Original Article

Global Spine Journal
2022, Vol. 12(5) 922–930
sagepub.com/journals-permissions
DOI: 10.1177/2192568220972080
journals.sagepub.com/home/gsj

The Effect of Traditional Single Growing Rod Technique on the Growth of Unsegmented Levels in Mixed-Type Congenital Scoliosis

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Abstract

Study Design: Retrospective case series.

Objectives: To present outcomes concerning patients with early-onset mixed-type congenital scoliosis (EOMTCS) treated with the traditional single growing rod (TSGR), focusing on the growth of unsegmented levels (USLs).

Methods: Patients with EOMTCS who underwent TSGR and had a minimum of 4 USLs, 4 distractions, and 3-year follow-up were enrolled. Spine radiographs before and after index surgery and at the latest follow-up were evaluated. The length of the concave and convex side of USLs and thoracic parameters were measured. The absolute value and percentage of growth were calculated.

Results: Fourteen patients (mean age, 7.3 $\pm$ 2.8 years) were enrolled. The average follow-up duration was 4.9 $\pm$ 1.2 years, during which time 84 distractions and 8 final fusions were performed. The average number of USLs was 6.3 $\pm$ 2.2. The total and annual percent growth of concave side of USLs was significantly higher than convex side (32.2 $\pm$ 13.3% vs. 23.9 $\pm$ 9.5%, $p = 0.007$; 6.8 $\pm$ 2.7%/year vs. 5.1% $\pm$ 2.2%/year, $p = 0.007$, respectively). The concave-to-convex ratio of USLs increased from 58.6 $\pm$ 6.4 $\pm$ 7.6% at baseline to 68.8 $\pm$ 9.3% at the latest follow-up ($p < 0.001$). The Campbell's space available for lung ratio increased from 74.9 $\pm$ 11.1% at baseline to 89.6 $\pm$ 7.0% at the latest follow-up ($p < 0.001$).

Conclusions: In patients with EOMTCS, unilateral repetitive lengthening with TSGR can accelerate the growth of the concave side of USLs and improve the symmetry of the thorax.

Keywords

mixed-type congenital scoliosis, failure of segmentation, single growing rod, spinal growth

Introduction

Congenital scoliosis (CS), characterized as the structural abnormality of the vertebra, is due to early embryonic somite dysplasia.[1] Given its innate origin, most of the CS can be classified as early-onset scoliosis (EOS), which was defined as scoliosis onset before 10 years of age.[2] A combination of 2 detrimental features, "congenital" and "early-onset," makes treatment particularly challenging. According to Winter's classification, CS can be categorized into 3 groups: failure of formation, failure of segmentation, and mixed type.[3] The most complicated form of this condition is early-onset mixed-type CS (EOMTCS) with failure of segmentation around the apex. The majority of the EOMTCS requires surgical intervention. Early fusion usually results in thorax shortening and respiratory insufficiency despite the relatively improved correction of the curvature.[4] Therefore, growth-friendly techniques, such as the growing rod (GR) have become a first-line surgical treatment for congenital EOS. In patients with complex long-segment deformities and/or structural compensatory curves, a GR is considered appropriate.[5,6]

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The dual growing rod (DGR) is advantageous in good correction and low implant-related complication rates.[7,8] However, patients with EOMTCS frequently have poor nutritional status and severe deformity, and their limited soft tissue and fixation points may not readily accommodate a second rod at the convex side.[9] Therefore, the traditional single growing rod (TSGR) serves as an alternative in the treatment of EOMTCS. This technique offers easier preoperative planning, less operative trauma, and theoretically, a lower incidence of cutaneous complications.[10] Elsebai et al reported reduced deformity and improved spinal growth in patients with congenital EOS who had undergone GR treatment, with 12 of 19 patients (63%) having received a TSGR.[11]

Previous studies have reported limited growth potential at the concave side in CS patients with an unsegmented unilateral bar.[12,13] Whether TSGR with concave repetitive lengthening can alter the natural history of EOMTCS remains unknown. We aimed to present our findings concerning patients with EOMTCS who had been treated with TSGR, focusing on the growth of unsegmented levels (USLs).

Materials and Methods

Following approval from the Institutional Review Board of our hospital, we retrospectively screened data from a prospectively collected database, and we retrieved medical records and imaging data concerning all eligible patients.

Participants

Patients with EOMTCS who had been surgically treated at our hospital between 2002 and 2019 were reviewed. Inclusion criteria comprised the following: (i) patients with miscellaneous CS according to Winter's original description,[14] with at least 4 USLs around the apex; (ii) patients initially treated with TSGR due to poor nutritional and soft tissue status (transferring to DGR during lengthening was permitted); (iii) patients with a minimum of 4 distractions and 3 years of clinical follow-up, and; (iv) patients with complete imaging data including all-spine radiographs, computed tomography (CT) with 3-dimensional reconstruction, and magnetic resonance imaging (MRI).

Clinical Data

Baseline data comprised patient demographics, medical history, and physical examination. Operative parameters including the foundation level, the rod diameter, the fixation method (hook, screw, or both), and the distraction strategy were extracted from patient medical records. Follow-up data was obtained through routine outpatient visits, phone calls, and/or emails, with patient consent. An implant-related complication was defined as anchor failure or rod breakage.

Radiographic Measurement

All-spine radiographs before and after index surgery and at the latest follow-up were evaluated. All the radiographs were taken by a standard protocol that ensured consistent posture and distance, and all the images were provided with scale information. The Surgimap version 2.3 (Nemaris, New York, USA) was used to calibrate and measure the images.[15] The parameters under observation included Cobb's angle of the major curve, thoracic height (T1-T12), all-spine height (T1-S1), and maximal thoracic width and depth (Figure 1). Particularly, the Cobb's angle was invariably measured using the upper and lower end vertebrae defined on pre-index radiographs. Campbell's space available for lung (SAL) ratio was measured from the middle of the most cephalad rib down to the center of the hemidiaphragm.[16] The lengths of the concave and convex sides of the USLs were measured using a free-hand approach on the coronal film (Figure 1).

Vertebral malformations and intraspinal anomalies were identified using CT and MRI, respectively. In this study, we defined failure of segmentation as all types of congenital bony fusion including a unilateral bar, blocked vertebra, fused lamina, and in most cases, a combination of these deformities.

Statistical Analysis

The absolute values and percentages (absolute change divided by baseline value) of growth were calculated. Statistical analysis was performed using SPSS version 22.0 (IBM, New York, USA). A paired Student's t-test and a Wilcoxon signed-rank test were applied to determine the significance of changes and to make comparisons between the concave and convex sides of the USLs. All statistical tests were 2-tailed and a p-value <0.05 was considered statistically significant.

Results

After an initial review of 130 patients, a total of 14 eligible patients with EOMTCS (Figure 2) were enrolled in this study (mean age, 7.3 $\pm$ 2.8 years; 6 males). The mean body mass index (BMI) before index surgery was 15.9 $\pm$ 2.5 kg/m^2. The number of USLs ranged from 4 to 10 segments (mean, 6.3 $\pm$ 2.2). The average Cobb's angle of the major curve was 88.9° $\pm$ 19.3°. The follow-up ranged from 3.5 to 7.0 years (mean, 4.9 $\pm$ 1.2 years), during which time 84 distractions and 8 final fusions were performed. Intraspinal anomalies were identified in 8 (57.1%) patients (Table 1). Concerning comorbidities, 4 (28.6%) patients were diagnosed with thoracic insufficiency syndrome, defined as the inability of the thorax to support normal respiration or lung growth.[16]

Eight of the 14 patients (57.1%) received small-diameter rod (Φ = 4.5 mm or 4.35 mm) implants and low-profile screws at index surgery. A standard 5.5 mm rod was considered only for older children with better soft tissue capacity. This strategy was advantageous in that only one skin-related complication was observed during a total of 106 surgical interventions. However, rod breakage occurred in 2 patients within the small-diameter rod group (2 of 8 patients, 25%), which were replaced with 5.5 mm rods during lengthening. During an average follow-up period of 4.9 $\pm$ 1.2 years, a total of 84 distractions were

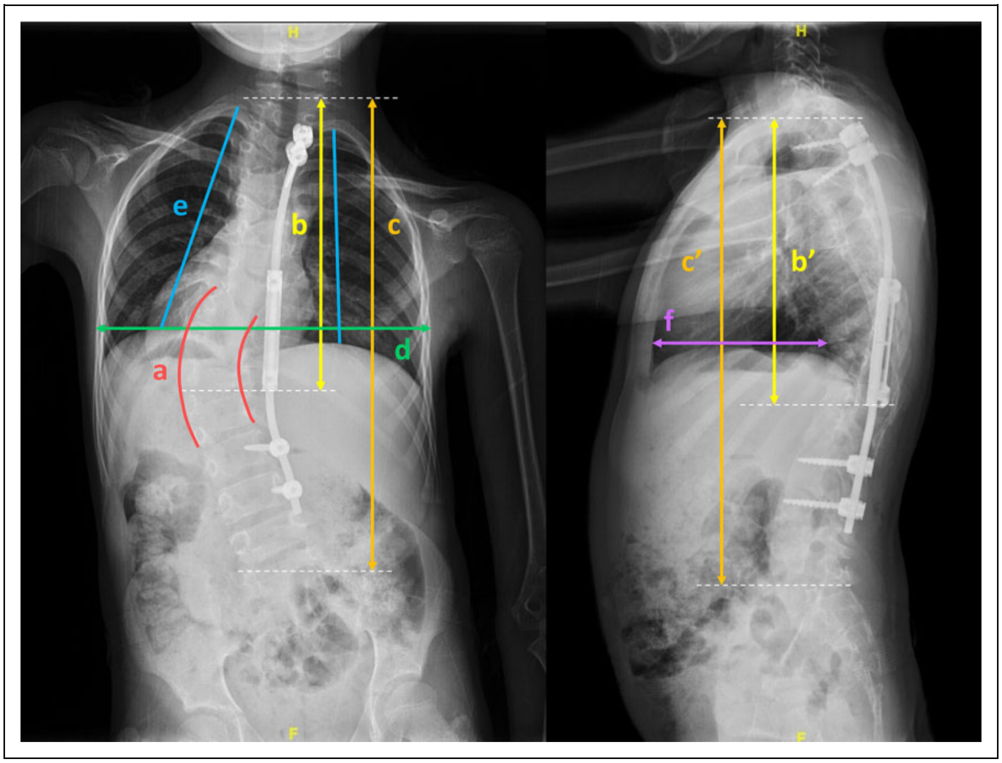

Figure 1. Schema of radiograph measurements. a) Freehand measurement of the concave and convex side of unsegmented levels; b and b') coronal and sagittal T1-T12 height; c and c') coronal and sagittal T1-S1 height; d) maximal thoracic width; e) Campbell's space available for lung ratio; f) maximal thoracic depth.

performed (mean, 6.0 ± 2.0; Table 2). Nine patients had graduated, comprising 8 final fusion and 1 graduation without fusion.

At index surgery, an intraoperative neuromonitoring alert was observed in 2 (14.3%) patients, with one occurring during T2 screw insertion and resolved through adjusting the direction of the screw, and the other occurring during the correction maneuver, which resulted in a slight compromise in correction rate (Figure 3). Neither patient reported any neurological abnormality postoperatively. Four patients (28.6%) subsequently received a DGR because of rod breakage coronal decompensation in 2 patients each.

During the follow-up, 8 (57.1%) patients sustained 14 implant-related complications, including 5 proximal anchor failures, 7 distal anchor failures, and 2 rod breakages. No subsequent neurological impairment was observed. All the complications were managed during routine lengthening procedures. Alignment complications occurred in 6 (42.9%) patients, including proximal junctional kyphosis and coronal decompensation in 3 patients, respectively. At the latest follow-up, no complication was reported in the 9 graduated patients following graduation.

Measured on pre-index and follow-up radiographs, the absolute total and annual change at the concave side were higher than those at the convex side, and these differences were statistically significant (23.6 ± 9.2 mm vs. 18.6 ± 9.9 mm, $p = 0.044$; 5.1 ± 2.6 mm/year vs. 4.0 ± 2.4 mm/year, $p = 0.036$, respectively). The concave side also had a significantly higher total and annual percent change than the convex side (40.5 ± 13.3% vs. 20.3 ± 12.8%, $p < 0.001$; 8.5 ± 3.0%/year vs. 4.3 ± 2.5%year, $p < 0.001$). To eliminate the influence of index surgery and focus on spinal growth, we calculated growth values from post-index to follow-up radiographs. The total and annual percent growth were significantly higher at concave side (32.2 ± 13.3% vs. 23.9 ± 9.5%, $p = 0.007$; 6.8 ± 2.7%/year vs. 5.1% ± 2.2%/year, $p = 0.007$, respectively). While, the total and annual absolute growth showed no statistical difference between 2 sides ($p > 0.05$, Table 3). The concave-to-convex ratio increased from 58.6 ± 6.4% to 64.4 ± 7.6% after index surgery ($p < 0.001$), and further increased to 68.8 ± 9.3% at the latest follow-up ($p = 0.006$, compared to post-index value).

At the latest follow-up, the total correction rate of the major curve was 27.3 ± 13.4%, with most of the correction occurring at index surgery (88.9 ± 19.3° vs. 66.2 ± 19.5°, $p < 0.001$). The Cobb's angle was stabilized by repeated distractions (66.2 ± 19.5° vs. 65.8 ± 21.0°, $p = 0.839$). The SAL ratio increased from 74.9 ± 11.1% to 84.5 ± 8.1% after index surgery ($p < 0.001$), and further increased to 89.6 ± 7.0% at the latest follow-up ($p = 0.003$, compared to post-index value). The ascending SAL ratio along with a statistically significant increase in forced vital capacity (64.4 ± 15.7% vs. 55.2 ±

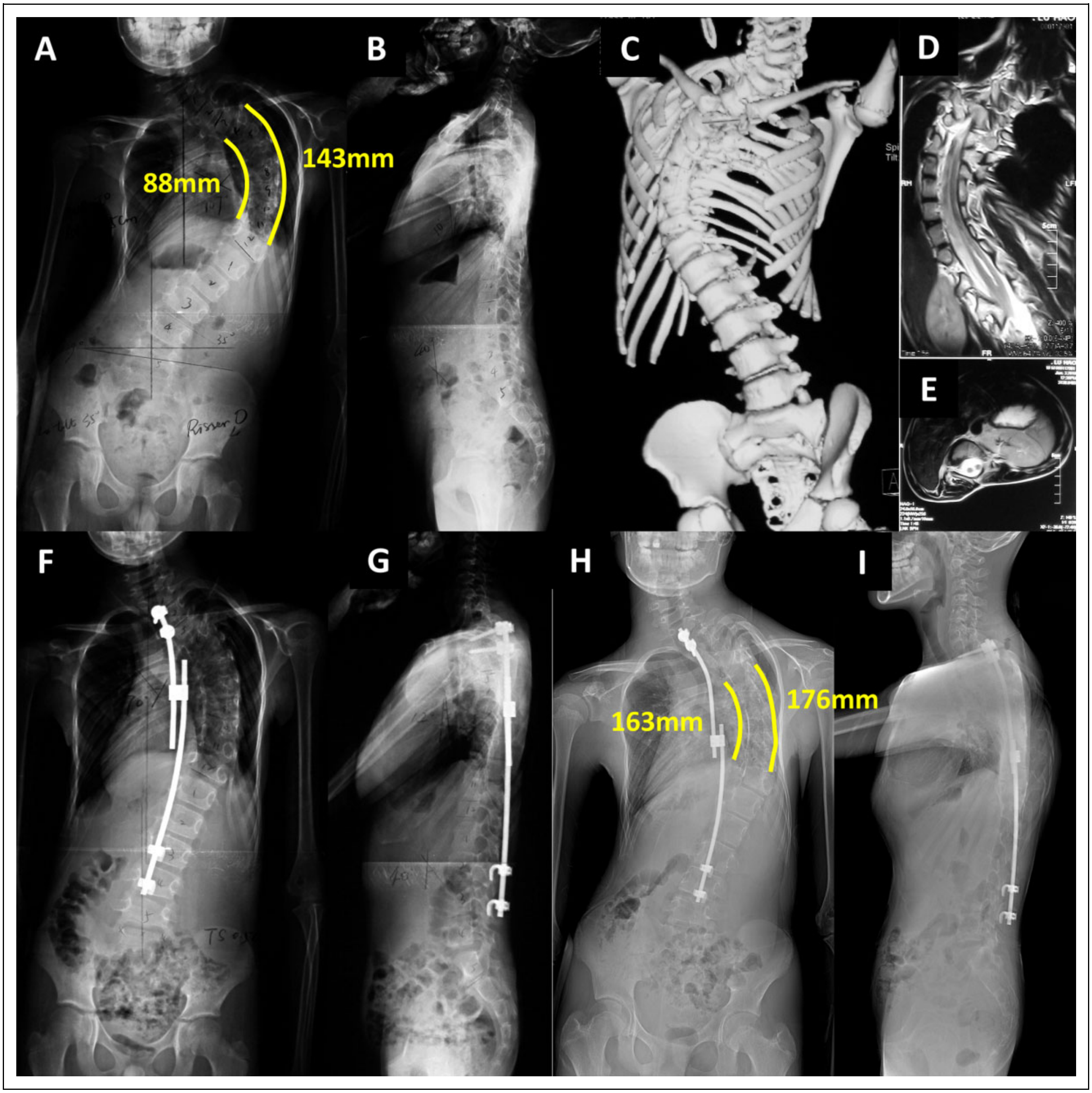

Figure 2. A & B) All-spine radiographs before index surgery; C) 3-D CT showed extensive vertebral malformation and segmentation failure; D & E) T2-weighted coronal and axial MRI identified type 2 split cord malformation at the thoracolumbar area. F & G) After index surgery. H & I) After seventh distraction with in-situ fusion.

12.7%, $p = 0.015$) suggested a positive effect of TSGR on the development of thorax. The total and annual absolute growth concerning T1-S1 height was 60.7 ± 20.9 mm and 13.1 ± 5.5 mm/year, respectively. The total and annual absolute growth concerning T1-T12 height was 32.0 ± 16.5 mm and 6.9 ± 4.1 mm/year, respectively. The maximal thoracic width and depth also showed significant growth ($p < 0.001$, Table 4).

Discussion

Previous studies have provided evidence to support the use of GR in congenital EOS.[17] However, no studies have examined the application of TSGR in patients with mixed-type CS. Our study focused on patients with EOMTCS and was significant in showing that the distraction force of the TSGR was able to

Table 1. Baseline Data of the Fourteen Patients With Early-Onset Mixed-Type Congenital Scoliosis.

Pt. No.	Age at index surgery (yr)	Sex	USLs	Unilateral bar	Fused ribs on concave side	Cobb angle of major curve	Compensatory curve	Intraspinal anomalies	Additional comorbidities
1	7.6	F	T7-T11	T9-T10	No	78	No	SCM (Type I)	No
2	6.6	M	T8-T11	T8-T11	No	82	No	No	Congenital eventration of right diaphragm
3	3.5	F	T7-T11	T7-T11	T5-T6	104	No	No	Klippel-Feil syndrome, bicuspid aortic valve
4	6.9	F	T2-T8	No	T5-T8	90	T10-L4	No	No
5	10.7	M	T5-T11	T7-T10	T4-T8	106	No	SCM (Type I), tethered cord, syringomyelia	Thoracic insufficiency syndrome
6	4.5	M	T11-L2	No	No	89	T1-T10	No	No
7	7.0	F	T6-T9	T8-T9	T6-T7, T8-T9	81	T11-L5	SCM (Type I)	No
8	10.2	M	T3-T11	T8-T11	No	95	No	No	No
9	9.2	M	T3-T11	No	T4-T10	119	No	Syringomyelia, tethered cord	Thoracic insufficiency syndrome
10	12.3	F	T2-T11	No	T4-T9	104	No	SCM (Type II), tethered cord	Thoracic insufficiency syndrome
11	8.9	F	T8-L1	T9-L1	No	68	No	Syringomyelia	No
12	4.0	F	T1-T9	T4-T8	T5-T6	85	No	SCM (Type II), tethered cord	No
13	3.3	F	T4-T8	T4-T8	T4-T8	103	T11-L5	SCM (Type I), syringomyelia	Thoracic insufficiency syndrome
14	7.5	M	T6-T9	No	No	41	T10-L4	No	Klippel-Feil syndrome, congenital atelectasis of left lung

Pt. No., patient number; *USLs*, unsegmented levels, comprising unilateral bar, block vertebra and segmentation failure of posterior structure; *M*, male; *F*, female; *SCM*, split cord malformation.

Table 2. Operative Parameters of the Fourteen Patients With Early-Onset Mixed-Type Congenital Scoliosis.

	Index surgery								
Pt. No.	Diameter of rod	Proximal anchor	Distal anchor	Number of distractions	Final fusion	Graduation	Transferred to DGR	IONM finding	Duration of follow-up (yr)
1	5.5 mm	T4 (H), T5 (H)	L4 (S)	4	Yes	Yes	No	-	5.7
2	5.5 mm	T3 (H), T4 (H)	L4 (S)	4	Yes	Yes	No	-	6.8
3	5.5 mm	T2 (H), T3 (H)	L4 (S)	4	Yes	Yes	No	-	5.0
4	4.5 mm	T1 (H), T11 (S)	T11 (S), L4 (S)	8	No	Yes	No	-	6.3
5	5.5 mm	T2 (S), T3 (S)	L3 (H), L4 (H)	7	Yes	Yes	No	-	4.1
6	4.5 mm	T8 (S), T9 (S)	L3 (S), L4 (S)	9	Yes	Yes	Yes	-	7.0
7	5.5 mm	T3 (S), T4 (S)	T12 (S), L1 (S), L2 (S)	10	Yes	Yes	No	+	5.7
8	4.5 mm	T2 (S), T3 (S)	L2 (S), L3 (S)	5	Yes	Yes	Yes	-	3.9
9	4.5 mm	T2 (S)	L1 (S), L2 (S)	6	No	No	No	+	4.4
10	4.5 mm	C7 (S), T1 (S)	L3 (S), L4 (S)	5	Yes	Yes	No	-	4.5
11	4.5 mm	T2 (S), T3 (S)	L2 (S), L3 (S)	7	No	No	Yes	-	4.5
12	4.5 mm	C7 (S)	T12 (S), L1 (S)	5	No	No	No	-	3.5
13	4.5 mm	C7 (S), T1 (S)	L2 (S), L3 (S)	4	No	No	Yes	-	3.7
14	5.5 mm	T3 (S), T4 (S)	T11 (S), T12 (S)	6	No	No	No	-	3.5

Pt. No., patient number; *TC,* tethered cord; *DGR,* dual growing rod; *IONM*, intraoperative neuromonitoring, + was defined a 50% or larger decrease of motor evoked potential; *(H)*, lamina hook; *(S)*, pedicle screw.

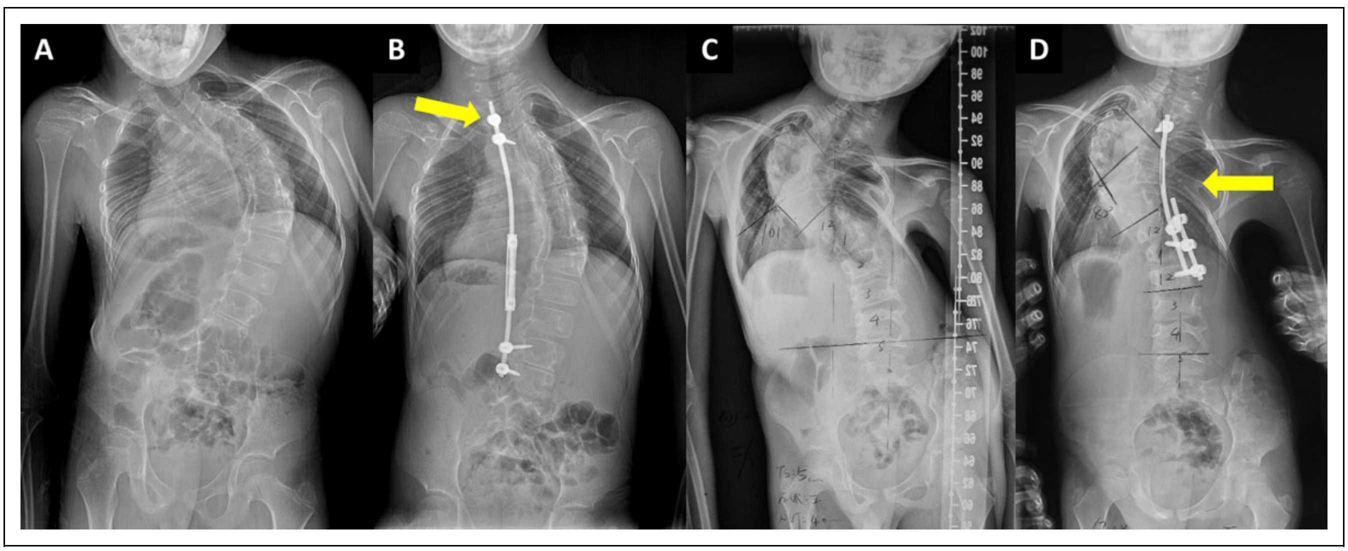

Figure 3. A & B) Coronal films before and after index surgery. Patient No. 8 experienced a 50% decrease of MEP when T2 screw insertion (yellow arrow), which was resolved by adjusting the direction of the screw. C & D) Coronal films before and after index surgery. Patient No. 9 had complex deformity with syringomyelia and tethered cord. He suffered a 60% decrease of MEP during correction maneuver, which was resolved by a slight compromise of correction rate (reducing the amount of distraction).

accelerate the percent growth of the concave side in USLs. When calculated between post-index and follow-up measurements, both the total and annual percent growth of the concave side was significantly higher than the convex side (Table 3), which eliminated the influence of index surgery and indicated the positive effect of TSGR on concave growth.

Currently, shortening procedures such as a grade 3 to 5 osteotomy[18] are performed for patients with mixed-type CS, and are likely to achieve good correction; however, shortening the spine, especially the thoracic spine in patients with EOS, is likely to retard chest development. Instead of external morphology, the TSGR targets the underlying mechanism of scoliosis, the imbalanced growth between 2 sides of the spine. Through lengthening the concave side, the TSGR works to rebalance spinal growth and consequently achieve correction. The single-rod construct may be more helpful for growth preservation and development of pulmonary function than the shortening procedures in certain patients with EOMTCS.

Previously, it was accepted that the unsegmented concave spine had limited growth potential and that the natural history of CS with unilateral segmentation failure was unfavorable.[19,20] With the development of surgical techniques, it has been reported that fused levels can also achieve substantial growth. In 2003, Campbell and Hell-Vocke[21] published their findings concerning concave side growth in patients with CS. In that study, 18 patients who had undergone expansion thoracoplasty and vertical expandable titanium prosthetic rib (VEPTR) treatment were followed for an average of 4.2 years, during which time significant growth occurred in the concave unilateral bar (7.9 mm/year or 7.1%/year) and in the corresponding convex side (8.3 mm/year or 6.4%/year). However, they reported no significant difference in growth between the concave and convex sides. The present study identified consistent annual percent growth at the concave side of the USLs (6.8%/year). However, our findings differed in that the concave side had significantly higher percent growth than the convex side. This may have been because GRs exert a more direct distraction force on the spine.

Table 3. Radiographic Measurements of the Concave and Convex Sides of the Unsegmented Levels.

Time points or durations	Length of unsegmented levels (mm or %)		p value*
	Concave side	Convex side	
Pre-index (1st measurements)	61.1 ± 25.0	103.4 ± 37.8	<0.001
Post-index (2nd measurments)	64.8 ± 25.9	100.1 ± 36.9	<0.001
The latest follow-up (3rd measurements)	84.7 ± 32.1	122.1 ± 38.8	<0.001
Changes from 1st to 3rd measurements$			
Total absolute change	23.6 ± 9.2	18.6 ± 9.9	0.044
Total percentile change	40.5 ± 13.3	20.3 ± 12.8	<0.001
Annual absolute change	5.1 ± 2.6	4.0 ± 2.4	0.036
Annual percentile change	8.5 ± 3.0	4.3 ± 2.5	<0.001
Growths from 2nd to 3rd measurements			
Total absolute growth	19.9 ± 8.5	22.0 ± 9.3	0.360
Total percentile growth	32.2 ± 13.3	23.9 ± 9.5	0.007
Annual absolute growth	4.3 ± 2.3	4.7 ± 2.4	0.413
Annual percentile growth	6.8 ± 2.7	5.1 ± 2.2	0.007

Data was expressed as mean ± standard deviation. *The data followed the normal distribution and the paired t-test was applied. $The total influence of index surgery and spinal growth.

The growth-promoting effect of the single-rod approach has been assumed to be weaker than the DGR. In this study, the 13.1 ± 5.5 mm/year growth in T1-S1 height was comparable to the value of 12.1–14.6 mm/year in previous studies concerning the DGR that involved only a small number of patients with CS (ranging from 1 of 13 patients to 3 of 23 patients),[7,22] and was slightly superior to the results from a multicenter study, where 19 patients with CS had been treated with a GR, in which the corresponding value was 11.7 mm/year.[11] Given the absolute growth of USLs (4.3 mm/year at the convex side and 4.7 mm/year at the concave side) only accounted for approximately one-third of T1-S1 growth (13.1 mm/year), the correction of curvature and the compensatory growth of fully segmented levels were likely to provide major contributions to the T1-S1 increase. Therefore, though being substantial, the growth-promoting effect of TSGR lengthenings and the consequent spinal growth observed in this study should be interpreted with caution. Concerning the less frequently reported T1-T12 height, our finding (6.9 mm/year) was slightly lower than that reported by Sanchez Márquez et al (8.6 mm/year).[23] In their report, 20 patients were treated with a DGR or a VEPTR, and most patients had been diagnosed with non-congenital scoliosis.

The reported TSGR correction rate ranged from 12.1% to 51.6%, which was generally lower than the DGR correction rate. Considering the complexity of deformity in this group, the average 27.3% correction of Cobb's angle remained within

Table 4. Follow-Up Results of the Fourteen Patients With Early-Onset Mixed-Type Congenital Scoliosis.

Variables	Pre-index	Post-index	Follow-up	p value	
				Follow-up vs. pre-index	Follow-up vs. post-index
Radiographic parameters					
Cobb angle (°)	88.9 ± 19.3	66.2 ± 19.5	65.8 ± 21.0	<0.001	0.839
T1-T12 height (mm)	146.1 ± 26.4	157.8 ± 25.6	189.7 ± 31.1	<0.001	<0.001
T1-S1 height (mm)	260.8 ± 43.9	277.2 ± 42.5	337.9 ± 44.6	<0.001	<0.001
Thoracic width (mm)	180.6 ± 22.6	181.3 ± 21.2	208.1 ± 28.8	<0.001	<0.001
Thoracic depth (mm)	72.9 ± 14.9	76.5 ± 13.9	96.9 ± 22.1	<0.001	<0.001
SAL ratio (%)	74.9 ± 11.1	84.5 ± 8.1	89.6 ± 7.0	<0.001	0.003
Nutritional status					
BMI (kg/m^2)	15.9 ± 2.5	N/A	19.2 ± 3.6	<0.001	N/A
Hemoglobin (g/L)	129.9 ± 7.0	N/A	134.6 ± 8.7	0.080	N/A
PFT (Actl/Pred)					
FEV1 (%)	60.5 ± 13.6	N/A	68.3 ± 14.2	0.055	N/A
FVC (%)	55.2 ± 12.7	N/A	64.4 ± 15.7	0.015	N/A

Data is expressed as mean ± standard deviation or median (minimum, maximum) as appropriate. *EOMTCS*, early-onset mixed-type congenital scoliosis; *SAL*, Campbell's space available for lung; *BMI*, body mass index; *PFT*, pulmonary function test; *FEV1*, forced expiratory volume in 1 second; *FVC*, forced vital capacity. *N/A*, not available. *Comparisons between baseline and follow-up values, calculated with paired-samples t-test or Wilcoxon signed-rank test as appropriate.

the mid-range of previously reported results and can be considered reasonable. More importantly, this less than optimal correction did not impede the significant increase in the SAL ratio (from 0.75 to 0.90), even in the presence of fused ribs. A similar result (from 0.81 to 0.94) was reported by Elsebai et al.[11] Improvements in the SAL ratio and forced vital capacity served to cross-validate and collectively demonstrate the positive effect of the TSGR on pulmonary development in patients with EOMTCS.

Of note, there was a relatively high incidence of implant-related complications. In a multi-center study[24] and in a United Kingdom single-center study[25] comprising the 2 largest TSGR cohorts to date (n = 71 and n = 88 enrolled patients, respectively), implant-related complications were observed in 47.9% and 53.4% of patients, respectively, despite the low proportion of patients with CS (range, 17.1%–20.5%). In the present cohort, we identified a 57.1% incidence of implant-related complications, which was slightly higher than that in previous reports, of which the underlying reasons may include the rigid deformities caused by extensive failure of segmentation and limited mechanical strength of TSGR.

The present study has some limitations. Firstly, this study is retrospective and single-arm in nature. Secondly, the sample size is small, due to the rarity of EOMTCS. Moreover, the CT had not been routinely performed during follow-up, and the freehand measurement on plain radiographs may be susceptible to systematic errors.

In conclusion, the present study indicated that unilateral repetitive distraction with TSGR increased the percent growth of the concave side of USLs in patients with EOMTCS and improved the asymmetry of the thorax. In patients with severe deformity and low BMI, as an alternative scheme, TSGR can be helpful for deformity correction and growth preservation.

Authors' Note

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. Informed consent was obtained from all individual participants included in the study. This manuscript is approved by all authors for publication. This study is exempted from ethical approval by the Institutional Review Board of Peking Union Medical College Hospital (protocol number, S-K1009). Prior Abstract Presentation: 13th International Congress on Early Onset Scoliosis (ICEOS), Nov. 21, 2019, Atlanta, USA.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported in part with a grant from the Chinese Academy of Medical Sciences Innovation Fund for Medical Sciences (Grant 2018-I2M-AI-003).

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