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Apical and Intermediate Anchors Without Fusion Improve Cobb Angle and Thoracic Kyphosis in Early-onset Scoliosis

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Abstract

Background The main goal of treatment in early-onset scoliosis is to obtain and maintain curve correction while simultaneously preserving spinal, trunk, and lung growth. This study introduces a new surgical strategy, called the modified growing rod technique, which allows spinal growth and lung development while controlling the main deformity with apical and intermediate anchors without fusion. The use of intraoperative traction at the initial procedure enables spontaneous correction of the deformity and decreases the need for forceful correction maneuvers on the immature spine and prevents possible implant failures. This study seeks to evaluate (1) curve correction; (2) spinal length; (3) number of procedures performed; and (4) complications with the new approach.

Description of Technique In the initial procedure, polyaxial pedicle screws were placed with a muscle-sparing technique. Rods were placed in situ after achieving correction with intraoperative skull-femoral traction. The most

proximal and most distal screws were fixed and the rest of the screws were left with nonlocked set screws to allow vertical growth. The lengthening reoperations were performed every 6 months.

Methods Between 2007 and 2011, we treated 19 patients surgically for early-onset scoliosis. Of those, 16 (29%) were treated with the modified growing rod technique by the senior author (AH); an additional three patients were treated using another technique that was being studied at the time by one of the coauthors (CO); those three were not included in this study. The 16 children included nine girls and seven boys (median, 5.5 years of age; range, 4–9 years), and all had progressive scoliosis (median, 64°; range, 38°–92°). All were available for followup at a minimum of 2 years (median, 4.5 years; range, 2–6 years). **Results** The initial curve Cobb angle of 64° (range, 38°–92°) improved to 21° (range, 4°–36°) and was maintained at 22° (range, 4°–36°) throughout followup. Preoperative thoracic kyphosis of 22° (range, 18°–46°) was maintained at 23° (range, 20°–39°) throughout followup without showing any substantial change. There was a 47 mm (range, 38–72 mm) increase in T1–S1 height throughout followup. The mean number of lengthening operations was 5.5 (range, 4–10). The mean T1–S1 length gain from the first lengthening was 1.18 cm (range, 1.03–2.24 cm) and decreased to 0.46 cm (range, 0.33–1.1 cm) after the fifth lengthening procedure ($p = 0.009$). The overall complication rate was 25% (four of 16 patients) and the procedural complication rate was 7% (seven of 102 procedures). We did not experience any rod breakages or other complications apart from two superficial wound infections managed without surgery during the treatment period. The only implant-related complications were loosening of two pedicle screws at the uppermost foundation in one patient.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Conclusions In this preliminary study, the modified growing rod technique with apical and intermediate anchors provided satisfactory curve control, prevented progression, maintained rotational stability, and allowed continuation of trunk growth with a low implant-related complication rate.

Introduction

The goal of management of early-onset scoliosis is to control spinal deformity without interfering with spinal growth [2, 13, 14, 21]. Surgical treatment should be considered for patients with progressive deformities when cast or brace treatment have failed or is contraindicated. Surgical treatment options include early definitive surgery or temporary surgery [6, 19, 29, 30]. Early definitive fusion [14, 15] before the age 10 years may not prevent progression of deformity and may cause a crankshaft phenomenon [9, 10] and/or thoracic insufficiency syndrome [8, 22, 30].

Many nonfusion options have been proposed and various types of spinal implants have been used to control deformity while allowing spinal and thoracic growth in immature spines [6, 16, 21, 25, 29]. Skaggs et al. [25] had classified these systems into three categories based on the forces of correction: distraction-based systems, compression-based systems, and guided growth systems. Moe et al. [20] first described the distraction-based growing rod system in 1984. This system had inadequate biomechanical properties and a concerning frequency of complications [20]. With the development of dual rods, strong upper and lower anchors, and expandable connectors, growing rods became a powerful tool and gained wide use in the treatment of early-onset scoliosis [2]. However, in general, growing rods are lengthened every 6 to 8 months, which can be problematic in children with comorbidities. Recently, McCarthy et al. [18] developed the Shilla growth guidance technique to treat early-onset spinal deformities without the necessity of repeated lengthening, which included short segment posterior fixation and fusion at the apex of the deformity. However, long-term effects of apical short segment fixation and fusion can be unpredictable. Apical fusion may result in a short trunk height and may cause sagittal imbalance in long-term followup.

Traditional growing rods are distraction-based systems [1, 3, 5, 7, 12, 31] that try to correct spinal deformity by applying distractive forces across apical segments of the deformity between proximal and distal anchors. Because there are no apical and intermediate anchors along the main curve, correction and control of the main curve will always be limited.

We theorized that adding apical and intermediate anchors will provide better correction and control of the main curve in both coronal and sagittal plane, prevent progression of deformity, and decrease implant-related complications. We thought that using intraoperative traction at the initial procedure would allow spontaneous correction, facilitate correction, and avoid excessive forces for correction of the deformity in immature spine. The purpose of this study was to evaluate the results of this new surgical technique, which involves a sliding, growing rod modification for the treatment of early-onset scoliosis. Specifically, we wished to evaluate this technique with respect to (1) curve correction; (2) spinal length achieved; (3) number of procedures performed; and (4) complications with the new approach.

Surgical Technique

Initial Procedure

After induction of anesthesia, a traction radiograph under general anesthesia was performed to assess curve flexibility and determine strategic vertebrae. Then a Gardner-Wells tong (Ossur, Iceland) apparatus was applied to the skull, and Steinmann pins were placed on each supracondylar femur to prepare for intraoperative skull-femoral traction that would facilitate correction during the initial procedure. After the skin incision, subcutaneous tissue dissection was carried out carefully without any subperiosteal dissection and polyaxial pedicle screws were placed into the strategic vertebrae under fluoroscopic guidance with a muscle-sparing technique. Pedicle screws were placed to the apical, end, intermediate, and transitional zone vertebrae. To avoid any dorsal bulkiness, cervical or pediatric pedicle screw instrumentations were preferred for fixation according to patient size.

Intraoperative skull-femoral traction was used only at the initial procedure to facilitate correction of the deformity. Traction was initiated with approximately 20% of the body weight of the patient in kilograms and gradually increased during the surgery. Maximum applied traction was limited to 40% of the patient's body weight in kilograms to avoid any neurological deficit resulting from excessive and sudden traction. Only initial procedures were performed under spinal monitoring. Skull-femoral traction was halted immediately if there was any signal loss that exceeded more than 20% to 30% of the initial measurements.

After giving proper contours, rods were placed in situ and the most proximal (two levels) and most distal (two levels) screws were locked while the rest of the screws

Fig. 1 Rods were placed in situ and the most proximal (two levels) and most distal (two levels) screws were locked, whereas the rest of the screws were left loose with unlocked set screws at apical and intermediate regions to allow vertical growth. This system will enable the rod to slide easily through screw heads in these segments.

were left loose with unlocked set screws (loosely captured) at apical and intermediate regions to allow vertical growth because screw heads could slide easily over the rods in these segments (Fig. 1). The patients were braced with thoracolumbosacral orthosis after surgeries for only 6 weeks after surgery.

Lengthening Surgery

The lengthening operations were performed every 6 months. A Gardner-Wells tong was applied to facilitate traction. After skin and subcutaneous tissue dissection, set screws in intermediate and apical vertebrae were controlled for whether or not they were loose. After loosening of locked most proximal and distal screws, manual traction was applied from the head and both legs for lengthening. In situ bending maneuvers were used for additional correction. Proximal and distal set screws were locked again immediately after application of manual traction. No corrective maneuvers were applied on the proximal and distal foundation during the lengthening procedure. Patients were braced again for only 6 weeks after lengthening procedures.

Patients and Methods

Between 2007 and 2011, we treated 19 patients surgically for early-onset scoliosis. Of those, 16 (29%) were treated with the modified growing rod technique by the senior author (AH); an additional three patients were treated using another technique that was being studied at the time by one of the coauthors (CO); those three were not included in this study. Indications for use of that technique were progressive juvenile idiopathic scoliosis with normal thoracic

kyphosis; because of small numbers, we elected not to try to compare those three patients with the 16 managed with the technique being studied here. An additional 35 patients were managed nonoperatively during this time, and, likewise, they were not included in this report, which focused on the new surgical technique. The 16 children included nine girls and seven boys (median age, 5.5 years; range, 2–9 years), and all had progressive scoliosis (median, 64°; range, 38°–92°). All were available for followup at a minimum of 2 years (median, 4.5 years; range, 2–6 years).

The number of vertebrae spanned during initial growing rod insertion was 11 (range, 9–15). The number of instrumented vertebra levels was 10 (range, 7–14).

Etiologies for early-onset scoliosis were infantile in two, juvenile in five, congenital in five, neuromuscular in two, and syndromic scoliosis in two patients. Standing AP and lateral radiographs taken before the operation, after every lengthening in the postoperative period, and at the final followup were measured for changes in Cobb angle, thoracic kyphosis, and lumbar lordosis. T1–S1 height was measured to determine spinal growth on standing AP radiographs after every lengthening procedure. All patients were evaluated with preoperative MRI studies to search for any associated intraspinal anomalies. The hospital charts were reviewed for demographic data, etiology of deformity, number of rod-lengthening procedures, and complications.

Preoperative MRI study of three patients (18%) showed concurrent intraspinal abnormality (tethered cord in one patient, Arnold Chiari malformation in one patient, and Type II split cord malformation in one patient), which were managed simultaneously at the same stage during the initial procedure. In two of the 16 patients, congenital scoliosis deformity was managed by a hybrid procedure including apical vertebra resection combined with the growing rod technique.

Results

The initial curve Cobb angle of 64° (range, 38°–92°) improved to 21° (range, 4°–36°) and was maintained at 22° (range, 4°–36°) throughout followup. Preoperative thoracic kyphosis 22° (range, 18°–46°) was maintained at 23° (range, 20°–39°) throughout the followup without showing any substantial change.

The spinal length between T1 and S1 had increased from 266 mm (range, 188–315 mm) to 313 mm (range, 257–362 mm) at latest followup. There was a 47 mm (range, 38–72 mm) increase in T1–S1 height throughout the followup. Spinal growth rate (T1–S1 length) was 1.4 cm (range, 1.13–2.17 cm) per year. The mean T1–S1 length gain from the first lengthening was 1.18 cm (range, 1.03–2.24 cm). The gain in T1–S1 length achieved after

each lengthening decreases by repeated lengthenings. The mean T1-S1 length gain was 0.46 cm (range, 0.33–1.1 cm). T1-S1 length gain decreased significantly after the fifth lengthening surgery ($p = 0.009$).

The mean number of lengthening operations was 5.5 (range, 4–10). The mean interval between lengthenings was 7 months (range, 6–9 months). Two of the 16 patients underwent a final permanent surgery after the fifth lengthening without any extension of previous instrumented levels (Fig. 2).

The most common postoperative radiological finding of the technique was the dislodgement of nonlocked set screws from the screw head (tulip) in nine of 16 patients at the apical region mainly on the concave side between lengthening procedures. Four of 16 patients had complications during the treatment period. In one patient, instrumentation was elongated distally as a result of lumbar curve progression, which occurred after the fifth lengthening procedure. In one patient, two pedicle screws at the proximal foundation were revised with one size larger diameter screws as a result of loosening. In three patients, spontaneous fusion was identified during lengthenings at the proximal or distal foundation. Two superficial wound problems were managed with simple débridement. There were no unplanned additional surgeries during the treatment period.

Discussion

Scoliosis in very young children is an extremely difficult surgical problem. The main goal of treatment is to obtain and maintain curve correction while simultaneously preserving spinal, trunk, and lung growth. Growing rods have become increasingly popular in the treatment of early-onset scoliosis. Several studies [1, 3, 11, 23, 24, 27] have shown growing rods to be effective for achieving spinal length increase on the immature spine. Correction of the deformity will be achieved through only pure distractive forces between proximal and distal anchors in a traditional technique [17, 26]. As anterior spinal growth continues, rotational deformity at the apical and intermediate segments will continue to progress and because there are no apical and intermediate anchors along the main curve, correction and control of the main deformity will be limited. We had modified the traditional growing rod technique mainly by adding multiple anchors at apical and intermediate vertebrae to provide better corrections. In addition, intraoperative traction was used at the initial procedure to achieve spontaneous deformity correction. Locking only proximal and distal anchors helped to maintain correction, and keeping all other set screws at the apical and intermediate region loose allowed vertical

growth. The Shilla growth guidance technique, designed by McCarthy et al. [18], to eliminate the necessity of repeated lengthenings had a similar construct as our modified technique. The Shilla system had an apical foundation with short segment posterior fixation and fusion with loose proximal and distal anchors to control deformity. Because proximal and distal foundations were loose in the Shilla technique, this may result in difficulty in resisting bending moments during axial loading of the spinal column and predispose to implant-related complications. In this retrospective study we tried to evaluate curve correction and also changes in thoracic kyphosis, spinal length achieved, number of procedures performed, and complications with the new approach.

The limitations of this study included its small patient sample, heterogeneity in terms of etiology, and retrospective design. The study also had a relatively short mean followup for a growing child. Further limitations included the basis of selection of patients because three of them were treated with another technique. Only two of the patients reached skeletal maturity and underwent final fusion surgery during the study period. Longer-term followup and a greater number of patients who underwent final surgery are needed to show the efficacy of the technique. Finally, our evidence for rotational control was limited by the fact that we did not obtain CT scans to assess rotational deformity; future studies should specifically evaluate this.

Our modified technique enabled us to preoperatively correct the Cobb angle from 64° (range, 38°–92°) to 22° (range, 4°–36°) with a 67% rate of correction. Various studies evaluating results of dual-rod growing systems reported a 47% (range, 43%–54%) overall correction rate [1, 3, 11, 23, 24, 27]. Keeping apical and intermediate anchor set screws loose prevented the hypokyphotic effect of posterior fixation in the immature spine. Thoracic kyphosis was maintained throughout the followup.

We achieved a 47-mm (range, 38–72 mm) increase in T1-S1 height with a spinal growth rate of 1.4 cm per year, which is comparable to previous studies. Addition of multiple anchors to the growing rod construct appears not to affect or decrease the rate of spinal growth during treatment period. Sankar et al. [23] reported a significant decrease in gain in T1-S1 length after the seventh lengthening in their study. The gain in T1-S1 length decreased significantly after the fifth lengthening surgery ($p = 0.009$) in our study.

The mean number of lengthening operations was 5.5 (range, 4–10) with a mean interval of 7 months (range, 6–9 months) between lengthenings.

The overall complication rate was 25% (four of 16 patients) and the procedural complication rate was 7% (seven of 102 procedures) in this study. The overall

Fig. 2A–F Preoperative AP (A) and lateral standing (B) radiographs of a 6.5-year-old girl with congenital kyphoscoliosis deformity. Preoperative 86° of Cobb angle was corrected to 24° (C) after the initial procedure. Kyphotic deformity (D) was also corrected. Final

posterior fusion surgery was performed after a fifth lengthening procedure. Coronal (E) and sagittal balance (F) was achieved at 11 years of age with the modified growing system.

complication rate ranges between 32% and 58% in previous studies [1, 3, 4, 11, 23, 24, 27, 28]. Bess et al. [4] reported that 42% of complications required an unplanned procedure

for treatment in their study. We did not perform any unplanned surgery and did not experience any rod breakages during the treatment period. The only implant-related

complications were loosening of two pedicle screws at the upper-most foundation in one patient. This low rate of implant-related complications can be explained by the use of multiple anchors at strategic vertebrae and use of intraoperative traction at the initial procedure. Stresses caused by pure distraction forces will be shared among multiple anchors and this may help eventually decrease overall hardware-related complications. The intraoperative use of traction enables spontaneous correction of the deformity, decreases the need for forceful correction maneuvers on the immature spine, and prevents possible implant failures. We did not see any intraoperative traction-related complications in our study. The most common postoperative radiological finding of the technique was the dislodgement of nonlocked set screws from the screw head (tulip) in nine (58%) patients between lengthening procedures. This finding is accepted as an indicator of sliding of the rod in the screw head resulting from vertical growth rather than a complication. Dislodgement of nonlocked set screws was mainly at the apical region, specifically on the concave side of the deformity. We believe this is also another important indicator that showed that apical anchors are necessary for controlling the deformity, mainly against rotational forces at the apex of the deformity. In our study, we identified spontaneous fusion during lengthenings at the proximal or distal foundation (not in apical or intermediate regions) in three (18%) patients. Although this rate was lower than previous studies, we suggest to start using the growing rod technique as late as possible in younger patients.

Preliminary assessment of our new treatment strategy, which uses multiple anchors at the apical and intermediate vertebrae, seems to provide satisfactory curve correction, prevents progression of the deformity, maintains rotational stability, and allows continuation of trunk growth with low rates of implant-related complications. This modified technique can be safely performed with any classical instrumentation system available on the market.

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