteotomy, which could be regarded as the origin of this procedure (19). They demonstrated that this kind of osteotomy provided an effective and mechanically superior correction for acute angle thoracolumbar kyphosis in adult patients with high subjective satisfaction. According to the range of resection, BDBO has three different subtypes and provides different amounts of correction, typically ranging from 35° to 60° (12). In this study, type 3 BDBO was defined as grade 4+ osteotomy to distinguish it from grade 4 osteotomy in the classical osteotomy classification. The main indications of BDBO are deformities with the disc space as the apex or center of the rotational axis (CORA) and severe sagittal plane deformities that necessitate correction rates exceeding those that a simple PSO can provide (11,14,20).

BDBO offers many potential advantages over other types of osteotomies. First, it provides higher correction rates, ranging from 35° to 60°, than other types of osteotomies except high-risk VCR (12). Second, bone-to-bone closure of the osteotomy site decreases the risk of postoperative pseudoarthrosis and implant failure (20). In particular, the four pedicle screws placed close to the osteotomy site in type 1 BDBO maintain better stability. In addition, it provided correction rates closer to those of VCR without sacrificing the nerve roots when it was applied to the lumbar spine for thoracolumbar/lumbar deformities (20). Domanic *et al.* reported an average correction of 49 degrees with type 3 BDBO in a group of 32 patients who had severe rigid kyphosis (21). They hypothesized that it could be an alternative to posterior VCR in patients with thoracolumbar/lumbar severe and rigid deformities, particularly when the apex of the deformity is at the disc level.

HPT has been an adjunctive apparatus in the treatment

Table 4 Comparison of Scoliosis Research Society 22 scores between preoperation and last follow-up

SRS-22 scores	Function	Pain	Self-image	Mental health	Satisfaction
Preoperation	3.62±0.30	4.18±0.42	2.66±0.27	4.02±0.22	–
Last follow-up	3.68±0.36	4.26±0.28	3.36±0.23	4.08±0.33	4.25±0.41
P value	0.293	0.103	<0.001	0.240	–

Values are presented as the mean ± standard deviation.

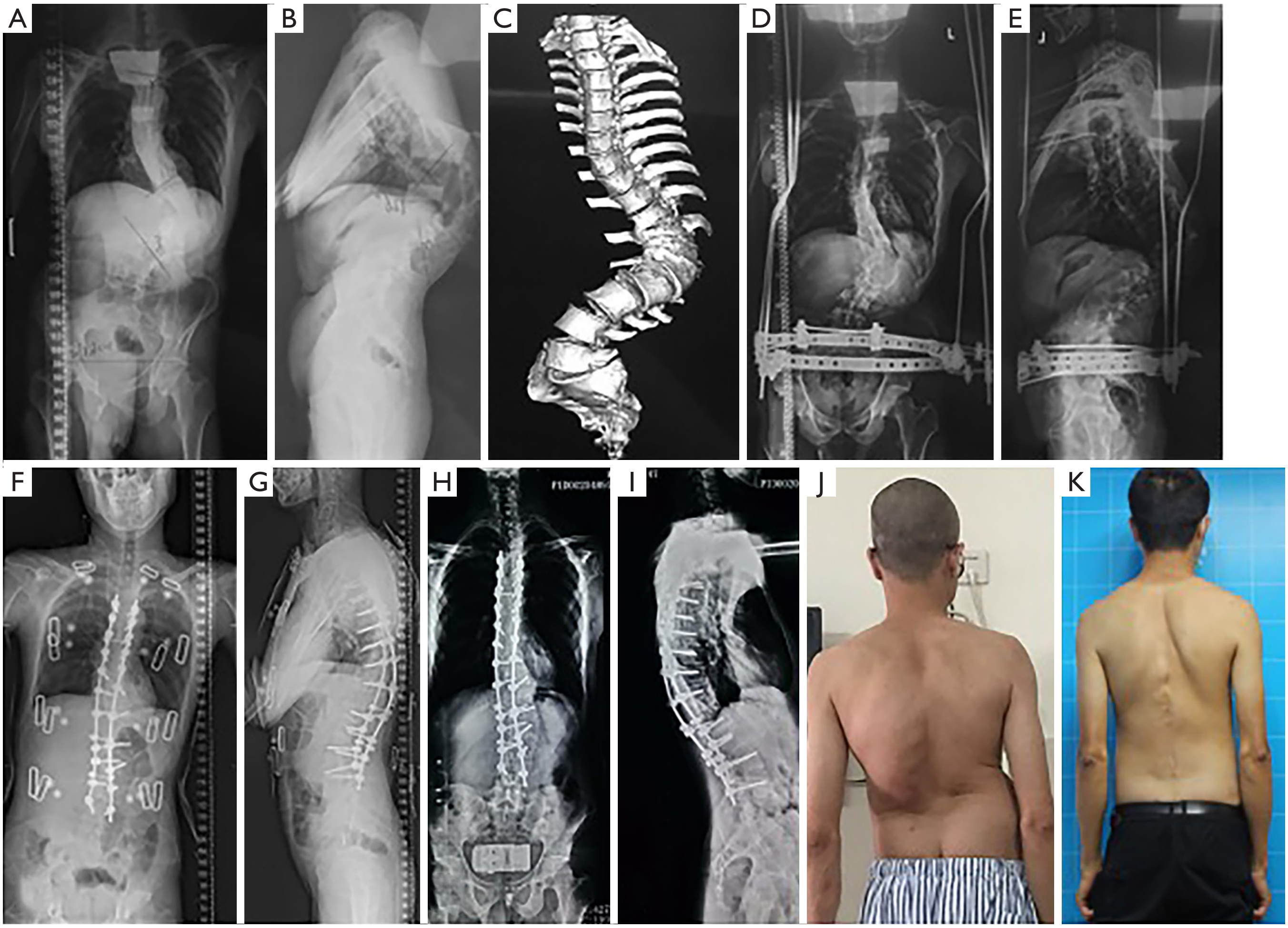

Figure 3 A patient with angular-like severe spinal deformities underwent presurgical halo-pelvic traction and type 3 bone-disc-bone osteotomy. Preoperative X-rays showed that the thoracolumbar scoliosis angle was 95° and the kyphosis angle was 125° (A-B). Preoperative computed tomography is also shown (C). After traction, the Cobb angles of scoliosis and kyphosis decreased to 65° and 110°, respectively (D,E). After surgery, the coronal and sagittal profiles were corrected (F,G) and maintained well during the 3-year follow-up (H,I). The pictures of the patient's back appearance showed excellent improvement (J,K).

of severe spinal deformities since the 1960s and can generate powerful distraction forces to correct various spinal deformities (22,23). Currently, it is mainly used for presurgical correction of extremely severe spinal deformities. Its gradual distraction not only decreases curve magnitude but also reduces neurologic risks. With appropriate management and sufficient correction, surgeons do not need to perform complex VCR for every patient with severe spinal deformities. Qi *et al.* found that HPT could also be used to help patients complicated with respiratory dysfunction achieve significant correction and improved respiratory function during the preoperative treatment period (24). Chen *et al.* compared the clinical outcomes of HPT with those of halo-gravity traction (HGT) in the presurgical treatment of severe rigid spinal deformities (25). They concluded that HPT had significantly better correction rates than HGP in both the coronal (15.33%±1.53% *vs.* 34.86%±3.11%) and sagittal (16.50%±2.13% *vs.* 44.09%±9.78%) planes. The improvement in pulmonary function was also better in patients with HPT (6.76%±1.85% *vs.* 15.6%±3.47%). These results showed the powerful corrective force of HPT and its advantages over other types of traction in the treatment of severe spinal deformities.

This study has several limitations. First, it is a retrospective analysis with the inherent possibility of data inaccuracy, and potential selection bias and information bias may exist. Second, due to the low incidence of severe spinal deformities, the sample size in this study was relatively small. More cases need to be included to compare patients with different etiologies and to eliminate the underlying confounders. Third, this study was an observational study and did not have controls for comparison. Therefore, large cohorts with different techniques and long follow-up in multiple centers are needed in future studies.

Conclusions

In summary, this study proposes a novel strategy to correct severe angular-like spinal deformities. The combination of presurgical HPT and type 3 BDBO (grade 4+ osteotomy) achieves substantial correction and satisfactory aesthetic outcomes. However, a comparison of this technique with VCR is needed to further evaluate its safety and efficiency in the future.

Acknowledgments

Funding: This study was supported by the National Natural Science Foundation of China (No. 82072519); Clinical Science and Technology Innovation Project of Shanghai Shenkang Hospital Development Center (No. SHDC22020206); and Shanghai Science and Technology Innovation Program (No. 22DZ2203300).

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-964/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-964/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). It was approved by the Ethics Committee of Xinhua Hospital Affiliated to Shanghai Jiaotong University School of Medicine, and all patients signed informed consent forms for the study and the use of clinical information.

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Cite this article as: Zhang T, Sui W, Shao X, Deng Y, Huang Z, Yang J, Yang J. Type 3 bone-disc-bone osteotomy (grade 4+ osteotomy) combined with presurgical halo-pelvic traction: a safe and effective solution to correct severe angular-like kyphoscoliosis. Quant Imaging Med Surg 2023;13(7):4196-4204. doi: 10.21037/qims-22-964