Benefits of Fixing 3 Proximal Vertebral Bodies vs. 2 in the Treatment of Early-Onset Scoliosis with Growing Rods

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Abstract

Background

The outcomes of early-onset scoliosis (EOS) treated with growing rods in which 6 proximal anchor points on 3 vertebrae were used vs. 4 proximal anchor points on 2 vertebra were compared.

Methods

The records of patients with EOS treated surgically from January 2016 to December 2017 were retrospectively reviewed. In the Proximal 4 group, 2 vertebral bodies were anchored proximally with 4 anchor points; in the Proximal 6 group, 3 vertebral bodies were anchored proximally with 6 anchor points.

Results

Forty-two patients (mean age 5.11 ± 1.93 years) were included; 22 Proximal 4 group, 20 Proximal 6 group. Mean follow-up was 40.86 ± 13.49 months. The decrease in main curve Cobb angle postoperatively was significantly greater in the Proximal 6 group (33.22° vs. 19.08°) ($P < 0.05$). Cobb thoracic kyphosis (TK) was significantly decreased postoperatively in the Proximal 6 group (mean 20.70°); no significant decrease occurred in the Proximal 4 group. The main curve Cobb angle decrease at last follow-up was significantly greater in the Proximal 6 group (37.84° vs. 24.23°) ($P < 0.05$). Cobb TK was significantly decreased at last follow-up in the Proximal 6 group (mean 25.17°, $P < 0.05$); no significant decrease occurred in the Proximal 4 group. Instrument complications were lower in the Proximal 6 group (15.00% vs. 45.45%) ($P < 0.05$). No proximal junctional kyphosis was noted.

Conclusion

Fixing 3 proximal vertebral bodies with 6 anchors improves outcomes of EOS treated with growing rods, and has a lower rate of instrument-related complications.

Background

Early-onset scoliosis (EOS) is defined as spine deformity (Cobb angle > 10°) present before the age of 10 years.[1] Children with EOS often experience rapid progression of the scoliosis angle as well as pulmonary insufficiency.[2] There are many treatment options for EOS include casting, bracing, Luque trolley, the Shilla technique, and anterior based tethering procedures.[3] The growing rods method is a standard surgical treatment for progressive curves ≥ 45° that cannot be controlled by casting and/or bracing.[4] Different from the traditional surgical methods of fusion and fixation, the main features of the growing rod technique are "non-fusion and repetitive distraction for lengthening", which can control scoliosis while maintaining growth of the spine.[5] In addition, the final spinal fusion operation can be performed after skeletal maturity.[6] In the growing rod technique, anchoring devices are placed at both ends of the spinal curvature, and the growing rod is placed between the ipsilateral anchoring devices. The anchor points are used to support the distraction force of the growing rod.[7] After the first placement of growing rods, lengthening procedures are performed at regular intervals.[7]

Many surgeons use pedicle screws as anchors at both the proximal and distal ends of the growing rods.[8,9] The most common fixation method rods is to fix 2 segments of vertebral bodies at both the distal and proximal ends, with 4 proximal anchor points and 4 distal anchor points. However, in patients with severe scoliosis combined with kyphosis this fixation method can result in the pedicle screw(s) cutting into the spinal canal when the patient moves.[10] In addition, the proximal screw(s) are easily pulled out due to the kyphosis deformity of the spine, and the growing rod technique is not effective for neurofibromatosis type 1 (NF-1) scoliosis,[11] the most common form of scoliosis with kyphosis.

Meza et al.[12] studied the impact of proximal anchor location and density in patients treated with magnetically controlled growing rods, and reported that proximal spine anchors and greater anchor density impart superior deformity correction but do not significantly impact the risk of device complications. Harris et al.[13] reported that 5 or more proximal anchors, and including the upper end vertebra (UEV), reduced the risk of screw pullout and the risk of reoperation in patients treated with distraction-based growing rods.

In our practice we observed that patients with severe scoliosis combined with kyphosis treated with growing rods had a higher anchor point-related complication rate. For this reason, we added 2 proximal anchor points (for a total of 6 on 3 vertebra) to reduce the possibility of complications. Thus, the purpose of this study was to compare the outcomes of patients with EOS treated with growing rods in which 6 proximal anchor points on 3 vertebra were used vs. 4 proximal anchor points on 2 vertebra.

Methods

Patients

The records of patients with EOS who received surgery at our center from January 2016 to December 2017 were retrospectively reviewed. The inclusion criteria were: 1) Diagnosis of EOS; 2) Treatment with dual growing rods; 3) Follow-up time ≥ 2 years; 4) Number of lengthenings ≥ 2; 5) Complete preoperative and postoperative imaging data; 6) Pedicle screws were used for anchoring points; 7) Submuscular placement of growing rods. The exclusion criteria were: 1) Prior spinal internal fixation; 2) History of spinal trauma; 3) Hybrid growing rod technique [simple screw connection or fixation at the top after osteotomy]; 4) Use of the vertical expandable prosthetic titanium rib (VEPTR) technique; 5) Unilateral growing rod technique; 6) Laminar hooks were used in the anchor points; 7) Subcutaneous placement of growing rods.

Patients were divided into 2 groups for analysis. Patients in whom 2 vertebral bodies were anchored at the proximal end of the rod, and 2 vertebral bodies were anchored at the distal end of the rod (a total of 4 proximal anchor points and 4 distal anchor points) were designated the Proximal 4 group. Patients in whom 3 vertebral bodies were anchored at the proximal end of the rod, and 2 vertebral bodies were anchored at the distal end (a total of 6 proximal anchor points and 4 distal anchor points) were designated the Proximal 6 group. Demographic and disease characteristics, surgical outcomes, and complications were compared between the groups. All surgical procedures were performed by a team of 2 experienced surgeons who also evaluated the patients preoperatively.

This study was approved by the Institutional Review Board (IRB) of our hospital, and written informed consent was waived due to the retrospective nature of this study.

Data collection

The data collected included patient age and sex, clinical disease information, and surgical, postoperative and follow-up data.

Radiographic evaluation indexes were measured preoperatively, after the first surgery, and at the last follow-up. Measurements included the Cobb angle of the main curve (Cobb MC); the vertical distance between the upper endplate of the T1 vertebral body and the upper endplate of the S1 vertebral body (T1-S1); the standing the horizontal distance from the plumb line of the C7 midpoint to the midline of the sacrum on a frontal radiograph of the whole spine (C7PL-CSVL); the vertical height difference between the soft tissue shadows above the bilateral acromioclavicular joints (radiographic shoulder height, RSH); the T5 vertebral body upper endplate-T12 vertebral body lower endplate Cobb angle (Cobb angle of thoracic kyphosis, Cobb TK); the horizontal distance from the vertical line of the C7 midpoint to the posterior upper corner of the S1 vertebral plate (sagittal vertical axis, SVA); the proximal junctional angle (PJA). Proximal junctional kyphosis (PJK) was defined as an increase of the PJA by $\geq 10°$. All parameters were measured by a spine surgeon, and the average value was calculated after 2 consecutive measurements.

Complications evaluated included loosening, displacement, and pullout of pedicle screws, and breakage and revisions of the rods during the postoperative follow-up period. Screw loosening was defined as a visible dark shadow around the screw on radiograph. Screw pullout was defined as partial reduction of the length of screw in the vertebra compared to that immediately after surgery.

Statistical analysis

Continuous data were presented as mean ± standard deviation, and categorical data were presented as number and percentage (%). Student’s paired sample t-test was used to examine differences in continuous data between pre-operation and post-1st operation, and between pre-operation and last follow-up within a group. Student’s independent sample t-test was used to examine differences in continuous data between the Proximal 4 group and the Proximal 6 group. Categorical data were compared with

Pearson chi-square test, or Fisher's exact test, as appropriate. All analyses were performed using IBM SPSS version 25 software (IBM Corporation, Somers, New York). Values of $P < 0.05$ were considered to indicate statistical significance.

Results

Patient demographic and clinical characteristics

A total of 58 patients with EOS received surgical treatment at our center from January 2016 to December 2017. Of these, 42 patients were treated with dual growing rods and met the inclusion criteria and were thus included in the analysis. There were 23 males and 19 females with a mean age of 5.11 ± 1.93 years). The etiologies of EOS included idiopathic scoliosis (n = 11), congenital scoliosis (n = 18), neurological scoliosis (n = 1) and NF-1 scoliosis(n = 12). There were 22 patients that received a total of 4 proximal anchor points and 4 distal anchor points (Proximal 4 group), and 20 patients that received a total of 6 proximal anchor points and 4 distal anchor points (Proximal 6 group). Patient characteristics are summarized in Table 1, and there were no differences in age, sex, number of lengthenings, the interval of lengthening, and follow-up duration between the Proximal 2 and Proximal 3 groups (all, $P > 0.05$). These characteristics were not considered to be confounding factors in subsequent analyses.

Comparisons of radiographic evaluations between groups

The mean follow-up duration of the 42 patients was 40.86 ± 13.49 months, and the follow-up duration of the 2 groups was similar ($P > 0.05$). Radiographic evaluation indexes are summarized Table 2.

Cobb angle of the main curve decreased significantly from pre-operation to post-first operation in both groups; however, the mean reduction in the Proximal 6 group (33.22 °) was significantly greater than the mean reduction (19.08 °) in the Proximal 4 group ($P < 0.05$). T1-S1 height improved significantly from pre-operation to post-first operation in both groups; however, the mean improvement in height in the Proximal 6 group (3.53 cm) was significantly greater than in the Proximal 4 group (1.33 cm) ($P < 0.05$). Cobb TK decreased significantly from pre-operation to post-first operation in the Proximal 6 group (mean reduction = 20.70 °), but there was no significant change in the Proximal 4 group (Table 3).

The reductions of Cobb angles and the improvement of T1-S1 height in Proximal 6 group were sustained at the last follow-up. The Cobb angle of the main curve decreased significantly from the pre-operative values to that at last follow-up in both groups; however, the mean decrease in the Proximal 6 group (37.84 °) was significantly greater than in the Proximal 4 group (24.23 °) ($P < 0.05$).

In both groups, T1-S1 height improved significantly from pre-operation to the last follow-up, but the mean increase in height was significantly greater in the Proximal 6 group than in the Proximal 4 group (7.03 cm vs. 4.73 cm, $P < 0.05$). Cobb TK decreased significantly from pre-operation to the last follow-up in

Proximal 6 group (mean decrease = 25.17*°, P < 0.05*), but there was no significant difference in the Proximal 4 group (Table 3).

Radiographic images of representative cases in the Proximal 4 group and the Proximal 6 group are shown in Figure 1 and Figure 2, respectively.

Safety evaluation

At the last follow-up, the incidence of instrument complications was significantly lower in Proximal 6 group (15.00%) than in the Proximal 4 group (45.45%) (P < 0.05). The total rate of distal screw loosening, displacement, and pullout, and the rate of screw loosening, displacement, and pullout of proximal screws was significantly lower in the Proximal 6 group than in the Proximal 4 group (1.47% vs. 11.36% and 1.47% vs. 5.68%, respectively, both, P < 0.05) (Table 1).

No patients in the Proximal 6 group required revision surgery during follow-up, while 1 patient in the Proximal 4 group required revision surgery. Revision surgery was required due to a broken rod that was not related to any problems with screws or anchoring. There were no patients who developed PJK in either group. There was no significant difference of the PJA between pre-operation and post-first surgery or between pre-operation and the last follow-up in both groups (Table 2 and 3).

Discussion

Growing rods are widely used to treat EOS, but few studies have been conducted to investigate characteristics and limitations of the proximal anchor points. Our results showed that fixing 3 proximal vertebral bodies with 6 anchors provides better outcomes than fixing 2 vertebral bodies with 4 anchors when using growing rods for the treatment of EOS, and is associated with a lower rate of instrument-related complications. Importantly, use of 6 anchors resulted in better outcomes of severe scoliosis and kyphosis without affecting growth of the spine.

A study of 107 patients with EOS treated with growing rod by Helenius et al. showed that patients with severe scoliosis (mean main Cobb angle = 101°) had a higher complication rate than those with moderate scoliosis (mean main Cobb angle = 67°), and they concluded that severe EOS can be effectively treated with growing rods but with a high risk of complications.[14] About 30% of patients with EOS have combined thoracic kyphosis, which is the main risk factor for internal fixation-related complications and increases the overall risk of complications 3-fold.[15,16] While various complications are associated with growing rods for the treatment of EOS, rates are reduced with careful patient selection.[10]

In our practice we also observed that patients with severe scoliosis combined with kyphosis treated with growing rods had a higher anchor point-related complication rate. For this reason, for children with large coronal major scoliosis, especially for children with large thoracic scoliosis, we added 2 proximal anchor points for fixation to reduce the possibility of complications and hence increase the effectiveness of the surgery. We chose to add anchor points at the proximal end rather than the distal end of the rods because combined proximal kyphosis will cause screws pullout because the distraction force and the screws are in the same direction. This problem does not exist at the distal end of the rods (in the thoracic-lumbar or lumbar spine). In addition, the distal vertebral bodies are larger than the proximal, thus thicker and longer pedicle screws can be used at the distal end of the rods to increase the anchoring force.

Our results showed that at the last follow-up the Cobb angle of the main curve in both groups was significantly reduced compared with the preoperative values, and the height of T1-S1 was significantly increased compared with the preoperative values. These results suggest that the 2 fixation methods aree both effective in controlling coronal scoliosis, while allowing for appropriate spinal growth. The results also showed that patients who received fixation of 3 proximal vertebral bodies received a greater benefit with respect to correction than those who received fixation of 2 proximal 2 vertebral bodies.

At the last follow-up, the Cobb angle of thoracic kyphosis was significantly decreased as compare to the preoperative value in the Proximal 6 group but not in the Proximal 4 group. These results indicate that fixing 3 proximal vertebral bodies can improve the sagittal TK, but this cannot be guaranteed when only 2 vertebral bodies are fixed. Furthermore, the changes in the Cobb angle of the main curve and the Cobb angle of thoracic kyphosis from preoperative to last follow-up were significantly greater in the Proximal 6 group than the Proximal 4 group. Taken together, the findings suggest that fixing 3 proximal vertebral bodies provides greater corrective ability for coronal main scoliosis and sagittal thoracic kyphosis. The improved correction of fixing 3 proximal 3 vertebral bodies may be attributed to the fact that the corrective force at the proximal end of the rods is dispersed to 6 pedicle screws, generating a greater distraction force during the lengthening procedures.

At the last follow-up, the rate of instrument complications, and the rates of proximal and distal screw loosening, displacement, and pullout were all significantly lower in the Proximal 6 group than the Proximal 4 group. These results suggest that for patients with severe kyphosis, the proximal 3 vertebral body fixation method can effectively reduce screw- and instrument-related complications, thus maintaining a constant distraction force. It is worth noting that among anchor point abnormalities, proximal anchor point abnormalities account for 56.52% (13/23).

None of the patients in this study had evidence of PJK (increase of PJA $\geq$ 10°). Some studies, however, have reported PJA increases of 20° or higher.[17] Pan et al. reported that in patients with EOS treated with growing rods the incidence of PJK was 28%, and the independent risk factor was locating the proximal anchor points at the T2 spinal segment.[18] Wantanabe et al.[17] reported risk factors for PJK included a lower instrumented vertebra at or cranial to L3 (odds ratio [OR] = 3.32), a proximal thoracic scoliosis of $\geq$ 40° (OR = 2.95), and a main thoracic kyphosis of $\geq$ 60° (OR = 5.08). These findings indicate that although increasing the number of proximal anchor points can reduce anchor point-related complications, it also increases the risk of spinal cord injury, and in addition proximal screw placement is relatively difficult because proximal pedicle screws are thin. Thus, in addition to increasing the number of anchor points, an appropriate proximal spine segment and pedicle screws should be selected for the anchor points.

Consistent with a report by Li et al.,[19] our results showed that treatment with growing rods has no effect on coronal imbalance.

There are limitations to this study that should be considered. The numbers of patients were relatively small, and the length of follow-up was relatively short for the treatment of EOS. In addition, radiographic parameters were determined by a single observer and no analyses of inter-observer or intra-observer reliability were performed.

Conclusions

Our results showed that fixing 3 proximal vertebral bodies with 6 anchors provides better outcomes than fixing 2 vertebral bodies with 4 anchors when using growing rods for the treatment of EOS, and is associated with a lower rate of instrument-related complications.

Abbreviations

EOS: early-onset scoliosis

TK: thoracic kyphosis

NF-1: neurofibromatosis type 1

UEV: upper end vertebra

VEPTR: vertical expandable prosthetic titanium rib

Cobb MC: Cobb angle of the main curve

PJA: proximal junctional angle

PJK: Proximal junctional kyphosis

Declarations

Ethics approval and consent to participate: This study was approved by the Institutional Review Board (IRB) of Beijing Children's Hospital, Capital Medical University, all methods were carried out in accordance with relevant guidelines and regulations, written informed consent was waived due to the retrospective nature of this study.

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Tables

Table 1. Patient characteristics

Parameters	Proximal 4 group (n = 22)	Proximal 6 group (n = 20)	All (N = 42)	P
Age	4.75 ± 2.02	5.51 ± 1.76	5.11 ± 1.93	0.210[a]
Sex				0.554[b]
Male	13 (59.09)	10 (50.00)	23 (54.76)	
Female	9 (40.91)	10 (50.00)	19 (45.24)	
Number of distractions				0.894[c]
2	7 (31.82)	4 (20.00)	11 (26.19)	
3	8 (36.36)	9 (45.00)	7 (40.48)	
4	4 (18.18)	5 (25.00)	9 (21.43)	
5	2 (9.09)	1 (5.00)	3 (7.14)	
7	1 (4.55)	1 (5.00)	2 (4.76)	
Interval of lengthening, years	0.94 ± 0.22	1.01 ± 0.12	0.98 ± 0.19	0.236[a]
Follow-up, months	41.45 ± 12.57	40.20 ± 14.41	40.86 ± 13.49	0.770[a]
Instrument complications	10 (45.45)	3 (15.00)	13 (30.95)	0.047[c]
Distal screws: loosening, displacement, pullout	20/176 (11.36%)	3/204 (1.47%)	23/380 (5%)	<0.001[b]
Proximal screws: loosening, displacement, pullout	10/176 (5.68%)	3/204 (1.47%)	13/380 (3.42%0)	0.024[b]

Data are presented as mean ± standard deviation, or count (percentage).

Proximal 4 group, 4 pedicle screws on 2 proximal vertebra; Proximal 6 group, 6 pedicle screws on 3 proximal vertebra.

[a]Student’s independent sample t-test; [b]Pearson chi-square test; [c]Fisher's exact test.

Table 2. Patient clinical outcomes

Parameters	Proximal 4 group (n = 22)	Proximal 6 group (n = 20)
Cobb angle main curve (°)		
Pre-operation	59.61 ± 19.03	79.78 ± 21.22
Post-1st surgery	40.54 ± 15.90	46.57 ± 16.30
Last follow-up	35.39 ± 13.65	41.95 ± 15.70
T1-S1 (cm)		
Pre-operation	26.30 ± 3.47	24.51 ± 4.39
Post-1st surgery	27.63 ± 3.40	28.04 ± 3.69
Last follow-up	31.04 ± 3.84	31.54 ± 3.72
C7PL-CSVL (mm)		
Pre-operation	17.47 ± 13.58	14.17 ± 10.61
Post-1st surgery	13.56 ± 9.48	11.66 ± 12.98
Last follow-up	10.73 ± 6.68	11.87 ± 10.23
RSH (mm)		
Pre-operation	13.50 ± 9.96	16.22 ± 13.11
Post-1st surgery	13.20 ± 9.41	10.63 ± 9.60
Last follow-up	12.24 ± 8.78	12.62 ± 9.76
Cobb TK (°)		
Pre-operation	29.11 ± 23.80	59.95 ± 29.90
Post-1st surgery	35.99 ± 11.05	39.25 ± 14.82
Last follow-up	31.45 ± 13.44	34.78 ± 14.81
SVA (mm)		
Pre-operation	20.72 ± 17.02	27.77 ± 15.42
Post-1st surgery	27.85 ± 19.05	23.68 ± 18.14
Last follow-up	25.87 ± 20.17	24.44 ± 15.71
PJA (°)		
Pre-operation	9.33 ± 3.72	8.82 ± 3.44

Post-1st surgery	8.85 ± 3.21	8.75 ± 3.40
Last follow-up	9.30 ± 3.72	8.33 ± 4.10

C7PL-CSVL, the standing the horizontal distance from the plumb line of the C7 midpoint to the midline of the sacrum on a frontal radiograph of the whole spine; Cobb TK, Cobb angle of thoracic kyphosis; RSH, radiographic shoulder height; SVA, sagittal vertical axis; PJA, proximal junctional angle.

Data are presented as mean ± standard deviation.

Table 3. Comparisons of changes between groups

Pre-operation to post-1st operation	Proximal 4 group (n = 22) Mean change (P^a)	Proximal 6 group (n = 20) Mean change (P^a)	P value[2]
Cobb MC (°)	-19.08 (<0.001)	-33.22 (<0.001)	<0.001
T1-S1 (cm)	1.33 (<0.038)	3.53 (<0.001)	0.014
C7PL-CSVL (mm)	-3.91 (0.287)	-2.52 (0.445)	0.776
RSH (mm)	-0.41 (0.843)	-5.59 (0.076)	0.153
Cobb TK (°)	6.88 (0.108)	-20.70 (0.001)	<0.001
SVA (mm)	7.14 (0.225)	-4.10 (0.328)	0.124
PJA (°)	-0.47 (0.424)	-0.07 (0.876)	0.590
Pre-operation to last follow-up			
Cobb MC (mm)	-24.23 (<0.001)	-37.84 (<0.001)	<0.001
T1-S1 (cm)	4.73 (<0.001)	7.03 (<0.001)	0.033
C7PL-CSVL (mm)	-6.74 (0.034)	-2.30 (0.509)	0.330
RSH (mm)	-1.37 (0.537)	-3.60 (0.286)	0.567
Cobb TK (°)	-2.34 (0.558)	-25.17 (<0.001)	<0.001
SVA (mm)	-5.15 (0.314)	-3.33 (0.495)	0.230
PJA (°)	-0.02 (0.984)	-0.49 (0.541)	0.739

C7PL-CSVL, the standing the horizontal distance from the plumb line of the C7 midpoint to the midline of the sacrum on a frontal radiograph of the whole spine; Cobb TK, Cobb angle of thoracic kyphosis; RSH, radiographic shoulder height; SVA, sagittal vertical axis; PJA, proximal junctional angle.

Data are presented as mean change.

[a]Student's paired sample t-test was used to examine differences between pre-operation and post-1[st] operation, and between pre-operation and last follow-up within a group.

[b]Student's independent sample t-test was used to examine differences between the Proximal 4 group and the Proximal 6 group.

Figures

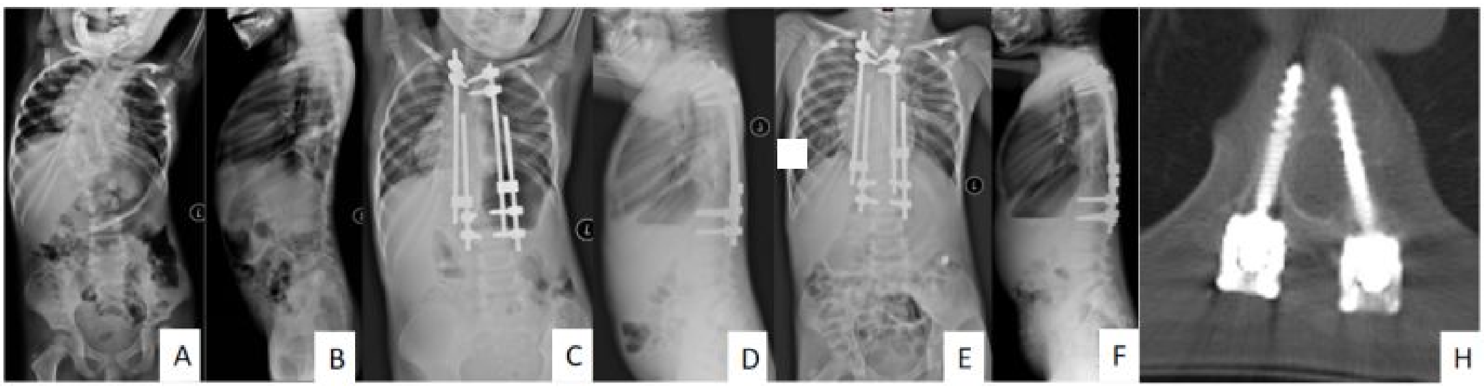

Figure 1

A representative case in the Proximal 4 group. A female child received the first operation at 2.9 years of age, with a total of 8 anchor points. A, B) Preoperative frontal and lateral radiographs showed the main curve Cobb angle = 64.0°, Cobb angle of thoracic kyphosis (Cobb TK) = 8.3°, and the T1-S1 height = 5 cm. C, D) The first postoperative frontal and lateral radiographs showed that the Cobb angle of the main curve had decreased, Cobb TK increased, and the height of T1-S1 increased. E, F) At the last follow-up (second lengthening) frontal and lateral radiographs showed the main curve Cobb angle = 23.4°, Cobb TK = 15.8°, T1-S1 height = 17.5 cm. G) The screw on the top right side was noted to be loose due to the presence of loose bone around it.

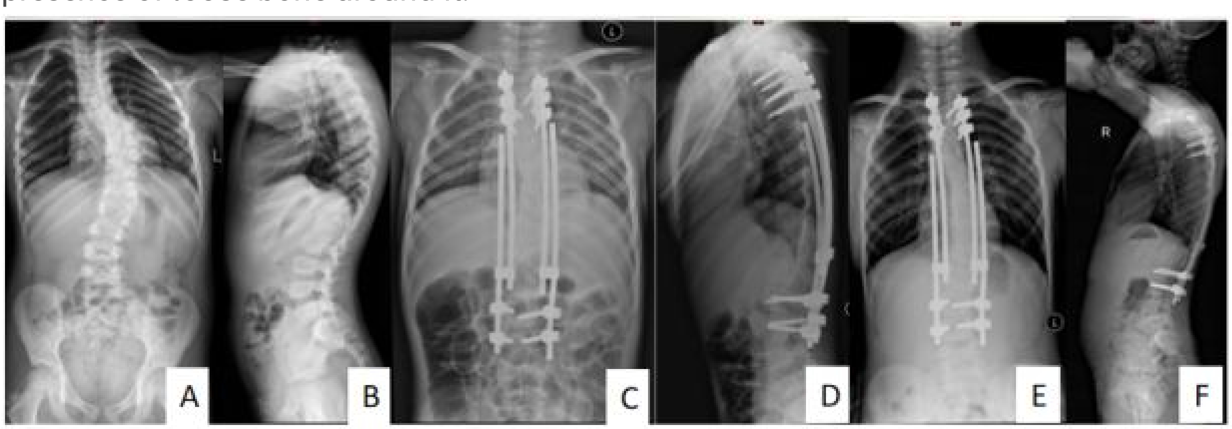

Figure 2

A representative case in the Proximal 6 group. A male child received the first operation at 5.8 years of age, with a total of 10 anchor points. A, B) Pre-operative frontal and lateral radiographs showed the Cobb angle of the main curve = 62.0°, Cobb TK = 50.5°, and the height of T1-S1 = 26.7 cm. C, D) The first postoperative frontal and lateral radiographs showed that the Cobb angle of the main curve decreased, the Cobb TK decreased, and the height of T1-S1 increased. E, F) At the last follow-up (second lengthening), frontal and lateral radiographs shows the Cobb angle of the main curve = 23.4 °, Cobb TK = 15.8°, and T1-S1 height = 28.7cm. The uppermost right screw was noted to be loose.