Growing Rods With Sliding Pedicle Screw System for the Treatment of Early-onset Scoliosis: a Retrospective Analysis of 18 Cases With More Than 5-year Follow-up

Zhi-Hua Ouyang  
The First Affiliated Hospital of University of South China

Jing-Bo Xue  
The First Affiliated Hospital of University of South China

Ming Tang  
The First Affiliated Hospital of University of South China

Ming-Xiang Zou  
The First Affiliated Hospital of University of South China

Cheng Wang  
The First Affiliated Hospital of University of South China

Yi-Guo Yan  
The First Affiliated Hospital of University of South China

Wen-Jun Wang ( wwj1202@hotmail.com )  
The First Affiliated Hospital of University of South China

Research Article

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Abstract

**Background:** The growing rod (GR) technique is a viable alternative for the current non-fusion treatment of early-onset scoliosis (EOS). However, conventional GRs are lengthened to allow for spinal growth, which requires multiple surgeries under general anesthesia in association with high cost and potentially negative psychosocial outcomes.

**Methods:** In this study, growing rods with a sliding pedicle screw system (GRSPSS) was developed for the treatment of EOS without need of repeated operative lengthening. A retrospective review of clinical data on EOS patients who were treated with GRSPSS system was performed to evaluate the safety and efficacy of this technique.

**Results:** 33 patients received GRSPSS instrumentation and 18 of them were finally included with more than 5-year follow-up data. There were 10 girls and 8 boys with a mean age of 9 years old. The mean preoperative curve (56.6 degrees) was corrected to 15.5 degrees at the 4-week follow-up. This magnitude of correction maintained at the 5-year follow-up. T1-S1 spinal height gained an average of 42 mm on measurement from postoperative to the final follow-up period. Complications included transient neurological deficit in one case and skin infection at one end of the rods in three cases during the early-postoperative period. Two patients required minimally invasive revision surgery because of shoulder imbalance. Rod breakage occurred in two cases.

**Conclusions:** The GRSPSS can safely and effectively correct spinal deformity at a 5-year follow-up. This new instrumentation may be a promising approach for facilitating spinal growth without repeated lengthening operations.

Introduction

It is still challenging for surgeons to treat Early-onset scoliosis (EOS) patients. For those patients, evidence show that increased deformity will develop without treatments. Mild scoliosis with the cobb angle between 25° and 45° at early stage can be treated with a brace, whereas surgical treatments can be used for progressive scoliosis greater than 50° \(^1\). In 1980’s, solid fusion surgery was thought to be the right decision, however, high mortality was found due to restriction to lung growth \(^2\). Thus, instrumentation without fusion has been proposed in patients with a large potential for skeletal growth to halt scoliotic progression and delay the definitive surgical procedure until spinal development is complete \(^3\)–\(^6\). Though distraction-based surgeries and vertical expandable prosthetic titanium rib expansion technique (VEPTR) can maintain satisfied growth, they require repeated surgeries as the spine grows with subsequent complications, which are influenced by the number of lengthening procedures \(^7\)–\(^9\).

Growth friendly instruments without needs for repeated surgeries have gained more attention such as Shilla technique and magnetically controlled growing rods, reporting with promising results \(^3\),\(^4\). We have been using our own system named growing rods with a sliding pedicle screw system (GRSPSS), which
was designed almost the same time and similar to Shilla technique, for more than ten years. Our preclinical study examined the safety and efficacy of this system in an animal model \(^{10}\). We found that the GRSPSS was able to maintain spinal growth. In this article, we reported our long term follow up results for this system.

**Methods and Materials**

**Patients**

From January 2009 to June 2019, a total of 33 patients underwent corrective surgery for EOS using GRSPSS instrumentation. All patients were treated by two surgeons from a single surgical center. Clinical and radiographic data were collected prospectively before and after the operation. Standard clinical preoperative assessment and planning for pediatric spinal deformity correction were performed, including upright posteroanterior and lateral scoliosis radiographs, supine bilateral bending and posteroanterior traction and hyperextension lateral radiographs when deemed appropriate by the treating physician.

From a cohort of 33 total patients, 18 patients (10 Females and 8 males) had reached a 5-year at least follow-up; only these patients were included in this study. Mean age at the time of surgery was 9.8 ± 1.8 years-old (range 3-12 years). The diagnoses were idiopathic scoliosis (n = 9), congenital scoliosis (n = 7), neuromuscular scoliosis (n = 2). All surgeries were performed by one-stage posterior approach. Mean time of follow-up was 82 months (range 60 to 131 months). All patient characteristics were shown in Table 1.
Table 1
Basic demographics and clinical outcomes of the 18 patients with EOS.

|                                | Values                          |
|--------------------------------|--------------------------------|
| Average age at the time of surgery (years) | 9                              |
| Sex (numbers)                  |                                |
| Female                         | 10                             |
| Male                           | 8                              |
| Types of scoliosis (numbers)   |                                |
| Idiopathic scoliosis           | 9                              |
| Congenital scoliosis           | 7                              |
| Neuromuscular scoliosis        | 2                              |
| Average follow-up time (months) | 82                             |
| Average operating time (minutes) | 240 (210-330)                  |
| Average blood loss (ml)        | 420 (300-1100)                 |
| Cobb angel (°)                 |                                |
| Preoperative                   | 56.6±15.1                      |
| Postoperative                  | 20.4±12.5                      |
| Last follow-up                 | 15.5±10.7                      |
| T1-S1 spinal height (cm)       |                                |
| Preoperative                   | 31.3±5.6                       |
| Postoperative                  | 34.9±5.6                       |
| Last follow-up                 | 39.1±5.5                       |
| Complications (numbers)        |                                |
| Transient neurological deficit | 1                              |
| Skin infection                 | 3                              |
| Rod break                      | 2                              |
| Revision surgery               | 2                              |

SD, standard deviation. EOS, early-onset scoliosis. T1-S1 spinal height, the length from the first thoracic vertebra to the first sacral vertebra.
Device description

The GRSPSS (HengJie Medical Devices Company, Changzhou, China) includes three parts: two stainless steel 5.5-mm diameter rods, sliding pedicle screws and conventional pedicle screws (Figure 1).

Sliding pedicle screws consist of a locking cap that fixes to the screw (not the rod), captures the rod, and allows it to slide in its groove in the longitudinal direction. When the rod is secured beneath the locking cap, there is a 0.75mm distance between the top of the rod and the bottom of the cap that permits the rod to slide through the screw. Conventional pedicle screws, which are sized for achieving maximal fixation, are inserted in apical segments of the spinal deformity. Sliding screws are placed in vertebrae between the apex and the end of the deformity. These sliding screws function to (1) maintain coronal and sagittal correction and (2) guide the growth of the spine during skeletal growth. The dual titanium rods are fixed to the corrected apex of the curve by conventional pedicle screws; fusion at the apex is limited. Vertebral growth then occurs outside the fused apex in the cephalad-caudal direction via extra-periosteally placed sliding pedicle screws.

Surgical technique

Each patient was placed prone on the operating table and carefully padded. Preoperative, patient-specific planning consisted of careful assessment of the upright coronal and sagittal films coupled with analysis of the flexibility of the curve by spine bending films, fulcrum bending films, or traction films. The essential point of preoperative planning was to determine the location of the apical vertebral segments. Apical segments, which are fused for maximum correction, are defined to be those three or four vertebral segments that are least corrected through flexibility testing. In the case of very stiff deformities, maximum correction of the apex was achieved using one of three different operations: Halo-pelvis traction, anterior disk and end plate excision of the apical levels, and posterior vertebral column resection.

A single midline incision was used to access the spinal region, and subperiosteal dissection was used to isolate the apical levels. Sliding screws were placed through the muscular layers without removing all soft tissues for visualization of the vertebrae. Conventional pedicle screws were placed in the apical vertebral segments. Ponte osteotomies or posterior vertebral column resection were performed between the apical segments to facilitate maximal correction. Apical fusion was performed using local bone graft and graft substitutes (Changsheng Company, Xuzhou, China). Since sliding screws were placed between the apex and the end of curve. Use of sliding screws does not decrease the risk of spontaneous autofusion, screws were placed carefully to avoid disruption of the periosteum. Dual titanium rods were contoured into desired sagittal curves and sized to be two to three vertebral levels long at caudal and cephalad ends to accommodate and guide projected growth. A crosslink was frequently placed in the apex to help limiting rod rotation. Patients were braced for the first three months postoperatively during spinal fusion of the apical segments (Typical case in Figure 2).

Results
The mean preoperative Cobb angle was 56.1°±15.7°, which was corrected to 15.5°±10.6° at 4 weeks after surgery and was maintained at 20.4°±12.5° at the end of follow-up. There was no significant difference between postoperative correction and the last follow up correction ($p > 0.05$). Mean T1–S1 height increased from 31.3 ± 5.6 cm preoperatively to 34.9 ± 5.6 cm ($p < 0.05$) immediately after surgery and to 39.1± 5.5cm ($p < 0.05$) at the last follow-up. Mean increase in T1-S1 length from preoperative to postoperative was 36 mm, and change from postoperative to final follow-up was 42 mm (6.4 mm/year).

The average operating time for the GRSPSS procedure was 240 minutes (range 210–330 minutes). Intraoperative blood loss averaged 420 mL (range 300-1100 mL). Incomplete paralysis in the left lower limb (ASIA grade is D) was found in one patient during the wake-up test. Intraoperative X-ray found a pedicle screw at T8 that protruded into the spinal canal; adjustment of the pedicle screw was made in time. The incomplete paralysis of the left lower limb recovered after one month (ASIA grade is E). There were no other neurological deficits. Mild skin infection at the end of the rod occurred in three cases during the early-postoperative period, they all cured after changes of wound dressing. Two patients required minimally invasive incision revision because of shoulder imbalance. Two patients experienced rod fractures, one followed by implant removal, another followed by revision surgery to change a new rod. There were no instances of autofusion or other complications. All patient clinical outcomes and comparison of that were depicted in Table 1 and Table 2, respectively.

| Values                        | P-Value  |
|-------------------------------|----------|
| Cobb angel                    | $< 0.0001$ |
| Preoperative and Postoperative| $< 0.0001$ |
| Preoperative and Last follow-up| $< 0.0001$ |
| Postoperative and Last follow-up| 0.13 |
| T1-S1 spinal height           |          |
| Preoperative and Postoperative| $< 0.0001$ |
| Preoperative and Last follow-up| $< 0.0001$ |
| Postoperative and Last follow-up| $< 0.0001$ |

Bold indicates $P < 0.05$. EOS, early-onset scoliosis. T1-S1 spinal height, the length from the first thoracic vertebra to the first sacral vertebra.

**Discussion**
Over the past decades, different growth friendly techniques have been used to treat EOS $^5,6,11$. Generally speaking, growth friendly techniques could be divided into 3 categories, distraction-based, compression-based and growth guided. Each technique has its own advantages and shortcomings. They all showed the ability to keep growth of the spine, since doctors have reached the consensus that the goal in treatments is to maximize spinal growth rather than a straight but limited spine growth $^6$. Some traditional growing rods and rib-based techniques need repeated surgeries, leading to increased cost and surgery related complications $^6,12,13$. Shilla and magnetically controlled growing rod allow spinal growth without repeated surgical lengthening. The purpose of GRSPSS technique is also designed to correct spinal curvature and maintain normal spinal growth without repeated surgical lengthening procedures.

The GRSPSS technique corrected scoliosis by 58% postoperatively, it maintained a 53% correction at the final follow-up. The degree of correction were comparable to the reported Shilla growth guidance system which showed 52.9% correction postoperatively $^{14}$. In this study, the average T1–S1 height increase 6 mm yearly by using GRSPSS. Akbarnia et al. reported that the increased average T1-S1 height was 14.6 mm per year for a series of EOS patients who underwent dual GR surgery and were followed for 3 to 11 years$^{15}$. McCarthy et al. reported preliminary results of Shilla technique at 2-year follow-up, whose results showed an average annual increase of 15.8 mm in T1-S1 $^{16}$. Scott et al. compared Shilla system with GR technique, showed 16.8 mm per year height change in T1-S1 with 3-5 years follow up in 19 patients $^{14}$. The height change seemed attractable and higher than our results. At the same time, Alexander et al. did the largest case series of patients with EOS treated with SHILLA outside of the inventor's institution $^{17}$. The increased average T1-S1 height in their study was only 4.2 mm per year, which is close to our case series by using GRSPSS.

There were 2 autofusion cases in our series. Autofusion is another common complication treated with growth friendly technique in immature skeletal children with scoliosis. The rate could be as high as 89% $^{18}$. The exact mechanism for autofusion is still unknown, poorly delineated in the literatures. Early in 1995, John et al. ascribed autofusion to microhemorrhage and subsequent bone formation and ankylosis $^{19}$. Patrick et al. suggested that autofusion likely occurred due to combination of factors including immobilization, the local disturbance of perispinal musculature, and proclivity of immature bone to rapidly and reliably heal fractures $^{18}$. In our study, rate of autofusion was lower than reported, which might due to preservation of periosteum and better protection of perispinal musculature by avoiding repeated distraction surgery.

Shoulder imbalance is one of the complications with GRSPSS technique that we should pay attention. some cases presented mild shoulder imbalance who did not need further surgery. There were two cases with severe shoulder imbalance requiring revision surgery in our study.

**Conclusion**
Our present study demonstrated that GRSPSS was effective for correction and maintenance of spinal curvature in EOS. It has the ability to maintain spinal growth, avoiding shortage of repeated lengthening procedures. Our long-term follow-up data show GRSPSS can be a promising alternative choice for treating early onset scoliosis children.

**Declarations**

**Conflict of interest statement:**

The authors declare that they have no competing interests.

**Ethics approval and consent to participate:**

The study protocol was approved by the Institutional Review Board at The First Affiliated Hospital, University of South China, Hunan, P.R. China. Written informed consent was obtained from each patient for publication of this study.

**Consent for publication:**

Not applicable.

**Availability of data and material:**

All data relevant to the study are included in the article or uploaded as supplementary information.

**Authorship:**

All authors participated in data acquisition. ZHO, JBX, CW, YGY and WJW contributed to the conception and design of the study. ZHO, JBX, MT, MXZ, and YGY did the data analysis and interpretation. ZHO, JBX, MT, MXZ, CW, YGY and WJW contributed to drafting and revision of the manuscript. All authors read and approved the final manuscript.

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**Figures**

![Figure 1](image)

**Figure 1**

Conventional pedicle screw (A) and sliding pedicle screw (B).
Figure 2

Typical case. Preoperative standing X-rays of a 6-year-old child with infantile idiopathic scoliosis (Figure A, B). One-month postoperative X-rays. (Figure C, D). Three years postoperative X-rays (Figure E, F). Ten years postoperative X-rays (Figure G, H). Distance between rod end to last pedicle screws shortened both cephalad and caudally (white arrow) compared with previous operation (Figure G). Appearance figures at preoperative, postoperative, three years and ten years follow-up separately (Figure I-L).