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CLINICAL ARTICLE

Deformed Complex Vertebral Osteotomy Technique for Management of Severe Congenital Spinal Angular Kyphotic Deformity

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Objectives: To (i) introduce the deformed complex vertebral osteotomy (DCVO) technique for the treatment of severe congenital angular spinal kyphosis; (ii) evaluate the sagittal correction efficacy of the DCVO technique; and (iii) discuss the advantages and limitations of the DCVO technique.

Methods: Multiple malformed vertebrae were considered a malformed complex, and large-range and angle wedge osteotomy was performed within the complex using the DCVO technique. Patients with local kyphosis greater than 80° who were treated with DCVO and did not have tumors, infections, or a history of surgery were included. A retrospective case study was performed in these patients with severe angular kyphosis who underwent the DCVO technique from 2008 to 2016. Demographic data, the operating time, and the volume of intraoperative blood loss were collected. Spinopelvic parameters (pelvic incidence [PI], pelvic tilt [PT], and sacral slope [SS]), local and global sagittal parameters (deformity angle, thoracic kyphosis [TK], and lumbar lordosis [LL]), visual analog scale (VAS) score, and Oswestry disability index (ODI) score were recorded pre- and postoperatively. Paired *t*-tests ($\alpha = 0.05$) were used for all data (to compare the mean preoperative value with the mean postoperative and most recent follow-up values). $P < 0.05$ was considered statistically significant.

Results: Twenty-nine patients with a mean age of 34 years (range, 15–55) were included in the final analysis. Seventeen patients were male, and 12 were female. The mean follow-up was 44 months (range, 26–62). The mean operating time was 299 min (range, 260–320 min). The mean blood loss was 2110 mL (range, 1500–2900 mL). Three patients had T_7–T_8 deformities (3/29, 10.3%), six had T_8–T_9 deformities (6/29, 20.7%), six had T_9–T_{10} deformities (6/29, 20.7%), 10 had T_{10}–T_{11} deformities (10/29, 34.5%), three had T_{11}–T_{12} deformities (3/29, 10.3%), and one had T_9–T_{11} deformities (1/29, 3.4%). The mean local deformity angle significantly improved from 94.9° ± 10.8° to 24.0° ± 2.3° through the DCVO technique, with no significant loss at the follow-up. Moreover, the global sagittal parameters and spinopelvic parameters exhibited ideal magnitudes of improvement; TK decreased from 86.1° ± 12.1° to 28.7° ± 2.5°, LL improved from 94.5° ± 4.1° to 46.1° ± 3.0°, and PI minus LL improved from –60.9° ± 6.5° to –13.7° ± 2.6°. Both the VAS and ODI scores significantly improved at the last follow-up. CSF fistula and neural injury did not occur during the perioperative period. At the last follow-up, fixation failure was not observed.

Conclusion: The DCVO technique provides an alternative and effective method for the treatment of congenital severe angular spinal kyphotic deformities and may decrease the occurrence of perioperative complications.

Key words: Osteotomy; Sagittal balance; Sagittal deformity; Severe congenital angular spinal kyphosis

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Introduction

Congenital kyphosis can be associated with severe sagittal plane imbalance. When not treated early, congenital kyphosis may progress rapidly and grow into severe kyphotic deformity, especially during adolescence. Besides, severe kyphosis can also cause severe cardiopulmonary dysfunction and neurological impairment, which dramatically influence the quality of life and lifespan of patients. Surgical osteotomy is the main choice for correcting the deformity and realigning the spine. Usual osteotomy techniques include posterior spinal column osteotomy and three-column osteotomy[1–3]. The corrective angle is limited with posterior spinal column osteotomy, and the compression which from the anterior column cannot be decompressed enough, so this type of osteotomy is not recommended for severe kyphosis. In recent years, three-column osteotomy has been considered the main treatment for congenital angular spinal kyphosis because it has been shown to be more effective[4].

Pedicle subtraction osteotomy (PSO) is a wedge-shaped resection involving one vertebral body, including the partial vertebral body and posterior column elements, and is classified as grade 3 osteotomy. To achieve the correction of kyphosis, a pre-bent rod is placed and compressed to close the osteotomy surfaces. The PSO technique limits the osteotomy to a single vertebral body and preserves partial stability of the anterior spinal column during correction. While performing the correction, the complications caused by intraoperative trauma are reduced, and because bone-to-bone fusion occurs, bone grafting is avoided so that the risk of nonunion can be decreased[5]. However, in the treatment of severe spinal kyphosis, PSO has several limitations, such as a small corrective angle and low corrective rate[6]. Generally, only about 30° of correction can be acquired at a single segment though the PSO technique. Additionally, the presence of stiff structures in the thoracic region, including the ribs and thorax, decreases the corrective rate[6]. Noticeably, congenital spinal deformities may exist in several vertebral congenital malformed fusions, and interbody discs among the malformed vertebrae rarely can be found, so PSO cannot utilize an appropriate resection region through either the PSO concept or the grade 3 or 4 osteotomy of Scoliosis Research Society (SRS)[2].

Vertebral column resection (VCR) requires the removal of one or several vertebral levels, including adjacent disks and a portion of the ribs in the thoracic region[2], and this procedure is classified as grade 5 or 6 osteotomy by the SRS. For the purposes of correction and realignment, pedicle screws and titanium mesh bone grafting are required. Prebent rods are used to connect pedicle screws, as they can realign and fix the spine. Moreover, titanium mesh bone grafting at the anterior column can preserve the height of the anterior column and promote anterior column bone fusion. As the most common technique for corrective treatment, posterior vertebral column resection (PVCR) proceeds the operation only through the posterior approach, as first presented by Suk *et al.*[7]. The advantage of PVCR is that it can achieve maximal correction for treating severe spinal kyphosis[8–11]. However, the resection of one or several vertebral segments can separate the spinal column into two parts completely, which causes spinal column instability during correction. Consequently, there are some risks, such as intraoperative spinal cord injury, more bleeding and failure of bone grafting. Lenke found that the incidence rate of perioperative complications was over 32% in a study of 147 patients with severe spinal deformities who underwent VCR[1,3,12]. In previous studies, the incidence rate of intraoperative spinal cord injury was 15.4%, and approximately 7.6% of patients developed complete paraplegia[13]. The overall incidence rate of complications was 32% to 59%.

In our clinical experience, the rate of complications related to the VCR technique was high in the treatment of various spinal deformities. This finding is consistent with those of previous studies. The VCR technique completely separates the spinal column into two separate sections, and subsequently, these sections are closed with instruments and titanium mesh. These procedures are associated with a high risk of neural injury, fixation failure, and nonunion. The PSO technique is not adequate for the treatment of severe angular kyphosis because it yields a small correction angle.

Therefore, we developed the deformed complex vertebral osteotomy (DCVO) technique, in which a larger range and angle of correction were achieved *via* the wedge osteotomy technique performed within the malformed vertebral complex. The purposes of this study were to: (i) introduce the DCVO technique for the treatment of congenital severe angular spinal kyphosis; (ii) evaluate the sagittal correction efficacy of the DCVO technique; and (iii) discuss the advantages and limitations of the DCVO technique. To achieve these purposes, preoperative and intraoperative data of the patients were collected. Spinal-pelvic parameters and local and global sagittal parameters were compared with each other preoperatively, postoperatively, and at the follow-up.

Materials and Methods

Patient Population

All patients in this cohort presented apparent kyphotic deformity and persistent back pain, and some of the patients incurred incomplete paralysis. The congenital deformity was confirmed through three-dimensional (3D) computed tomography (CT). The selected patients underwent surgery using the DCVO technique.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (i) patients who presented with a spinal deformity diagnosed as congenital spinal kyphosis and a local deformity angle >80°; (ii) patients treated with the DCVO technique; (iii) patients with magnetic resonance imaging and CT findings confirming congenital spinal kyphosis; (iv) patients in whom all spinopelvic and sagittal balance parameters could be assessed; and (v) patients who underwent corrective surgery with a minimum of 2 years of follow-up. The exclusion criteria were as follows: (i) a combination of spine deformities caused by spinal tuberculosis or trauma; (ii) a history of revision surgery; and (iii) a history of spinal surgery.

Surgical Technique

Step 1 General anesthesia, prone positioning, and intraoperative neurophysiological monitoring (IONM) were utilized.

Step 2 Through a medial incision, sufficient detachment of the paravertebral muscle was performed to expose the posterior spinal element. A C-arm X-ray instrument was used to confirm the location of vertebrae.

Step 3 Multiple malformed vertebrae were considered as a complex. Pedicle screws were inserted into three levels above and three below the complex (Fig. 1A, B). Ribs of the complex were resected enough to reveal the lateral aspect of the vertebral body. The laminae and facet joint were removed, allowing exposure of the spinal canal and nerve root canal. The nerve root was identified and preserved. Isolation and decompression of the nerve root were performed to reduce the intensity of the spinal cord and dura (Fig. 1C).

Step 4 The temporary rod was adhered to screws alternately. A wider wedge-shaped osteotomy was performed within the deformed complex using piezosurgery, osteotomes, and high-speed drilling. The upper and lower end plates of the complex that adjoined the normal vertebra were preserved (Figs 1D, 2A). Special attention was taken to not break the anterior longitudinal ligament, which served as a hinge when closing.

Step 5 Pre-bent rods were used to gently and progressively replace the temporary rod. Compression was applied on the screws and rods to achieve bone-to-bone closure (Figs 1E, F, 2B, C). An artificial nerve canal was prepared to avoid root entrapment. Laminectomy was performed on the adjacent regions of the normal vertebrae when the dura was obviously folded, while expanding the inner diameter of the spinal canal could further decompress the shortened spinal cord.

Decortication of the posterior spinal element before autologous bone grafting is beneficial to achieve early fusion.

Radiographic Measurements

Patient demographics and data on previous surgical treatment and perioperative complications were collected by reviewing the medical records from the HiTai Electronic Medical Record (EMR) version 3.0 and iMedPacs version 4.1 retrospectively. Standing full-length radiographs and 3D CT and MRI of the spine were performed preoperatively, postoperatively, and at follow-up.

Deformity Angle

The deformity angle was used to evaluate the local spinal kyphosis angle. The deformity angle is defined as the Cobb angle from the upper endplate of the proximal junctional normal vertebra to the lower endplate of the distal junctional normal vertebra (Fig. 3A).

Global Sagittal Parameters (TK and LL)

The TK and LL were used to evaluate the global sagittal balance of the spine. The TK is defined as the Cobb angle from

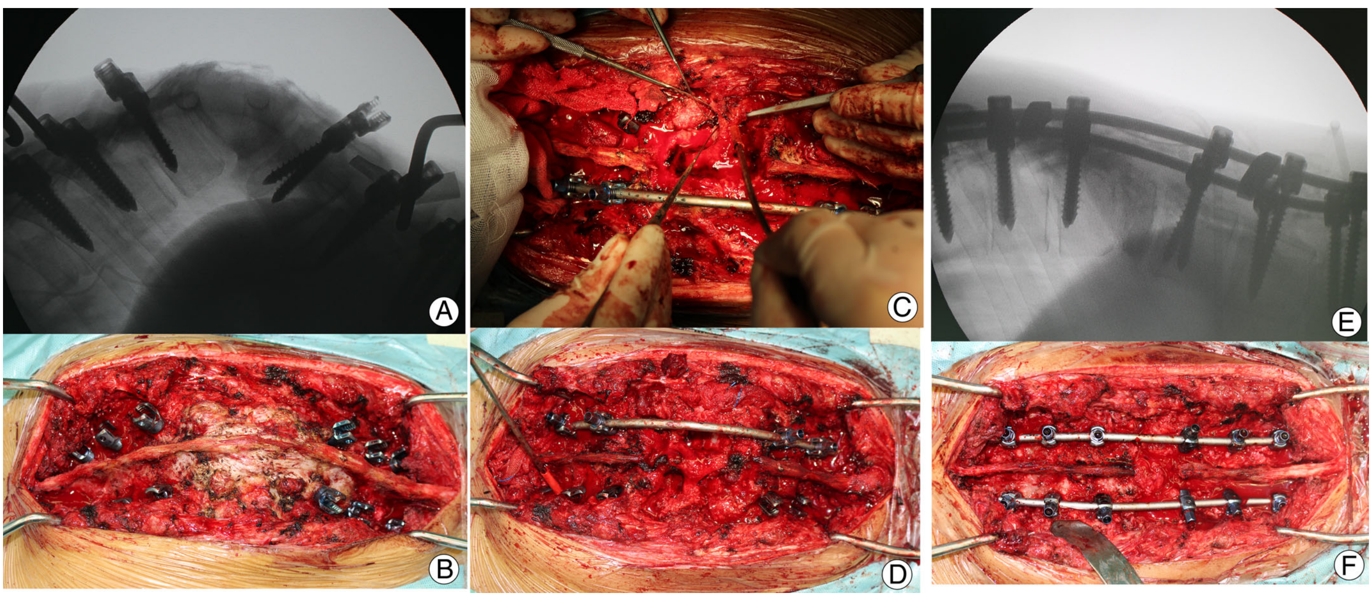

Fig. 1 Operative details of DCVO technique. (A, B) A C-arm X-ray instrument confirmed the location and inserted pedicle screws. (C) Isolation and decompression of the nerve root, spinal cord, and dura. (D) Accomplished osteotomy. (E, F) Bone-to-bone closure and laminectomy was performed to avoid folded dura.

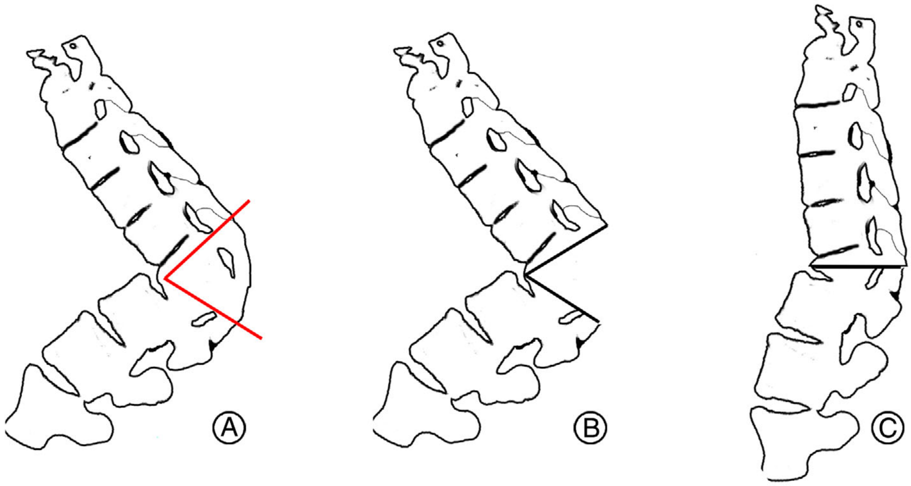

Fig. 2 Diagram of the DCVO technique. (A) A wider wedge-shaped osteotomy was performed within the deformed complex; upper and lower end pates were preserved. (B) The anterior longitudinal ligament was preserved as a closed hinge. (C) Gentle and progressive closing, bone-to-bone closure.

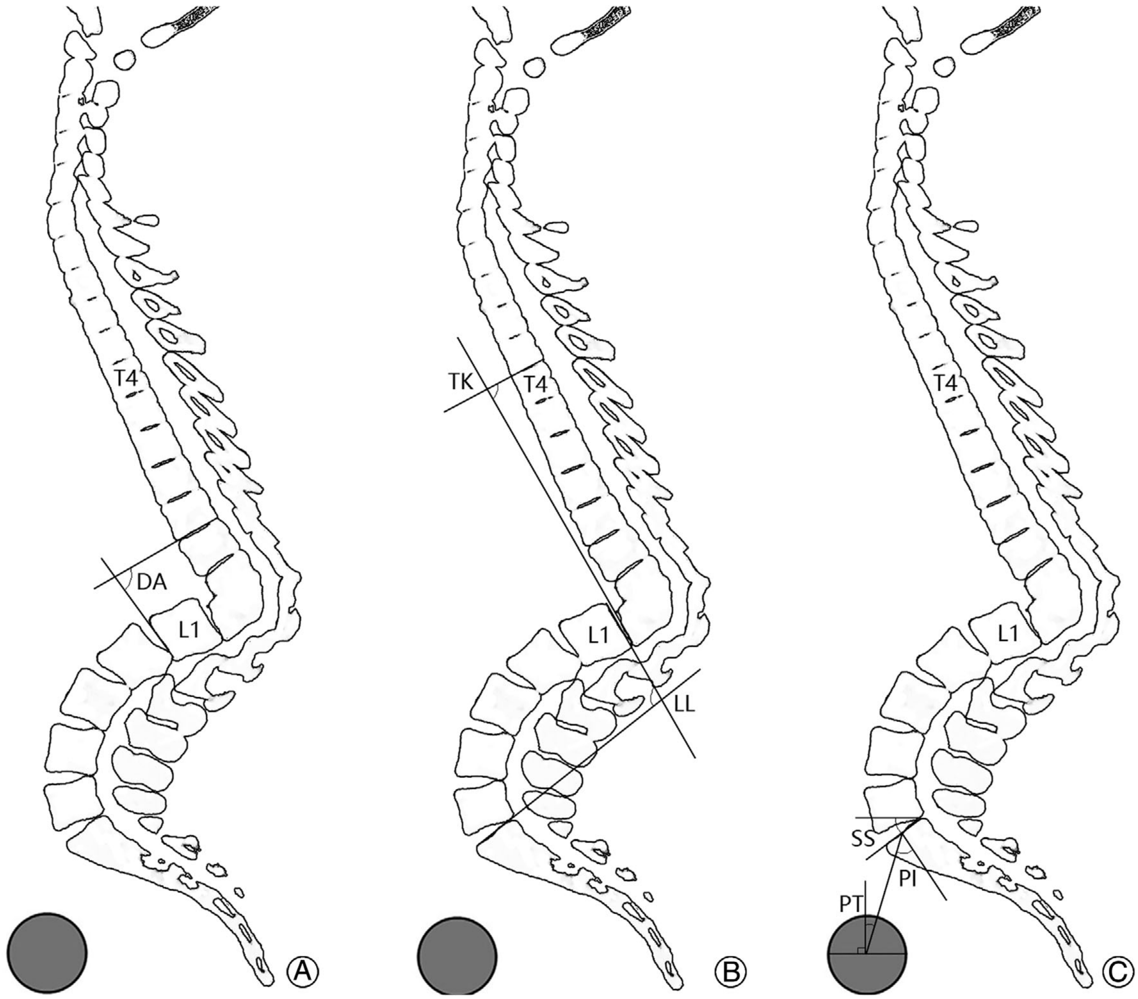

Fig. 3 Diagram of measurements. (A) The diagram of the measurement of deformity angle. (B) The diagram of the measurement of global sagittal parameters (TK and LL). (C) The diagram of the measurement of pelvic parameters (PI, PT, and SS).

the upper endplate of T_4 to the lower endplate of T_{12}. The LL is defined as the Cobb angle from the upper endplate of L_1 to the endplate of S_1. The normal range of TK is from 10° to 40°. TK <10° is consider a hypokyphosis, when TK >40° is considered a hyperkyphosis. The normal range of LL is from 30° to 70° (Fig. 3B).

Pelvic Parameters (PI, PT, and SS)
The pelvic parameters were used to evaluate the balance between the spine and pelvis. The measurement method was performed according to a previous study[14]. Generally, the basic relationship of pelvic parameters is PI = PT + SS. The goals of the sagittal correction were SVA < 40 mm, −20° < PI-LL < 10° and PT < 20° (Fig. 3C).

Measurement was executed using iMedPacs software (version 4.1, Donghua software, Beijing, China).

Statistical Analysis
Paired *t*-tests (α = 0.05) were used on all data (mean preoperative *vs* postoperative and the most recent follow-up). $P < 0.05$ was considered statistically significant. SPSS 22.0 (IBM, USA) was used for this calculation.

Results

Patient Demographics
We selected 29 patients who were consecutively operated on by the same team between 2008 and 2016. The average age was 34 (range, 15–55) years. Seventeen patients were male and 12 were female.

The thoracic sagittal deformity was distributed from T_7–T_{12}. Three patients had T_7–T_8 deformities (3/29, 10.3%), six had T_8–T_9 deformities (6/29, 20.7%), six had T_9–T_{10} deformities (6/29, 20.7%), 10 had T_{10}–T_{11} deformities (10/29, 34.5%), three had T_{11}–T_{12} deformities (3/29, 10.3%), and the last patient had T_9–T_{11} deformities (1/29, 3.4%).

The DCVO technique was carried out in the deformed complex of each patient. The mean operating time was 299 min (range, 260–320 min). The mean blood loss was 2110 mL (range, 1500–2900 mL). The mean follow-up after surgery was 44 months (range, 26–62 months).

Radiological Outcomes

Deformity Angle
The mean local deformity angle significantly improved from 94.9° ± 10.8° to 24.0° ± 2.3° through the DCVO technique, with a *P* value was <0.01. The local kyphosis correction was 70.9° on average (Figs 4A–F, 5A–F, 6A–F). The average loss at final follow-up was 1.0°, with a DA of 24.0° ± 2.3° at post-operation *vs* 24.9° ± 2.6° at final follow-up, and no statistical differences were detected between post-operation and follow-up ($P > 0.05$) (Figs 4G, 5G, 6G) (Table 1).

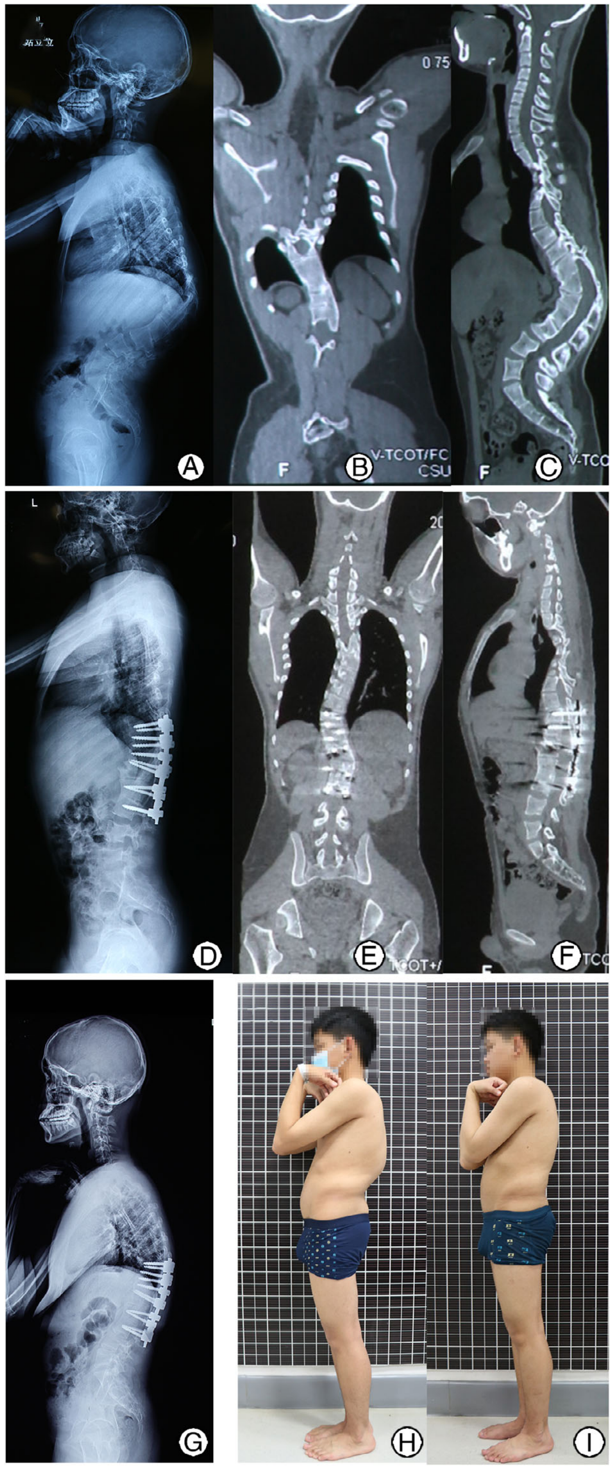

Fig. 4 A 20–30-year-old case with T_{10-12} congenital spinal angular kyphosis. (A–C) Preoperative lateral X-ray and 3D CT scan showed a T_{10}-L_2 congenital kyphosis, with a deformity angle of 88.3°. (D–F) Postoperative lateral X-ray and 3D CT scan showed DCVO at T_{11-12} complex, with a deformity angle of 20.0°. (G) Latest follow-up X-ray showed a deformity angle of 29.9°. (H, I) Preoperative, postoperative, and last follow-up clinical photos.

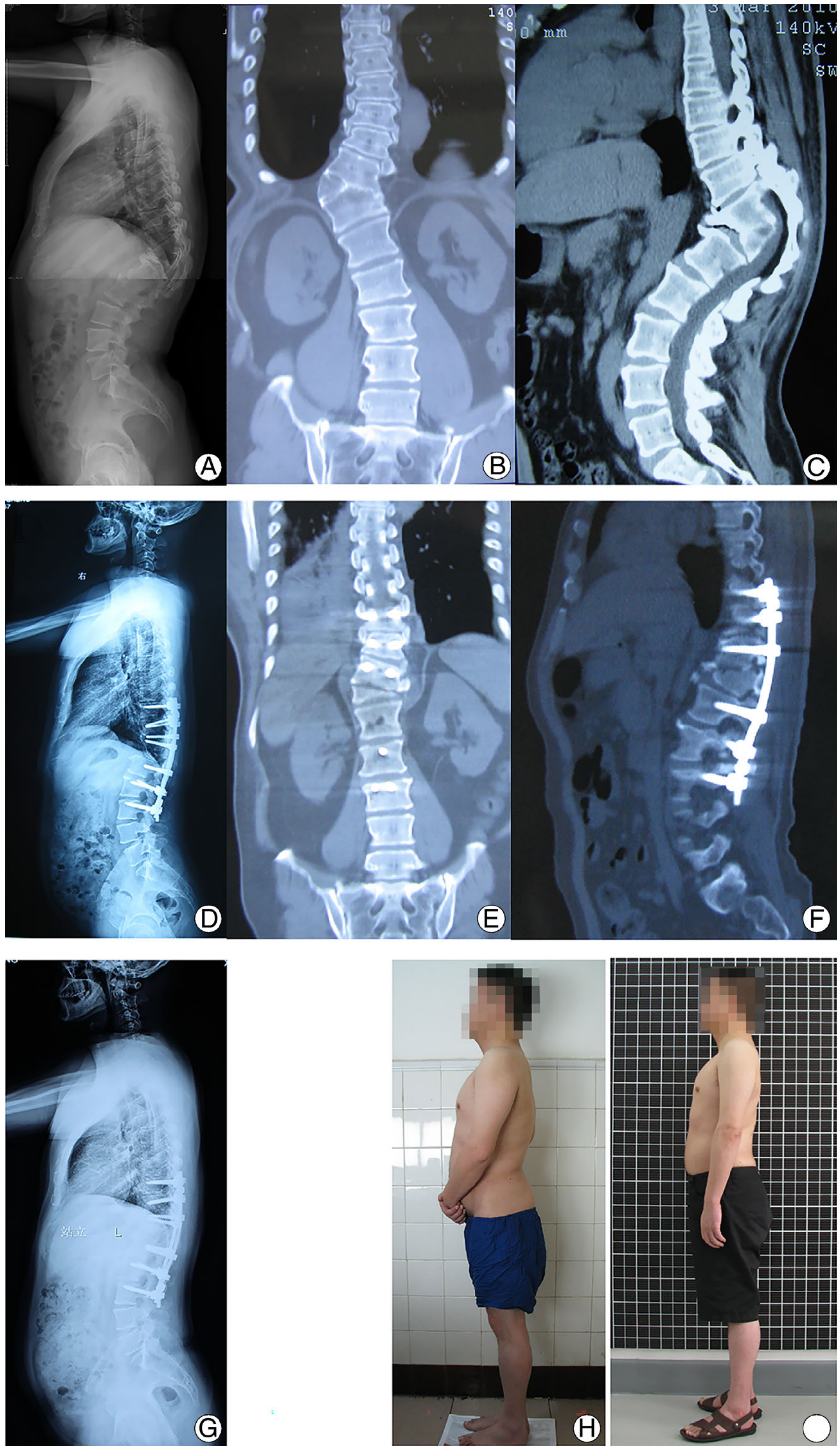

Fig. 5 A 40–50-year-old case with $T_{11–12}$ congenital spinal angular kyphosis. (A–C) Preoperative lateral X-ray and 3D CT scan showed a $T_{11\text{-}12}$ congenital kyphosis, with a deformity angle of 80°. (D–F) Postoperative lateral X-ray and 3D CT scan showed DCVO at $T_{11–12}$ complex, with a deformity angle of 23°. (G) Latest follow-up X-ray showed a deformity angle of 22.2°. (H, I) Preoperative and last follow-up clinical photos.

Global Sagittal Parameters (TK and LL)

Thoracic kyphosis (TK) decreased from 86.1° ± 12.1° to 28.7° ± 2.5°, lumbar lordosis (LL) improved from 94.5° ± 4.1° to 46.1° ± 3.0°. Both global sagittal parameters gained a significant improvement ($P < 0.01$) (Figs 4A–F, 5A–F, 6A–F). The loss of TK and LL was not obvious at the final follow-up, with P values of 0.31 and 0.12, respectively (Figs 4G, 5G, 6G) (Table 1).

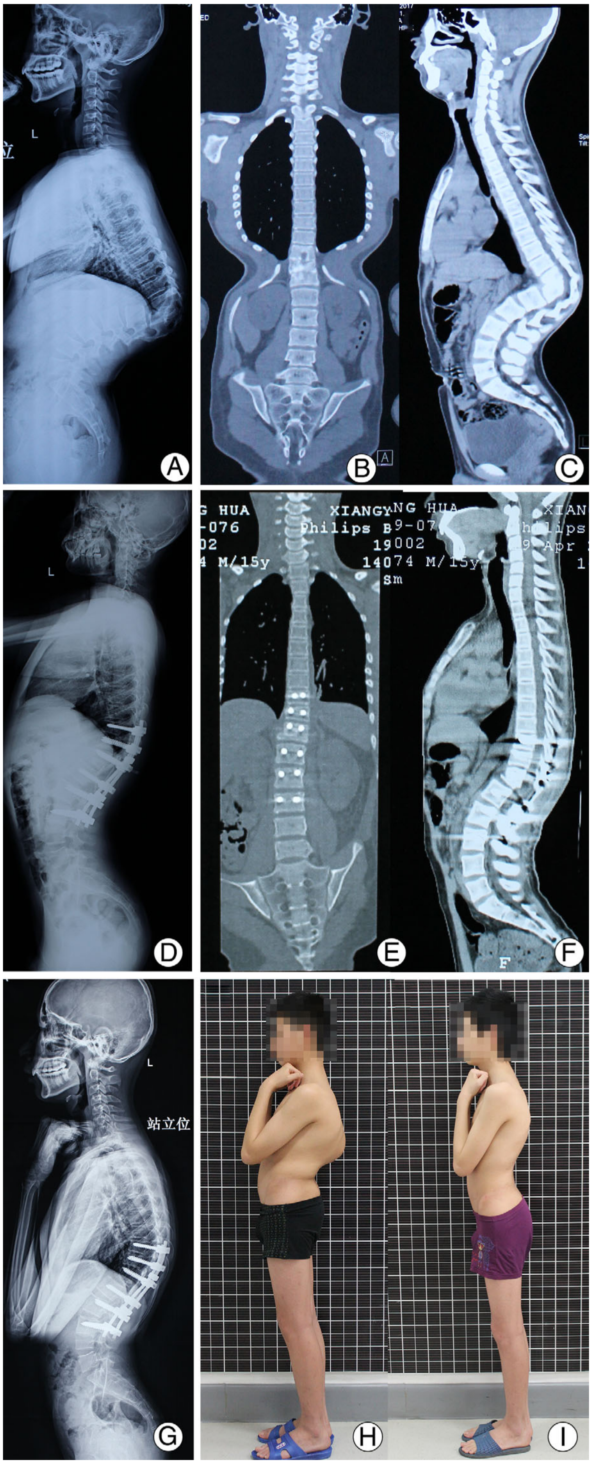

Fig. 6 A 10–20-year-old case with T_{9-11} congenital spinal angular kyphosis. (A–C) Preoperative lateral X-ray and 3D CT scan showed a T_{9-11} congenital kyphosis, with a deformity angle of 110.2°. (D–F) Postoperative lateral X-ray and 3D CT scan showed DCVO at T_{9-11} complex, with a deformity angle of 23.1°. (G) Latest follow-up X-ray showed a deformity angle of 21.6°. (H, I) Preoperative and last follow-up clinical photos.

Pelvic Parameters (PI, PT, and SS)

Pelvic incidence (PI) minus LL improved from −60.9° ± 6.5° to −13.7° ± 2.6°, and there was a statistically significant difference between pre-operation and post-operation ($P < 0.01$). The mean pelvic tilt (PT) and sacral slope (SS) improved globally after surgery (6.1° ± 10.3° *vs* 9.3° ± 3.9°, 27.5° ± 13.9° *vs* 23.1° ± 4.8°), and there was a significant improvement at post-operation ($P < 0.05$). All pelvic parameters did not suggest statistical differences between post-operation and final follow-up ($P > 0.05$) (Table 2).

Clinical Function Evaluation

The visual analog scale (VAS) score was on average 5.4 preoperatively compared with 1.9 at the last follow-up. The average Oswestry Disability Index (ODI) score was 21.3 preoperatively and 8.6 at the last follow-up. The Frankel D grade of two patients who exhibited neural impairment was increased to the Frankel E grade 2 weeks postoperatively (Table 1).

Complications

Ten patients experienced motor evoked potential (MEP) changes that were reduced by more than 50% of the baseline amplitude. An intraoperative wake-up test in all patients was successful. CSF fistula and neural injury did not occur during the perioperative period. At the last follow-up, fixation failure was not observed.

Discussion

Characteristics of DCVO

A retrospective study of 236 scoliosis and kyphosis patients whose mean kyphotic angle was 93.3° who underwent VCR showed that the average kyphosis correction was 34.4°, and the corrective rate was 63.1%[1]. Several studies have verified that PVCR is the most therapeutic technique for the treatment of kyphosis caused by spinal tuberculosis[15–17]. However, the PVCR technique can result in a high rate of complications, including neural injury during the perioperative period and fixation failure caused by nonunion or pseudo articulation formation[3,16,18–23]. PSO can achieve 30°–40° correction in a single segment[5,24,25]. The advantages of PSO are a shorter operation time, reduced surgical trauma, and lower complication rates than PVCR. Nevertheless, PSO cannot achieve the corrective goal in the treatment of severe kyphotic deformities.

The local kyphosis angle of the congenital severe angular kyphosis cases in this study was on average 95° preoperatively, and all apical vertebrae were in the thoracic segments. With these disease parameters, it is difficult to find an osteotomy technique that can be both safe and effective. Meanwhile, because of the congenital malformation fusion of two or three vertebrae, it was confusing to choose the operative region and locate the affected vertebra. Considering these situations, Lenke *et al.* “agree on a definition of a VCR that included complete separation of the spinal column into two

TABLE 1 Summary of sagittal parameters and clinical outcomes

Variable	Preoperative	Postoperative	Last follow-up	*t* value	*P* value
Deformity angle	94.9° ± 10.8°	24.0° ± 2.3°	24.9° ± 2.6°	33.572	0.00*
				31.087	0.00†
				−1.295	0.20‡
Thoracic kyphosis (TK) (T_4–T_{12})	86.1° ± 12.1°	28.7° ± 2.5°	29.2° ± 2.1°	25.415	0.00*
				25.322	0.00†
				1.041	0.31‡
Lumbar lordosis (L_1-S_1)	94.5° ± 4.1°	46.1° ± 3.0°	45.4° ± 2.8°	52.404	0.00*
				51.463	0.00†
				1.622	0.12‡
DAR	23.6° ± 2.6°	—	—	—	—
VAS	5.4 ± 0.9	—	1.9 ± 0.9	15.058	0.00†
ODI (%)	21.3 ± 9.4	—	8.6 ± 1.7	6.989	0.00†

Data represent mean ± standard deviation.; * Preoperative *vs* Postoperative.; † Preoperative *vs* Last follow-up.; ‡ Postoperative *vs* Last follow-up.

TABLE 2 Summary of spinopelvic parameters

Variable	Preoperative	Postoperative	Last follow-up	*t* value	*P* value
PI-LL	−60.9° ± 6.5°	−13.7° ± 2.6°	−12.9° ± 2.4°	31.758	0.00*
				36.826	0.00†
				1.686	0.10‡
Pelvic incidence (PI)	33.6° ± 5.2°	32.4° ± 2.0°	32.6° ± 2.0°	1.337	0.19*
				1.146	0.26†
				0.774	0.45‡
Pelvic tilt (PT)	6.1° ± 10.3°	9.3° ± 3.9°	9.4° ± 3.7°	2.362	0.02*
				2.448	0.02†
				0.252	0.80‡
Sacral slope (SS)	27.5° ± 13.9°	23.1° ± 4.8°	23.2° ± 4.8°	2.337	0.03*
				2.295	0.03†
				0.294	0.93‡

Data represent mean ± standard deviation. PI-LL indicates pelvic incidence minus lumbar lordosis.; * Preoperative *vs* Postoperative.; † Preoperative *vs* Last follow-up.; ‡ Postoperative *vs* Last follow-up.

separate limbs, which are subsequently brought together for deformity correction"[3]. Based on the above reasons and concepts, our team proceeded with the caution that VCR causes a high incidence of operative risks and complications when treating severe congenital angular kyphosis. In addition, the separated spine is difficult to realign because the spine was completely separated into two limbs without any closing hinge. The PSO technique only achieves a limited deformity correction that does not reach the treatment goal. Therefore, our team designed the DCVO technique to treat this type of angular kyphosis.

The characteristics of DCVO are as follows: (i) the facet joints and intervertebral discs of several levels exhibit partial or complete fusion, so we consider the malformed regions as a complex and proceed with osteotomy in this complex; (ii) a larger range and angle wedge osteotomy was performed in the complex. Meanwhile, the anterior longitudinal ligament is retained. The upper and lower endplates and part of the cancellous bone of the complex that is adjacent to the normal vertebral body were preserved without involving the normal discs; (iii) to minimize the effects of the thorax on correction, the longer ribs were resected (3–4 cm).

The advantages of DCVO compared with PSO and VCR are as follows. (i) The DCVO technique considers multiple malformed vertebrae as a complex. This concept simplifies complicated problems, which consider the malformed complex vertebrae as a whole, to help develop a more complete surgical plan and precise positioning during surgery. (ii) Limiting the osteotomy to the complex is beneficial to reduce surgical trauma and intraoperative bleeding compared with grade 4 or higher osteotomy. (iii) The anterior longitudinal ligament is preserved as a closed hinge. The spine is relatively stable, and the closing resistance is lower, which reduces the possibility of displacement. (iv) Bone-to-bone fusion is achieved without the need for an interbody fusion cage to assist fusion, and the fusion efficiency is higher. (v) The corrective angle is larger after osteotomy. The corrective angle of this group was 55°–90°, with an average of 70.9° ± 11.7°. Compared with PSO, the corrective angle is greatly improved. (vi) Avoiding the bone graft at the anterior column and reducing the times of manipulation in front of the spinal cord, which lower the risks of spinal injury.

Corrective Effect on Sagittal Balance

Attention should be paid to changes and mutual compensation in the sagittal parameters. Sagittal parameters are an important basis for the treatment plans and evaluation of corrective effects. In addition, these parameters are closely related to the patients' quality of life scores (i.e. ODI and VAS scores)[14]. The goals of the sagittal correction were SVA < 40 mm, −20° < PI-LL < 10°, and PT < 20°[26,27]. However, when developing a surgical plan, the surgeon should consider the age of the patient. Schwab *et al.* believe that patients <35 years of age should be corrected in strict accordance with the above objectives, but for patients >35 years old, a reduced angle according to the patient's age should be the goal and not to strictly achieve the above goals[28]. The preoperative, postoperative, and latest follow-up SVAs were all less than 40 mm in our study, which could be related to sagittal compensation because the patients' lumbar and cervical spines were normal. The preoperative PI-LL was −72.5° to −51.2°, with an average of −60.9° ± 6.5°. The postoperative PI-LL was −18.6° to −7.1°, with an average of −13.7° ± 2.6°. The latest follow-up PI-LL was −17.1° to −7.1°, with an average of −12.9° ± 2.4°. There were significant differences between the preoperative and postoperative measures and the preoperative and last follow-up measures, and there was no significant difference between the postoperative and the last follow-up measures. The preoperative PI-LL suggests severe deepening of LL. Through the DCVO technique, TK was significantly reduced, so the compensation of LL was also reduced. The postoperative and last follow-up PT were both <20°. The above data indicate that the postoperative sagittal parameters of 29 patients recovered to a relatively balanced state.

Intraoperative Neurological Damage

The deformity angular ratio (DAR) was first proposed by Lenke *et al.*; this ratio was calculated by dividing the deformity angle by the number of vertebral bodies covered by the deformed area, including the coronal plane ratio and the sagittal plane ratio, and the global ratio obtained by adding the ratio of the coronal plane to the sagittal plane. The DAR was used to predict the risk of intraoperative nerve damage[29,30]. The incidence of MEP alerts was approximately 75% when the sagittal DAR was greater than 22°. When the sagittal DAR reached 28°, the incidence was up to 90%. The sagittal DARs were 20.2°–28.5°, with an average of 23.6° ± 2.6° (Table 2). IONM showed that 10 cases had a transient change with a maximum drop of 50%, which may be caused by vibrations during osteotomy and closing. In this group, the intraoperative wake-up test was performed when the correction was completed, and all patients had good activity in both lower limbs. There was no loss or weakening of muscle strength in either lower limb postoperatively.

Considering whether osteotomy with DCVO technology can even proceed, there is still a certain risk of neurological damage. We suggest using IONM during surgery, and it is necessary to perform the intraoperative wake-up test after correction. Meanwhile, because of the large deformity angle and posterior column shortening, different degrees of dural and spinal cord compression, swelling, or shrinkage might occur that would result in damage to neural function when closing. Therefore, it is necessary to expand the sagittal diameter of the spinal canal by removing part of the bone in the inner wall of the lamina of the normal segment adjacent to the osteotomy surface to effectively prevent compression caused by osteotomy closure.

Limitation of the Study

There are some limitations that should be considered. One is the limited sample size of the included patients. The second limitation is that the medium- and long-term follow-up results should be further evaluated. The third limitation is that it is recommended that only experienced spinal surgeons and teams perform the DCVO technique.

Conclusion

In conclusion, DCVO is a specific osteotomy technique that applies to correct severe congenital angular kyphosis and cannot be classified by the SRS classification. The DCVO technique described for an effective and safe osteotomy of severe congenital angular spinal kyphosis is an excellent option for correcting the deformity and may decrease the occurrence of perioperative complications.

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Authorship declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

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