Growing-Rod Graduates: Lessons Learned from Ninety-nine Patients Who Completed Lengthening

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Background: Growing-rod spinal instrumentation systems are a valuable tool for managing severe early-onset scoliosis. There is little information about the end point of treatment.

Methods: A multicenter early-onset-scoliosis database was searched to identify patients who had undergone treatment with growing rods and either had had a final operative procedure or were still being treated with the growing rods after reaching skeletal maturity (defined as fourteen years of age or older). Clinical, radiographic, and operative data were analyzed.

Results: Ninety-nine patients met the inclusion criteria, and ninety-two (93%) of them had had a final operative procedure. The remaining seven patients (7%) were older than fourteen years but had not undergone a final procedure. Of the ninety-two patients who had a final procedure, seventy-nine (86%) had an instrumented fusion, nine (10%) had growing-rod exchanges and fusion in situ, three (3%) had the growing rods left in place and fusion in situ, and one (1%) had only growing-rod removal. The mean age (and standard deviation) at the final fusion was 12.4 ± 1.9 years. In forty-four (55%) of eighty patients for whom the information was available, the number of vertebral levels fused was the same as the number of vertebral levels spanned by the growing rods. The percent correction of the curve after final fusion was none or minimal (≤20%) in eleven (18%) of the sixty-two patients for whom sufficient-quality radiographs were available, moderate (21% to 50%) in thirty (48%), and substantial (≥51%) in nine (15%); the curve had worsened in twelve patients (19%). The mean duration of growing-rod treatment was 5.0 ± 2.6 years. Of fifty-eight operative reports made at final fusion that contained comments on spinal flexibility, eleven (19%) described the spine as being mobile, eleven (19%) described decreased flexibility, and thirty-six (62%) described the spine as being completely stiff. At final fusion, twenty-two patients (24%) had osteotomies and seven patients (8%) had a thoracoplasty.

Conclusions: Most patients underwent growing-rod removal and final instrumented fusion. The final fusion often included the same levels spanned by the growing rods and usually achieved <50% additional correction of the deformity remaining at the end of the growing-rod management.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Over the past two decades, there has been a paradigm shift in the management of early-onset scoliosis. The previous recommendations of early in situ fusion have been replaced by various methods of instrumentation without full-length fusion, followed by periodic and repetitive surgical distraction. However, surgeons and patients alike...
embark on this relatively common and accepted growing-rod algorithm with no evidence to guide the final stage of treatment because there are no published series focused on the transition from repetitive lengthening to the final surgical procedure that will end the treatment.

An understanding of the criteria guiding the decision to end growing-rod treatment would determine the course of treatment from the start, and involves the following questions:

- What are the indications to stop lengthening and proceed to final fusion—i.e., do they consist of a certain age, a failure (an implant-related complication or infection) during pre-adolescence, family/patient fatigue, and/or the inability to distract further due to spine stiffness?
- Should the shortest spine segment possible be spanned at the initial insertion of growing rods, or is decompensation so common that the initially inserted rods should extend from a stable vertebra to a stable vertebra, or farther?
- Are the foundation sites used for growing rods destroyed by years of distraction, or are they available at the final fusion?
- What is the condition of the spine at the time of final fusion—i.e., is it flexible, partially stiff, or completely autofused?
- Is the final fusion a difficult procedure, in terms of neurologic risk, blood loss, and dissection, or is it a relatively simple implant exchange and bone-grafting procedure?
- How much final correction can be expected, and does this depend on the diagnosis or on the length of time that the rods have been in place?
- Are osteotomies necessary? Should areas of autofusion be resected to restore some mobility?

We are among the earliest adopters of the growing-rod techniques and have access to high-quality, multicenter data contributed by the pioneers of this procedure. These data were derived from a large international group of patients treated with growing rods who had either reached skeletal maturity or had had a final fusion. This experience and these data create a unique opportunity to provide the first report on "growing-rod graduates."

Materials and Methods

We searched the largest and most comprehensive international multicenter early-onset-scoliosis database to identify all patients who had been managed with growing rods and either had undergone a final fusion procedure or were fourteen years of age or older but were still being treated with the growing rods. We chose fourteen years of age as a time when most girls and many boys in this population would be at or near the end of their spinal growth. The information in the database was used to determine demographic characteristics, underlying diagnoses, and a variety of perioperative information. Individual operative reports of the final fusion procedure were reviewed to determine the indication for the final fusion, the upper and lower instrumented vertebrae, the difficulty of the exposure, the condition of the spine (whether it was flexible, partially fused, or extensively autofused), the condition of the growing-rod foundation sites, whether an osteotomy or a thoracoplasty had been performed, the type and duration of instrumentation, the estimated
intraoperative blood loss, the spinal cord neuromonitoring results, and any occurrence of intraoperative complications.

The radiographs made immediately before and after the final fusion were reviewed in order to determine prefusion and postfusion curve measurements, prefusion and postfusion upper and lower instrumented vertebrae, instrumentation constructs, and prefusion and postfusion coronal and sagittal plane balance (Fig. 1).

We recorded the difference between the number of levels spanned by the growing rods and the number spanned by the final fusion, and we calculated the percent correction in the Cobb angle by comparing the radiographs made immediately before the final fusion with those made immediately after it.

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Results

Of the ninety-nine patients who met the inclusion criteria, ninety-two (93%) had a final operative procedure. The remaining seven patients (7%) were older than fourteen years of age at the time of the database search but had not undergone a final procedure. Of these seven patients, three were between fourteen and fifteen years of age at their most recent follow-up visit and the remaining four patients were fifteen years of age or older; all continued to return for observational follow-up visits at the discretion of the surgeon.

Of the ninety-two patients who had a final procedure, seventy-nine (86%) had a final instrumented fusion, nine (10%) had growing-rod exchanges and fusion in situ, three (3%) had the growing rods left in place and fusion in situ, and one (1%) had growing-rod removal only. The mean age at the final procedure (and standard deviation) was 12.4 ± 1.9 years (range, 8.8 to 18.4 years).

The diagnoses, which varied among the patients, included neuromuscular scoliosis in forty-three (43%), idiopathic scoliosis in twenty-seven (27%), syndromic scoliosis in seventeen (17%), congenital scoliosis in nine (9%), and a condition not included within the other categories in three (3%) (three patients with spinal deformity resulting from a tumor).

For eighty (87%) of the ninety-two patients who had a final procedure, enough information was available to determine the last instrumented levels spanned by the growing rods and the final fusion. When postoperative radiographs were not available, operative reports were used to determine these fusion levels. In forty-four (55%) of the eighty patients, the number of levels instrumented in the final fusion was the same as the number spanned by the growing rods. The differences between the number of levels in the final fusion and the number spanned by the growing-rod instrumentation are shown in Table I.

The curve correction at final fusion varied considerably among the patients. A fusion in situ was performed in some cases; in others, maximum correction was sought by performing osteotomies. Also, when surgeons first began performing growing-rod procedures, it was the practice of some to carry out an apical fusion at the time of rod implantation. Sixteen (16%) of the ninety-nine patients in this series had an apical fusion. All sixteen underwent a final procedure, and thirteen of the sixteen underwent a final instrumented fusion. Thirteen of the sixteen patients had a stiff spine at the time of their final procedure. The spine flexibility of the additional three patients who underwent apical fusion was not described in the operative records.

To classify the correction obtained between the time of the prefusion radiograph and the time of the postfusion radiograph, we created three categories: none or minimal (≤20%), moderate (21% to 50%), and substantial (≥51%). Of the sixty-two patients for whom this category could be determined, eleven (18%) had no or minimal correction after the final fusion; thirty (48%), moderate correction; and nine (15%), substantial correction. Twelve patients (19%) had worsening of the main curve following the final fusion. Due to the unavailability of some radiographs and the quality of some available radiographs, the mean percent correction could not be calculated for thirty patients.

A similar categorical system was used to describe the amount of correction by comparing the main curve prior to implantation of the growing-rod instrumentation with the main curve following the final fusion. Eight patients (13%) had

<p>| TABLE I Extension of Fusion Levels Relative to Final Growing-Rod Instrumentation |</p>
<table>
<thead>
<tr>
<th>No. of Additional Vertebral Levels*</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal end only (n = 5)</td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>3</td>
</tr>
<tr>
<td>+2</td>
<td>1</td>
</tr>
<tr>
<td>+3</td>
<td>1</td>
</tr>
<tr>
<td>Distal end only (n = 10)</td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>1</td>
</tr>
<tr>
<td>+2</td>
<td>7</td>
</tr>
<tr>
<td>+3</td>
<td>2</td>
</tr>
<tr>
<td>+4</td>
<td>1</td>
</tr>
<tr>
<td>Both proximal and distal ends (n = 10)</td>
<td></td>
</tr>
<tr>
<td>+1, +1</td>
<td>1</td>
</tr>
<tr>
<td>+1, +2</td>
<td>3</td>
</tr>
<tr>
<td>+1, +3</td>
<td>1</td>
</tr>
<tr>
<td>+2, +1</td>
<td>2</td>
</tr>
<tr>
<td>+2, +3</td>
<td>1</td>
</tr>
<tr>
<td>+3, +1</td>
<td>1</td>
</tr>
<tr>
<td>+4, +1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Thirty-five patients (44% of the eighty patients who had a final fusion and for whom the information was available) required fusion to levels beyond their last growing-rod instrumentation. In forty-four patients (55%), the final fusion involved the same number of levels as spanned by their last growing-rod instrumentation, and one patient (1%) underwent a growing-rod removal only ("not applicable").

†In the two subjects who needed a fusion extending an additional five or six levels distally, the initial instrumentation was performed with a single growing rod along the thoracic curve. Due to a progressive lumbar curve in the first subject and a proximal and junctional kyphosis as well as a sagittal imbalance in the second subject, a longer fusion was chosen to prevent further deformities.
The overall duration of the growing-rod treatment varied. We also created three categories to define the time the growing rods were in place: short (2.4 years or less), moderate (2.5 to 6.4 years), and substantial (6.5 years or more). The mean duration of growing-rod treatment was 5.0 ± 2.6 years (range, 0.6 to 11.0 years). At the time of their final procedure, seventeen patients (18%) had had the growing-rod instrumentation for a short time; forty-six (50%), for a moderate time; and twenty-nine (32%), for a substantial time.

Surgeon-reported indications for the final procedure varied. They included limited growth remaining in twenty-two patients (36%), continuous progression of deformity in fourteen (23%), loss of fixation or the failure of the spinal implant in twelve (20%) (Fig. 2), infection in six (10%), clinical suspicion of autofusion in five (8%), and syndromic-related issues in two (3%). The indications for the final procedure were not reported for thirty-one (34%) of the patients in this series.

Of the fifty-eight patients whose operative report specifically commented on spinal mobility at the time of the final procedure, eleven (19%) had a mobile spine, eleven (19%) had decreased flexibility with certain areas of autofusion, and thirty-six (62%) had a completely stiff (or completely autofused) spine. These numbers include the sixteen patients who underwent a final procedure but who were treated initially with an apical fusion. Spine mobility was not mentioned in the remaining thirty-four operative reports. Osteotomies were reported for twenty-two (24%) of the patients who underwent a final procedure, anterior fusion or anterior release was reported for twelve patients (13%), and thoracoplasty was reported for seven patients (8%).

In most cases, the growing-rod proximal and distal foundation sites were maintained for the final fusion. Growing-rod hooks or screws were often (but not always) exchanged for larger sizes. In several cases, proximal hooks were attached to an area of osseous fusion but not to the transverse processes or to the lamina where they had initially been placed. In many cases, the operative report described the exposure and dissection as “difficult” or reported that “there was extensive scar tissue.”

The estimated blood loss varied considerably, ranging from 50 to 5000 mL. The median amount of blood loss was 675 mL, with an interquartile range of 450 to 1000 mL. This reflects the large differences in the final fusion procedures, which ranged from simple rod removal to long fusions with osteotomies and segmental instrumentation. Three (3%) of the ninety-two patients who had a final procedure had neuromonitoring changes. One of these patients, who had an unspecified syndrome, had a decrease in electromyographic activity. Another patient, who had congenital anomalies (not of the spine), had a change in somatosensory evoked potentials following electrocauterization in the area of the

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Fig. 2
Posteroanterior and lateral radiographs made before (Fig. 2-A) and after (Figs. 2-B and 2-C) the final fusion in a twelve-year-old girl with severe juvenile idiopathic scoliosis. The posteroanterior radiograph made before the final fusion shows a single broken growing rod. Because of the patient’s loss of correction, curve severity, and degree of skeletal maturity, a decision was made to proceed with the final fusion. The posteroanterior and lateral radiographs made after the final fusion show a dual-rod segmental construct with excellent overall correction of the deformity.
L2-L3 ligamentum flavum; this resulted in an aborted procedure, which was reattempted four days later. The third patient, who had idiopathic juvenile scoliosis, had decreased movement of the right lower extremity on waking, which resolved thirty minutes after surgery. All three subjects had a normal neurologic status at the time of their postoperative clinical visit.

**Discussion**

Most procedures used to correct spine deformity are intended to be a single operation. Studies that investigate the indications and best techniques for these procedures can focus on the natural history of the untreated patient, perioperative findings, and ultimate outcomes. **Growing-rod treatment, as it is currently practiced, is an entirely different paradigm.** Surgery is deferred until the latest possible time; then initial instrumentation with limited fusion is performed, followed by repetitive distraction. Based on several excellent recent investigations, we have learned many concepts to improve treatment, including the importance of delaying the application of instrumentation, avoiding subperiosteal dissection, submuscular positioning of the rods, the use of dual rods, the distraction interval, the role of neuromonitoring, the management of various complications, and the problems associated with apical fusion at the time of the initial instrumentation. To our knowledge, the one element of the treatment paradigm that has not been studied specifically is the final fusion. Our hope is that, by studying the indications for and the perioperative details of the final fusion, we can help surgeons do the best operation from the time of the initial growing-rod implantation, decide when to stop distraction treatment, know what to expect at the final fusion, and know how to counsel families from the start about the end point in this treatment paradigm.

From this investigation of ninety-nine patients, we gained additional information about the management of these challenging patients. The final fusion is most often performed on patients who are between eleven and thirteen years of age, although there were several children older or younger, for a variety of reasons. The decision to proceed with the final fusion is commonly triggered by a problem (such as an implant failure or infection) or by the assessment that there is not much spinal movement or growth remaining. Only seven patients fourteen years of age or older had not yet undergone a final procedure at the time of our study. Our study did not provide enough long-term data to determine if watchful waiting this long is a viable strategy. In some cases, the final fusion length was longer than the span of the growing rods, but most often it was only one or two vertebral levels longer. On radiographs, it appeared that fusion was extended distally for coronal balance, and proximally to address proximal junctional kyphosis or because the proximal foundation implants had displaced posteriorly. The original growing-rod foundation sites were almost always surrounded by a solid local fusion, and were useful in the final fusion instrumentation plan. In many cases, the hooks or screws were exchanged for larger implants. The final fusion involves a relatively difficult spinal exposure: landmarks can be altered, there is a large amount of fibrous tissue, and the growing-rod instru-

mentation may be encased in bone. However, intraoperative blood loss is not much different from that in a typical posterior spinal fusion with segmental instrumentation. There were three neurologic events with no specific pattern related to diagnosis, surgical technique, or intraoperative neuromonitoring findings in our series. Many more patients need to be studied in order for us to comment on whether a final fusion following growing-rod management is inherently more risky than other surgical procedures used to correct spinal deformities.

Forty-seven patients (81%) who had a final procedure and whose operative record commented on spinal flexibility had some areas of autofusion, a stiff spine, or a completely fused spine. However, this series included some patients who were treated early and had an apical fusion at the time of the initial application of the growing-rod instrumentation, a treatment paradigm not routinely used today. This series also included several cases treated with a single growing rod, an instrumentation construct presumably far less rigid than the dual-rod constructs popular today. Both of these factors—the apical fusion and the variation in instrumentation—make it difficult to draw a strong conclusion on the autofusion effect of growing rods spanning the spine. In most cases, additional correction can be achieved at the final procedure, but aggressive facetectomies and osteotomies are necessary when the growing-rod instrumentation has been in place for several years. In general, the coronal curve magnitude can be corrected into a very acceptable range; however, substantial sagittal correction, especially of proximal kyphosis, was much less frequently achieved.

This study had important limitations. Because it was a retrospective study, we were unable to capture many important details, such as the precise reason for proceeding to the final fusion. We were also unable to analyze in more detail spinal flexibility or bone quality of the spine (i.e., weak, soft, friable, osteomalacic, osteopenic, etc.) at the time of final fusion. As is the case with so many studies of early-onset scoliosis, this study was hampered by the great variety of patient diagnoses, which including syndromes, neuromuscular deformities, and infantile idiopathic and congenital deformities. With so many subgroups, we cannot conclusively parse out distinctions among diagnoses, which would be very helpful for counseling families at the time of initial implantation. We can conclude from this first study of “growing-rod graduates” that the final fusion is usually performed in older children or during early adolescence; is similar, with regard to the number of levels involved, to the growing-rod instrumentation immediately prior to the final procedure; achieves correction in most cases; and has a reasonable complication profile compared with other fusion procedures for spinal deformity.

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