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ORIGINAL ARTICLE

Selective thoracic fusion for adolescent thoracic scoliosis secondary to Chiari I malformation: a comparison between the left and the right curves

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Abstract

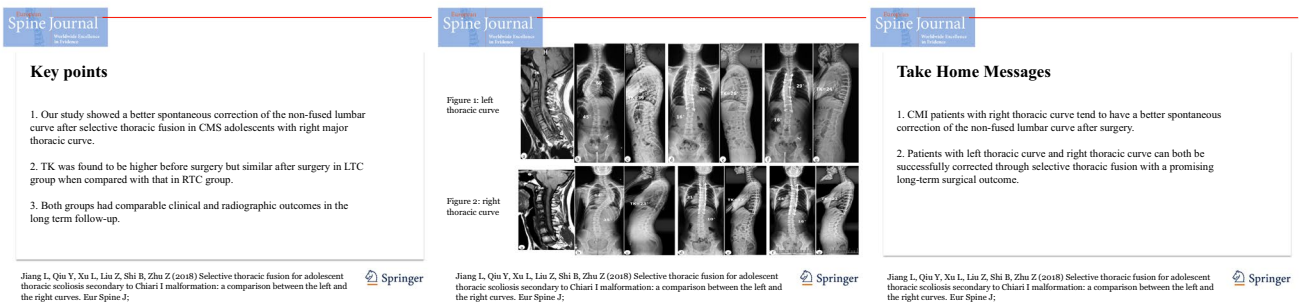
Purpose The aim of this study was to compare the clinical outcomes of selective thoracic fusion in the surgical treatment of Chiari malformation type I (CMI) adolescents with different curve patterns.

Methods Sixty-three CMI patients with left thoracic curve (LTC) and 63 age- and curve-magnitude-matched CMI patients with right thoracic curve (RTC) were recruited. Selective thoracic fusion was performed for two groups. The coronal and sagittal parameters including the thoracic and lumbar Cobb angle, apical vertebral translation, trunk shift, thoracic kyphosis (TK), lumbar lordosis and sagittal vertical axis were measured before surgery, immediately postoperative and at the final follow-up. The accuracy of pedicle screw placement between both groups was also compared.

Results All preoperative radiographic parameters were matched in both groups except for TK (LTC group 40.1° vs. RTC group 23.0°, $P=0.021$). The immediately postoperative spontaneous correction of the lumbar curve was 56.9% in LTC group, which was remarkably lower than in RTC patients (67.9%). Patients with LTC were found to have obviously increased trunk shift than those with RTC (15.1 mm vs. 8.0 mm, $P=0.038$). At the final follow-up, the correction of the thoracic curve was comparable between the two groups (59.9% vs. 62.6%, $P=0.610$). The rate of the pedicle screw perforations was similar between both groups.

Conclusions Patients with LTC and RTC can both be successfully corrected through selective thoracic fusion with a promising long-term surgical outcome. CMI patients with RTC tend to have a better spontaneous correction of the lumbar curve after surgery.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



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Extended author information available on the last page of the article

Keywords Selective thoracic fusion · Chiari malformation type I · Curve patterns · Radiographic outcomes

Introduction

Chiari I malformation (CMI) associated with syringomyelia is a common condition that may lead to the development of scoliosis, especially in adolescents. As a common type of neuromuscular scoliosis, Chiari malformation-associated scoliosis (CMS) was reported to have more progressive and less flexible curves when compared with idiopathic scoliosis (IS) [1]. Patients with CMS are commonly recommended to undergo surgical intervention when having curves larger than 50° or significant curve progression [2]. Selective thoracic fusion (STF) has been used to correct the major curve meanwhile maintaining mobile lumbar motion segments. It has been confirmed to yield favorable clinical and radiographic outcomes in IS patients with major thoracic curve [3–6]. However, the effectiveness of STF in patients with CMS has been rarely reported [7]. Furthermore, results of previously published studies regarding surgical outcomes for CMS have been inconclusive due to the heterogeneity of the curve patterns, surgical approaches, types of instrumentation constructs as well as by the short follow-up periods [2, 8].

Generally, CMS involving the thoracic spine can present two different curve patterns, including the "idiopathic-like" pattern shown as right thoracic curve (RTC) and the atypical pattern shown as left thoracic curve (LTC). Compared with idiopathic scoliosis (IS), the prevalence of LTC is remarkably higher in CMI patients. Several studies have shown that the prevalence of LTC among patients with CMI ranges from 24.0 to 41.7% [9–11]. Although the mechanism underlying the development of scoliosis secondary to CMI and syringomyelia remains poorly understood, the correlation between curve direction and the side of tonsillar ectopia and syrinx deviation has been explored in recent studies, suggesting that the curve convexity could be influenced by deviation of the tonsillar and syrinx [12, 13].

CMS patients with different curve patterns could have divergent response to surgical interventions. Sengupta et al. [14] reported that posterior fossa decompression (PFD) could be more effective in patients with LTC, saving 75% from further correction surgery. Therefore, it is probable that CMS patients with LTC could have more favorable surgical outcomes of STF than those with RTC. To address these issues, we compared the radiographic and clinical outcomes of STF between patients with LTC and age- and curve-magnitude-matched patients with RTC with a minimum 2-year follow-up.

Materials and methods

Subjects

Following the approval of institutional review board (IRB), all CMS patients treated at our clinic from June 2006 to August 2015 were retrospectively reviewed. Patients were included in the study according to the following inclusion criteria: (1) aged from 12 to 18 years at surgery; (2) having major thoracic curve (Cobb angle ranging from 45° to 80°) with a lumbar curve type comparable to lumbar modifier A or B as indicated by the Lenke classification of IS (with type C excluded) [15]; (3) undergoing STF stopped at T12 or L1; (4) having a minimum 2-year follow-up. Patients with congenital spinal deformity or history of spine surgery were excluded. Finally, 63 patients with left thoracic curve were assigned to LTC group. We also reviewed our database to identify patients with CMS who had undergone STF for a right thoracic curve during the same period and chose those who were the best matches, with respect to age and curve magnitude (within 5°). Sixty-three patients with right thoracic curve served as the RTC group (Fig. 1).

CMI was defined as > 5 mm of cerebellar tonsil herniation through the foramen magnum into the spinal canal [16].

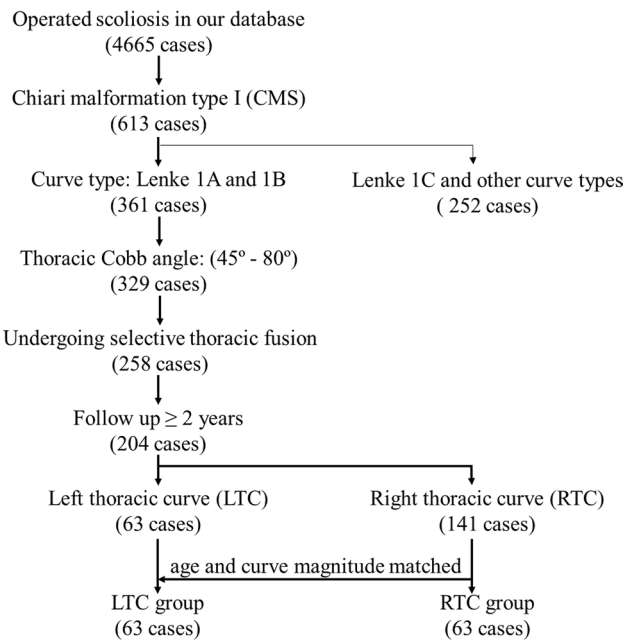

Fig. 1 A flowchart shows the recruitment of patients with left thoracic curve or right thoracic curve. *CMS* Chiari malformation type I-associated scoliosis

Surgical procedures

All recruited CMI patients received a standard posterior fossa decompression (PFD) procedure, which consisted of a suboccipital craniectomy, C1 laminectomy and duraplasty as described by Isu et al. [17]. With posterior approach, a 3 × 3 cm section of the squamous part of the occipital bone and 2.5-cm-wide section of the posterior arches of the C1 were removed. The thickened occipital fascia was excised, the dura mater was Y-sheared, and muscular fascia was then used to expand and repair the dura mater. PFD was performed six to ten months prior to deformity correction. The indications for PFD included the presence of both a CMI and syringomyelia, particularly in patients with progressive scoliosis or neurologic deficits.

Posterior spinal correction and instrumentation with total pedicle screws (titanium; Medtronic) were performed by the senior spine surgeons for enrolled patients. Simply removing the inferior facet was performed along the whole length of the instrumentation for achieving better fusion. Osteotomies such as Smith–Peterson or Ponte were not used in all cases. Pedicle screws were placed bilaterally at the upper and lower instrumented vertebrae, and at least one pedicle screw was placed at the remaining levels. Appropriate compression at the convex side and distraction at the concave side were applied to achieve satisfied correction. Autogenous local bone grafts in combination with cortical and cancellous allograft were used for fusion. Intraoperative neurophysiological monitoring of somatosensory evoked potentials (SEPs) and transcranial electrical stimulation MEPs (TES-MEP) was performed in all patients. SEPs and TES-MEP were at least evoked in the following time points: before pedicle screw insertion, after pedicle screw insertion and after curve correction. A neurophysiological change was defined significant (i.e., an "alert") when it consisted of a persistent unilateral or bilateral reduction in amplitude > 50% or > 10% increase in latency of cortical wave for SEPs and > 80% decrease in waveforms for TES-MEPs compared with baseline.

Radiographic measurement

Radiographic parameters were measured on standing full-spine radiographs obtained preoperatively, early postoperatively (within two weeks) and at a minimum of two years postoperatively, including thoracic and lumbar Cobb angles, apical vertebral translation (AVT), trunk shift (TS), thoracic kyphosis (TK), lumbar lordosis (LL) and sagittal vertical axis (SVA). AVT was defined as the distance from the midpoint of the thoracic apical vertebra to the C7 plumb line in the thoracic spine. TS was determined by measuring the horizontal distance from the C7 plumb line relative to the center sacral vertical line, and a > 20-mm shift of the C7 plumb line was considered to indicate coronal imbalance [18]. TK was evaluated by the angle between the upper endplate of T5 and the lower endplate of T12. LL was assessed by the Cobb angle between the two lines through the superior endplate of T12 and S1, respectively. SVA was defined as the distance between the C7 plumb line and the posterior superior corner of S1. For all sagittal parameters, the angle was considered to be negative if the curve was lordotic and positive if the curve was kyphotic. SVA was determined to be positive if C7 was shifted anteriorly and negative if C7 was posterior to the posterior–superior corner of S1. With the lateral bending radiographs taken before surgery, the curve flexibility was calculated according to the following formula: The percentage of flexibility = (preoperative Cobb angle − bending Cobb angle)/preoperative Cobb angle × 100% [19]. The proximal junctional angle (PJA) was determined by lines drawn from the caudal end plate of the upper instrumented vertebra to the cephalad end plate of the vertebra two levels above the upper instrumented vertebra, and proximal junctional kyphosis was defined as PJA > 10° [20]. The distal junctional angle (DJA) was defined as the angle between the superior end plate of the lower instrumented vertebra and the inferior end plate of the adjacent distal vertebra, and distal junctional kyphosis was defined as DJA ≥ 10° [18]. Distal adding-on was characterized by a progressive correction loss due to an increase in either vertebral deviation of the lumbar spine or disk angulation below the instrumentation [21]. The presence of syrinx and extent of tonsillar herniation were also recorded.

Accuracy assessment of the pedicle screws

The postoperative computed tomography (CT) images were analyzed by one senior spine surgeon for the accuracy of pedicle screw placement. Screw accuracy was categorized using Gertzbein classification [22]: grade 0 (screws were completely within the pedicle), grade 1 (penetration < 2 mm), grade 2 (penetration between 2 and 4 mm) and grade 3 (penetration > 4 mm). A pedicle breach of up to 2 mm is considered to be within the safe zone. Hence, grades 0 and 1 were considered to be satisfactory (screws in), whereas grades 2 and 3 (> 2 mm) were considered to be perforations (screws out).

Evaluation of quality of life (QOL)

QOL was evaluated by SRS-22 questionnaire composed of five domains including pain, general self-image, function/activity, satisfaction and mental health. Each domain has a score ranging from 1 to 5, with 5 considered as the most favorable.

Statistical analysis

Statistical analysis was carried out using SPSS 18.0 package software (Chicago, IL, USA). Continuous data are described as the mean ± standard deviation (range). For comparisons between the two groups, the paired t test was applied for continuous variables. Comparisons of categorical variables were made with the Chi-square test. All tests were two tailed, with significance set at a P value < 0.05.

Results

Demographic data

Baseline characteristics of the patients are given in Table 1. There were 63 patients (32 males and 31 females) in LTC group with an average age of 14.4 ± 1.4 years. Another 63 (33 males and 30 females) patients with an average age of 14.7 ± 1.7 years were included in RTC group. The duration of follow-up in LTC and RTC groups was 28.1 ± 21.5 months and 27.3 ± 19.0 months, respectively.

Clinical symptoms in two groups

In LTC group, 53 patients presented symptoms, including back pain noted in nine cases (14.3%), headache in five (7.9%), weakness of the lower extremities in three (4.8%), sensory deficits in five (7.9%) and abnormal abdominal reflexes in 31 (49.2%). In RTC group, symptoms included back pain in seven cases (11.1%), headache in four (6.3%), sensory deficits in three (4.8%) and abnormal abdominal reflexes in 35 (55.5%).

Table 1 Baseline characteristics of patients

	LTC	RTC	P value
No.	21	21	–
Age (year)	14.4 ± 1.4 (12–18)	14.7 ± 1.7 (12–18)	0.610
Sex (female)	14/21	13/21	0.747
Risser grade	3.1 ± 1.1 (0–5)	2.9 ± 1.0 (0–5)	0.542
Symptoms			
Back pain	3/21	2/21	0.634
Headache	2/21	0/21	0.488
Motor deficit	1/21	0/21	0.311
Sensory deficit	2/21	3/21	0.634
Abnormal reflexes	10/21	12/21	0.537
Duration of follow-up	28.1 ± 21.5	27.3 ± 19.0	0.841
(mo)	(24–84)	(24–91)	

PFD posterior fossa decompression

Radiological features of syrinx and tonsillar herniation

The herniation of cerebellar tonsil in both groups was located within the posterior arch of the first cervical. In LTC group, syrinx was found in 49 patients, including expansion type in 23 cases, rosary type in 19 and slender type in 7. The syrinx was located at the cervical region in 23 patients and at both cervical and thoracic region in 26 patients. In RTC group, syrinx was found in 44 patients, including expansion type in 18 cases, rosary type in 16 and slender type in 10. The syrinx was located at the cervical region in 20 patients and at both cervical and thoracic region in 24 patients.

Preoperative radiographic data in two groups

Preoperative radiographic evaluation of the two groups is summarized in Table 2. For LTC patients, TK was significantly higher than that of RTC patients (40.1° vs. 23.0°, P = 0.021). Besides, LTC patients tended to have less flexible curve than RTC patients but without significant difference. As for other radiographic parameters, no significant difference was found between the two groups.

Postoperative radiographic data in two groups

The average fusion level was comparable between the two groups (10.1 ± 1.1 vs. 10.0 ± 0.9, P = 0.765) (Table 3). The thoracic curve improved from 54.2° preoperatively to 20.2° immediately after surgery in the LTC group and from 54.8° to 18.1° in the RTC group (Figs. 2, 3). At the final follow-up, a comparable correction rate of the thoracic curve was found between the two groups (59.9% vs. 62.6%, P = 0.610). Moreover, no significant correction loss was noticed in both groups (LTC 3.4% vs. RTC 3.0%, P = 0.617). The immediately postoperative spontaneous correction of the lumbar curve was 56.9% ± 19.2% in LTC patients, which was remarkably lower than in RTC patients (67.9% ± 14.6%, P = 0.023). In addition, patients in LTC group were found to have obviously increased trunk shift than those in RTC group (15.1 mm ± 10.9 mm vs. 8.0 mm ± 8.7 mm, P = 0.038). No distal adding-on was observed in two groups at the final follow-up.

The thoracic kyphosis was averaged 23.0° immediately after surgery and 25.1° at the final follow-up of LTC patients. In RTC group, the TK was averaged 19.7° after surgery and 20.3° at the final follow-up. No significant difference was found in terms of the sagittal balance between two groups at the final follow-up (LTC − 19.3 mm ± 17.2 mm vs. RTC

Table 2 Comparison of preoperative curve characteristics between the LTC and RTC groups

	LTC	RTC	*P* value
Thoracic curve			
Cobb angle (°)	54.2 ± 9.5 (45–80)	54.8 ± 11.4 (45–80)	0.761
Flexibility (%)	34.9 ± 16.7 (16–86)	37.6 ± 11.6 (18–85)	0.622
AVT (mm)	39.8 ± 14.8 (19–132)	44.3 ± 18.6 (22–127)	0.504
Lumbar curve			
Cobb angle (°)	24.4 ± 12.7 (9–51)	29.3 ± 6.9 (10–50)	0.186
Flexibility (%)	72.9 ± 14.0 (19–178)	76.4 ± 22.7 (21–178)	0.643
AVT (mm)	8.3 ± 5.1 (0–21)	9.3 ± 4.5 (0–29)	0.695
Trunk shift (mm)	12.9 ± 9.5 (0–29)	15.8 ± 8.6 (0–32)	0.437
Thoracic kyphosis (°)	40.1 ± 9.0 (18–61)	23.0 ± 11.3 (10–29)	0.021*
Lumbar lordosis (°)	− 55.4 ± 9.9 (− 70–31)	− 48.9 ± 9.4 (− 61–29)	0.170
SVA (mm)	− 16.3 ± 52.5 (− 78–72)	− 23.7 ± 21.8 (-82-69)	0.297

AVT apical vertebral translation, *SVA* sagittal vertical axis

*Significant difference ($P < 0.05$)

− 29.2 mm ± 18.3 mm, $P = 0.204$). There was no proximal or distal junctional kyphosis in both groups.

Complications and health-related quality of life

A total of 1890 screws were inserted, and 1661 screws (87.9%) were identified as accurate (grade 0) screws. Eighty-two of 929 screws (8.8%) in the LTC group and 68 of 961 screws (7.1%) in the RTC group were out of the safe zone (screw out). This difference was found to be statistically insignificant ($P = 0.491$). A total of 61 screws (41 in LTC and 20 in RTC) had grade 3 breaches. As there was no evidence of compression of the dural sac and aorta, none of malpositioned screws was removed. There were no neurologic or other major complications related to the surgery in either group.

The SRS-22 questionnaire was completed by 55 patients with LTC and 58 with RTC completed. The mean self-image at the final follow-up was remarkably higher than that before surgery in both groups (LTC 3.9 vs. 3.1, RTC 4.0 vs. 3.0). For all domains, there were no significant differences between the two groups (Table 4).

Discussion

Comparisons of characteristics between the left and right curve types have been frequently made for CMS patients in recent years. Wu et al. [23] found higher proportion of males and more severe curve magnitude in CMI patients with LTC. Moreover, Sengupta et al. [14] documented that curve improvement appeared more probable in patients with left thoracic curves, with 75% (6 of 8) avoiding scoliosis surgery after PFD. In another study reported by Mackel et al. [9], a better response to PFD was also found in CMS patients with left thoracic curve. However, Faloon et al. [24] found no difference in the proportion of pooled neuraxial abnormalities in right and left curves. For the first time, we investigated the surgical outcome of the scoliosis in CMI patients with different curve patterns after PFD.

In our study, the preoperative thoracic Cobb angle of both groups was matched well; however, a less flexible thoracic curve was noticed in LTC patients, which may indicate that those patients with progressive left thoracic scoliosis after PFD could have more rigid curve than the patients with right thoracic scoliosis. The correction rate of thoracic curve and lumbar curve was found comparable between two groups. At the final follow-up, the correction rate of patients with LTC and RTC was averagely 59.9% and 62.6% for thoracic curve. Meanwhile, spontaneous correction of the compensatory lumbar curve was observed with an average rate of 58.0% (LTC group) and 65.5% (RTC group). Both groups had a low correction loss rate of the thoracic curve and the lumbar curve. Overall, STF appears to produce satisfying outcomes in CMS patients which were comparable to those of adolescent idiopathic scoliosis (AIS) [7]. Takahashi et al. [4] reported a 64% correction of the thoracic curve in AIS patients with total pedicle screws. In another study with a minimum 5-year follow-up reported by Suk et al. [5], the correction rate of the thoracic curve and the spontaneous correction of the non-instrumented lumbar curve was 69% and 66% at the final follow-up, respectively.

Swarup et al. [25] demonstrated that TK was not associated with neural axis abnormalities in AIS patients.

Table 3 Postoperative radiographic data for patients with LTC and RTC

	LTC	RTC	*P* value
No. of fused vertebrae	10.1 ± 1.1	10.0 ± 0.9	0.765
Thoracic Cobb angle (°)			
Immediate post-op.			
Magnitude (°)	20.2 ± 8.0	18.1 ± 7.7	0.561
Correction (%)	62.6 ± 19.0	65.0 ± 9.2	0.599
Final follow-up			
Magnitude (°)	21.5 ± 8.4	19.5 ± 6.1	0.614
Correction (%)	59.9 ± 9.2	62.6 ± 13.2	0.610
Correction loss (%)	3.4 ± 5.7	3.0 ± 5.6	0.617
Lumbar Cobb angle (°)			
Immediate post-op.			
Magnitude (°)	12.6 ± 9.1	9.8 ± 4.7	0.174
Correction (%)	56.9 ± 19.2	67.9 ± 14.6	0.023*
Final follow-up			
Correction (%)	58.0 ± 18.4	65.5 ± 11.8	0.052
Correction loss (%)	1.1 ± 12.0	4.9 ± 9.0	0.181
Thoracic AVT (mm)			
Immediate post-op.	15.7 ± 11.8	12.4 ± 9.3	0.467
Final follow-up	14.1 ± 9.2	10.8 ± 9.1	0.409
Lumbar AVT (mm)			
Immediate post-op.	10.1 ± 8.2	7.6 ± 5.2	0.349
Final follow-up	8.2 ± 7.7	8.1 ± 6.0	0.972
Trunk shift (mm)			
Immediate post-op.	15.1 ± 10.9	8.0 ± 8.7	0.038*
Final follow-up	8.9 ± 2.9	8.4 ± 2.5	0.884
Thoracic kyphosis (°)			
Immediate post-op.	23.0 ± 7.0	19.7 ± 6.0	0.239
Final follow-up	25.1 ± 7.7	20.3 ± 6.4	0.103
Lumbar lordosis (°)			
Immediate post-op.	−46.7 ± 13.9	−46.4 ± 8.5	0.953
Final follow-up	−40.7 ± 38.8	−50.9 ± 9.3	0.282
SVA (mm)			
Immediate post-op.	6.7 ± 45.3	−12.5 ± 29.7	0.211
Final follow-up	−19.3 ± 17.2	−29.2 ± 18.3	0.204
PJA			
Immediate post-op.	8.2 ± 3.0	7.4 ± 3.1	0.798
Final follow-up	8.9 ± 4.2	7.0 ± 3.2	0.462
DJA			
Immediate post-op.	−0.1 ± 3.6	−0.5 ± 4.1	0.815
Final follow-up	−0.1 ± 4.8	1.1 ± 5.8	0.603

AVT apical vertebral translation, *SVA* sagittal vertical axis, *DJA* distal junctional angle

*Significant difference ($P < 0.05$)

However, Whitaker et al. [26] reported a case of thoracic hyperkyphosis, which might be an indicator of syringomyelia in idiopathic scoliosis. Furthermore, Zhu et al. [27] found that CMS patients with different thoracic curve directions might have different sagittal profiles. In this study, TK was found significantly higher in LTC group than in RTC group before surgery, which was in accordance with the results reported by Zhu et al. [27]. After surgical correction with total pedicle screws, patients of the LTC group tended to have restoration of TK and LL. In this study, we found that no proximal or distal junctional kyphosis occurred in CMS patients with either thoracic hyperkyphosis or normal kyphosis. Moreover, the global sagittal balance was well maintained in both groups at the final follow-up. In addition to sagittal profile, the coronal file of CMS patients after surgery was also investigated in the current study. We found that the trunk shift was more significant in LTC group immediately after surgery, which might be attributable to the relatively lower spontaneous correction rate of the lumbar curve. Sullivan et al. [28] proposed that the spontaneous correction of the lumbar curve in AIS patients could reduce post-STF coronal decompensation. In this study, the spontaneous correction rates in two groups were over 50%, and no coronal imbalance was found in either group at the final follow-up. Overall, these findings indicated that STF could help restore a favorable sagittal and coronal profile in CMS patients with different curve patterns.

The placement of thoracic pedicle screw in patients with neuromuscular scoliosis (NMS) is technically challenging. Modi et al. [29] reported 75% accuracy and 94.8% safety of screw placement in NMS patients with their curves less than 90°. In the present study, 150 of the 1890 inserted screws were found to be misplaced (screw out), showing an overall accuracy of 87.9% (86.9% in the LTC group and 88.9% in the RTC group). There were 41 grade 2 misplaced screws and 41 grade 3 misplaced screws in the LTC group and 48 grade 2 and 20 grade 3 misplaced screws in the RTC group; the prevalence of screw perforation was low in both groups, though it was slightly higher in LTC group, which may be correlated with the familiarity of operators with different curve convexities. Nevertheless, we found no serious complications caused by screw perforation in each group; hence, pedicle screws placement in CMS patients with different thoracic curve sides who meet the criteria of selective thoracic fusion for AIS patients was safe.

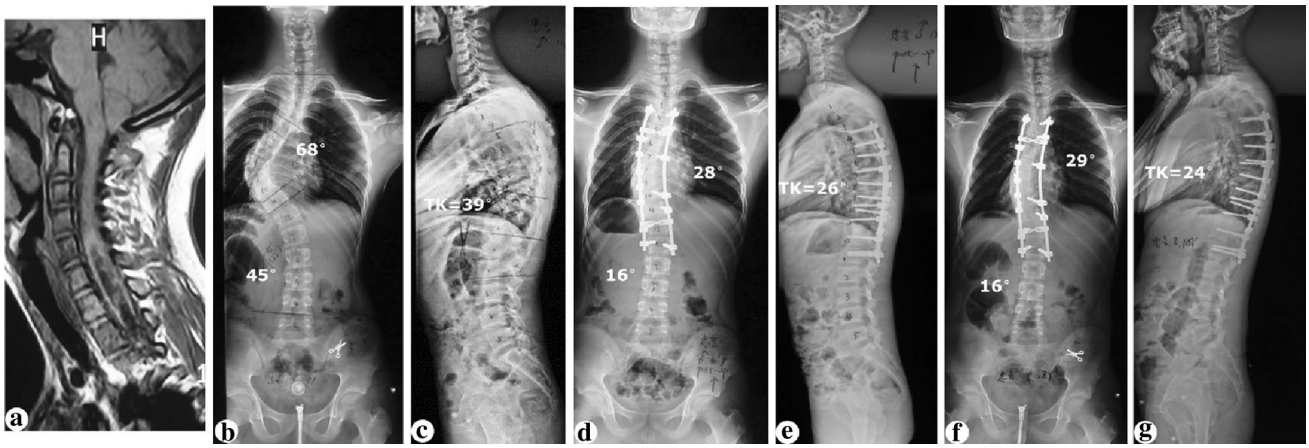

Fig. 2 A 16-year-old boy with a main left thoracic curve secondary to Chiari I malformation and syringomyelia (**a**). The radiographs demonstrate a left thoracic curve of 68° and a thoracic hyperkyphosis with TK of 39° (**b** and **c**). Postoperative (**d**) and lateral (**e**) radiographs following posterior instrumentation from T4 to L1 demonstrate good correction of the thoracic curve and kyphosis. Radiographs made at 2.5 years after surgery (**f** and **g**) reveal that both coronal balance and sagittal balance were maintained well

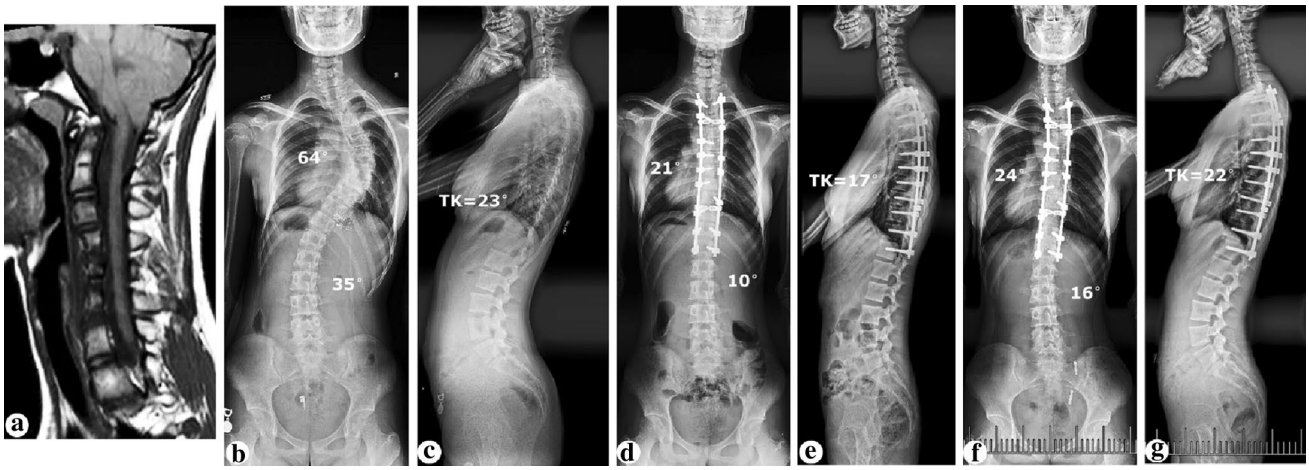

Fig. 3 A 14-year-old girl with a right thoracic curve secondary to Chiari I malformation (**a**). The radiographs demonstrate a thoracic curve of 64° and a normal thoracic kyphosis (**b** and **c**). Postoperative radiographs (**d**, **e**) following posterior spinal fusion from T2 to T12 demonstrate excellent correction of the curves. Radiographs made at 2.4 years after surgery (**f** and **g**) revealed well-maintained global coronal and sagittal balance

Limitations inherent to this work include the retrospective design. And the sample size was relatively small; in order to reduce the enrollment bias, we only select CMS patients with major thoracic scoliosis undergoing selective thoracic fusion. However, to our knowledge, this is the first study to compare the surgical outcomes in CMI patients with different thoracic curve patterns. The future study will focus on CMS patients with lumbar modifier C or undergoing non-STF and further investigate the clinical outcomes between the left and right curves.

Conclusions

This study was conducted to compare the clinical outcomes of STF in the surgical treatment of CMS adolescents with "Lenke 1A" or "1B" curve types. Our findings

Table 4 Scores of SRS-22 for patients with LTC and RTC

	LTC	RTC	*P* value
Function			
Preop.	3.5 ± 0.64	3.7 ± 0.92	0.478
Final follow-up	3.6 ± 0.81	3.6 ± 0.49	0.690
Pain			
Preop.	3.9 ± 0.66	3.9 ± 0.61	0.731
Final follow-up	4.0 ± 0.92	3.9 ± 0.77	0.610
Self-image			
Preop.	3.1 ± 0.42	3.0 ± 0.31	0.583
Final follow-up	3.9 ± 0.50	4.0 ± 0.47	0.670
Mental health			
Preop.	3.4 ± 0.49	3.3 ± 0.51	0.622
Final follow-up	3.4 ± 0.62	3.2 ± 0.71	0.501

revealed that CMS patients with RTC tended to have a better spontaneous correction of the non-fused lumbar curve after surgery. Both groups had comparable clinical and radiographic outcomes in the long-term follow-up.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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