Benefits of fixing 3 proximal vertebral bodies vs. 2 in the treatment of early-onset scoliosis with growing rods

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Additional proximal fixation for growing rods in early-onset scoliosis (EOS) may offer a more effective and safer option for severe scoliosis patients with hyper-kyphosis. Here, we compared the outcomes of EOS patients treated with growing rods in which 6 proximal anchor points on 3 vertebrae were used vs. 4 proximal anchor points on 2 vertebrae. 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. 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 in the Proximal 6 group (mean 20.70°); 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. Fixing 3 proximal vertebral bodies with 6 anchors improves radiographic outcomes of EOS treated with growing rods, and has a lower rate of screw pull-out. J Pediatr Orthop B 32: 342–349 Copyright © 2022 The Author(s). Published by Wolters Kluwer Health, Inc.

Keywords: complication, early-onset scoliosis, growing rod, pedicle screw, proximal anchor

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Introduction

Early-onset scoliosis (EOS) is defined as spine deformity (Cobb angle > 10°) that is 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, including casting, bracing, Luque trolley, the Shilla technique, and anterior-based tethering procedures [3]. The growing rod 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, and patients who reach skeletal maturity with good alignment do not routinely require final surgical fusion [5,6]. 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 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 hyper-kyphosis, this fixation method can result in pedicle screw(s) cutting into the spinal canal when the patient moves, and pull-out of the proximal screws due to the hyper-kyphosis deformity.[10]

Meza et al. [11] studied the impact of proximal anchor location and density in patients treated with magnetically

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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. [12] reported that 5 or more proximal anchors, 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 hyper-kyphosis treated with growing rods had a higher anchor point-related complication rate. We hypothesize that additional proximal fixation for growing rods in EOS could offer a more effective and safer option for severe scoliosis patients with hyper-kyphosis. For this reason, we added 2 proximal anchor points (for a total of 6 on 3 vertebra) to reduce complication risks. 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 as follows: (1) diagnosis of EOS; (2) treatment with traditional, dual growing rods; (3) submuscular placement of growing rods; (4) number of lengthening ≥ 2; (5) complete preoperative and postoperative imaging data; (6) pedicle screws were used for anchoring points; (7) follow-up time ≥ 2 years. The exclusion criteria were as follows: (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. No patients were treated with magnetic growing rods, and no patients had severe hyper-kyphosis at the upper thoracic vertebra. All internal fixation devices were made of titanium alloy.

Patients were divided into two 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. In all patients, distal fixations were performed at two instrumented levels, aiming to avoid the influence of different fixation levels.

The decision to use 4 or 6 proximal anchor points was based on the characteristics of the scoliosis and hyper-kyphosis and vertebral body development. Patients with scoliosis combined with severe hyper-kyphosis (usually > 50°) were treated with 6 proximal screws (Proximal 6 group), while patients with simple scoliosis with or without concomitant mild hyper-kyphosis were treated with 4 proximal screws (Proximal 4 group). If the development of the proximal fixed vertebra (upper instrumented vertebra, UIV) was poor, patients were treated with 6 proximal screws with the aim of providing a greater fixation force. Reasons for poor development vertebral development include a young age, developmental delay, and congenital malformation. Patients with good development of the UIV were treated with 4 proximal screws. In both groups, the UIV and lower instrumented vertebrae (LIV) depended on the scoliosis upper end curve vertebra (UEV), neutral vertebra (NV), and lower end curve vertebra (LEV). The NV was defined as the first vertebra below the LEV on the midline of the S1 vertebral body. In general, in Group 4 the UIV were UEV and UEV+1. In Group 6, the UIV were UEV-2, UEV-1, and UEV, or UEV-1, UEV, and UEV+1. In both groups, the LIV were NV-1 and NV. In both groups, distractions were done from 9 months to 1 year. The timing was based on radiographic findings (whether Cobb angle had increased) and clinical symptoms.

Demographic and disease characteristics, radiographic surgical outcomes, and complications were compared between the groups. All surgical procedures were performed by a team of two 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 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); the proximal junctional angle. Proximal junctional hyper-kyphosis was defined as an increase of the proximal junctional angle by ≥10°. All parameters were measured by a spine surgeon, and the average value was calculated after two 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 ± SD, 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, 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 eligibility 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 most common type of scoliosis was congenital scoliosis (n = 18), followed by NF-1 scoliosis (n = 12), and idiopathic scoliosis (n = 11). The types of scoliosis by group are summarized in Supplemental Table 1 and Table 2, Supplemental Digital Content 1, http://links.lww.com/JPOB/A71. Twenty two patients received 4 proximal anchor points and 4 distal anchor points (the Proximal 4 group), and 20 patients received 6 proximal anchor points and 4 distal anchor points (the Proximal 6 group). The median number of vertebra bodies instrumented was 11 (range 9–12) in the Proximal 6 group and 10 (range 8–12) in the Proximal 4 group. Patient characteristics are summarized in Table 1, and there were no differences in age, sex, length of instrumentation, the interval of lengthening, and follow-up duration between the two 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 two groups was similar (P > 0.05). Radiographic evaluation indexes are summarized in Table 2.

The Cobb angle of the main curve decreased significantly post first operation from the preoperative angle in both groups; however, the Proximal 6 group had a significantly greater mean reduction in Cobb angle [was than the Proximal 4 group (33.22° vs.19.08°, 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 (24.23°) (P < 0.05).

In both groups, T1-S1 height at the final follow-up visit improved significantly compared to the baseline, 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 at the final follow-up visit from the baseline in Proximal 6 group (mean decrease = 25.17°, P < 0.05), but there was no significant difference in the Proximal 4 group (Table 3).

We also analyzed the Cobb angle correction rate between the groups. The Cobb angle correction rate post the first operation was significantly greater in the Proximal 6 group than the Proximal 4 group (50.42% vs. 41.05%, P = 0.030). Similarly, the correction rate at the last follow-up was significantly greater in the Proximal 6 group (48.32% vs. 39.88%, P = 0.041).

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

Safety evaluation
At the last follow-up, the incidence of instrument complications was significantly lower in the 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
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Table 1 Patient characteristics

| Parameters                      | Proximal 4 group (n = 22) | Proximal 6 group (n = 20) | All (N = 42) | P-value |
|--------------------------------|---------------------------|---------------------------|--------------|---------|
| 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)                 | 6 (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)             | 41.49 ± 12.97             | 40.20 ± 14.41             | 40.86 ± 13.49| 0.770^a |
| Instrument complications       | 20/176 (11.36%)           | 3/204 (1.47%)             | 23/380 (5%)  | <0.001^b|
| Data are presented as mean ± SD, or count (percentage). Proximal 4 group, 4 pedicle screws on 2 proximal vertebra; Proximal 6 group, 6 pedicle screws on 3 proximal vertebra.

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)                     | 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                  | 8.33 ± 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               |
| Cobb angle correction (%)      |                           |                           |
| Pre-operation to post-1st surgery | 41.05 ± 14.26       | 50.42 ± 10.48             |
| Pre-operation to last follow-up | 39.88 ± 14.11           | 48.32 ± 10.77             |

Data are presented as mean ± SD. C7PL-CSVL, the standing 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 PJA, proximal junctional angle; RSH, radiographic shoulder height; SVA, sagittal vertical axis; TK, Cobb angle of thoracic kyphosis.

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 radiographic outcomes of severe scoliosis and hyper-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 [13]. About 30% of patients with EOS have combined thoracic hyper-kyphosis, which is the main risk factor for internal fixation-related complications and increases the overall risk of complications three-fold [14,15]. 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 hyper-kyphosis treated with growing rods had a higher anchor point-related complication rate. For this reason, for children with large related to any problems with screws or anchoring. There were no patients who developed proximal junctional hyper-kyphosis in either group. There was no significant difference of the proximal junctional angle between pre-operation and post-first surgery or between pre-operation and the last follow-up in both groups (Tables 2 and 3).
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 hyper-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).

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 two fixation methods are both effective in controlling coronal scoliosis, while allowing for appropriate spinal growth. The results also showed that patients who received fixation of three proximal vertebral bodies received a greater benefit with respect to correction than those who received fixation of two proximal vertebral bodies; the Cobb angle correction rate from pre-operation to post-1st operation and from pre-operation to last follow-up was significantly greater in the Proximal 6 group than in the Proximal 4 group. We hypothesize that the greater correction rates in the Proximal 6 group is because the overall anchoring force is greater, and thus changes to the surgical correction are less likely, that is, the overall internal fixation is more stable.

Table 3 Comparisons of changes between groups

|                        | Proximal 4 group (n = 22) | Proximal 6 group (n = 20) | P-value |
|------------------------|---------------------------|---------------------------|---------|
| Pre-operation to post-1st operation |                        |                           |         |
| 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   |
| Cobb TK(°)             | 6.88 (0.108)              | −20.70 (0.001)            | <0.001  |
| SWA (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   |
| Cobb TK(°)             | −1.37 (0.537)             | −3.60 (0.286)             | 0.567   |
| SWA (mm)               | −5.15 (0.314)             | −3.33 (0.495)             | 0.230   |
| PJA(°)                 | −0.02 (0.984)             | −0.49 (0.541)             | 0.739   |

Data are presented as mean change. 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; SWA, sagittal vertical axis; PJA, proximal junctional angle.

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

At the last follow-up, the Cobb angle of thoracic kyphosis was significantly decreased compared 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 two vertebral bodies are fixed. Furthermore, the changes in the Cobb angle of the main curve and the Cobb angle of thoracic kyphosis from pre-operative to last follow-up were significantly greater in the Proximal 6 group than the Proximal 4 group. Taken together, the findings suggest that fixing three proximal vertebral bodies provides greater corrective ability for

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Fig. 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.
coronal main scoliosis and sagittal thoracic hyper-kyphosis. The improved correction of fixing three proximal three 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 hyper-kyphosis, the proximal three vertebral body fixation method can effectively reduce screw- and instrument-related complications, thus maintaining a constant distraction force during the lengthening procedures.

In the present study, screw loosening that required repair surgery was not observed. However, in general if screws become only slightly loosened or partially pulled-out, patients are observed if the treatment effect is not affected. If there is marked loosening of screws and the scoliosis worsens, the screws are replaced surgically and usually larger screws are used and/or more segments are fixed. This is usually performed at more than 3 years after the prior surgery.

None of the patients in this study had evidence of proximal junctional hyper-kyphosis (increase of proximal junctional angle ≥ 10°). Some studies, however, have reported an increase of proximal junctional angle of 20° or higher [16]. Pan et al. reported that in patients with EOS treated with growing rods, the incidence of proximal junctional hyper-kyphosis was 28%, and the independent risk factor was locating the proximal anchor points at the T2 spinal segment [17]. Wantanabe et al. [16] reported risk factors for proximal junctional hyper-kyphosis included a lower instrumented vertebra at or cranial to L3 (odds ratio (OR) = 3.32), a proximal thoracic scoliosis of ≥ 40° (OR = 2.95), and a main thoracic hyper-kyphosis of ≥ 60° (OR = 5.08). Consistent with a report by Li et al. [18] our results showed that treatment with growing rods had no effect on coronal imbalance.

It is known that treatment of scoliosis can affect pulmonary function and should be considered in designing treatments. We were not able to examine lung function, or the potential pulmonary effects of instrumenting 3 vs. 2 upper vertebrae, because the majority of the children
in this study were < 6 years of age and could not cooperate with pulmonary function testing. However, the upper part of the thorax is relatively narrow compared with the lower portion. In the Proximal 6 group, the improved correction of scoliosis and hyper-kyphosis was marked, and this increased the thoracic height, primarily due to an increase of the lower portion. Thus, in theory this should improve lung function.

Notably, there were no postoperative infections in any of the 42 patients in this study. There are a number of reasons for this finding. All patients were treated with antibiotics prophylactically in the perioperative period. If the leukocyte count was higher than normal after surgery, antibiotics treatment continued until the leukocyte count returned to normal. Also, we used strict criteria for defining postoperative infection: persistent fever after surgery, delayed wound healing, and positive blood culture or wound exudate culture. A postoperative infection was diagnosed only if these criteria were met.

It should be noted that factors such as surgeon experience, better pedicle screw placement technique, and a history of conservative brace therapy can affect outcomes. In this study, all operations in both groups were performed by the same group of surgeons and thus there was no difference in experience of the surgeons between the two groups. As such, there was no difference in the screw placement technique between the groups, other than that 6 proximal screws were placed vs. 4. Conservative brace therapy is not a routine treatment before surgery, and no patients in this study were treated with a brace preoperatively. However, postoperatively we require patients to wear a brace for 3 months. Thus, brace use was consistent between the two groups.

This study has several limitations. The study cohort is small, and the duration of follow-up is short for the treatment of EOS. Clearly 6 implants appear to perform better in the short-term; however, long-term effects are not known and remain to be fully investigated. In addition, patient selection for the two groups may have potentially biased the results. Radiographic parameters were determined by a single observer, and no analyses of interobserver or intraobserver reliability were performed. Although radiographic difference between the groups may be statistically significant, it may not be clinically meaningful. As the aim of the study was to examine radiographic outcomes and complications, we did not study clinical outcomes by measures such as the 24-item Early-Onset Scoliosis Questionnaire (EOSQ-24). Given the small size, we were unable to perform a statistical analysis of the relationship between outcomes and type of scoliosis. We did not use a standardized classification scheme for complications. Karol et al. and Canavese et al. have pointed out that upper thoracic spine fusion may impact the development of the thoracic cage/spine [19,20]. However, because most of the patients were very young in our study, pulmonary function testing could not be performed preoperatively; thus, we did not examine the effect of having 3 vs. 2 upper vertebral bodies instrumented on pulmonary function. We believe that proximal fixation with 6 implants may be conducive to the development of the thoracic cage/spine of EOS patients as they had achieved a higher correction rate of scoliosis and hyper-kyphosis, which could overcome the impact of fixation with an additional vertebra. We will monitor the pulmonary function of patients treated with growing rods in the follow-up of these patients and compare the impact of 6 implants on the development of the thoracic cage/spine of EOS patients vs. 4 implants. Although proximal fixation with 6 implants yielded a higher correction rate of scoliosis and hyper-kyphosis in EOS patients, it is a more complicated surgical procedure requiring fixation of an additional vertebra and may incur the risk associated with using more screws. We believe that such long-term adverse effects only become obvious with better comparative effective studies in a prospective, randomized methodology. Before long-term data are available, we recommend that proximal fixation with 6 implants be indicated only for EOS patients with severe hyper-kyphosis who have a fully developed thoracic cage/spine and who are fit for additional screw placement.

Conclusion
When using growing rods for the treatment of EOS, fixing 3 proximal vertebral bodies with 6 anchors provides better radiographic outcomes, with a higher Cobb angle correction rate, than fixing 2 vertebral bodies with 4 anchors. Using 6 anchors is also associated with a lower rate of postoperative screw loosening.

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Conflicts of interest

There are no conflicts of interest.

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