Dual Growing Rods for the Treatment of Early-Onset Scoliosis

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Introduction

The dual growing-rod technique involves implantation of a set of two rods and two anchor groups (upper and lower foundations) to exert frequent distractions to allow for spinal growth. Concepts and techniques for growth-sparing deformity correction in the immature spine have evolved substantially in the last decade. Surgical treatment for progressive early-onset scoliosis is patient-specific and deformity-specific, so it requires experience with multiple techniques for deformity correction and growth modulation. Treatment of scoliosis with non-fusion techniques in young patients was introduced in 1984 by Moe et al.¹. The results of two studies on this technique were later reported by Tello² and Klemme et al.³. The traditional dual-growing-rod technique was initially reported by Akbarnia and Marks in 2000⁴. Later, in 2005, they and colleagues reported the results of the use of dual growing rods for the treatment of progressive early-onset scoliosis in twenty-three patients, describing the details of this technique, which has gained widespread use⁵. Despite several modifications and improvements, the principles of the original technique remain the same. The decision regarding when to obtain final fusion is multifactorial, influenced by patient age, skeletal maturity, chest/pulmonary development, and duration of growing-rod treatment.

Correction of the deformity is partly achieved through the index surgery. Growth of the immature spine is then modulated by future spinal lengthening procedures to achieve as much spinal height as possible to provide the thoracic cage adequate space in which to develop. Final correction of the deformity is obtained by spinal arthrodesis and instrumentation when the patient reaches skeletal maturity.

The procedures consist of the following steps, which are presented both for the initial surgery and for the subsequent lengthening procedures:

Step 1 (Initial Surgery): Positioning

Pay special attention to the effect of positioning on sagittal alignment.

- After induction of general anesthesia and administration of appropriate antibiotics, place the child prone on chest rolls or on a Jackson table with the Hall-Relton frame, paying special attention to the effect of positioning on sagittal alignment.

Step 2 (Initial Surgery): Neuromonitoring

Use multimodality intraoperative neuromonitoring, including SSEPs, MEPs, EMG, and H-Reflexes.

- Abnormal neurophysiologic changes have been reported during primary growing-rod surgery (0.9%), growing-rod exchange (0.9%), and lengthening procedures (0.5%)⁶. The Scoliosis Research Society (2009 statement) considers multimodality intraoperative neuromonitoring as the preferred method for the early detection of an evolving or impending spinal cord deficit during surgical manipulation of the spine⁷. The use of intraoperative neuromonitoring in growing-rod lengthening is controversial despite case reports of neurophysiologic changes during lengthening procedures⁶, but we recommend using such monitoring.
- In order to have wide-spectrum neurologic surveillance, use multimodality intraoperative neuromonitoring including somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), electromyography (EMG), and Hoffmann reflexes (H-reflexes) in all growing-rod surgical procedures including primary sur-

gery, adjustment/revision, and all lengthening procedures.

- A relevant change prompting surgeon intervention includes a change in SSEP of >50% or any change in MEP from baseline.

Step 3 (Initial Surgery): Exposure (Figs. 1-A and 1-B)

Avoid broad exposure of uninstrumented levels to prevent the risk of spontaneous fusion.

- Prior to skin incision, use fluoroscopy to identify the levels at which to place the proximal and distal foundations.
- Make one straight 5 to 7-cm midline incision over the site of the proximal foundation.
- After incising the deep fascia, carry out subperiosteal dissection only at the levels to be fused. Take meticulous care of the facet joints and soft tissues at the other levels.
- Avoid broad exposure of uninstrumented levels to prevent the risk of spontaneous fusion.
- Repeat these steps at the distal foundation, leaving a long intact skin bridge between anchor sites.
- If one long midline skin incision is utilized, limit the subperiosteal dissection only to the foundation levels.

Step 4 (Initial Surgery): Preparation of Foundations (Figs. 1-A and 1-B)

The foundation is an assembly of at least four anchors at two or three vertebrae along with one or two rods.

- Select the foundation sites on the basis of the type and location of the scoliotic curve(s) as well as the patient's age and diagnosis. For example, patients with neuromuscular scoliosis require longer instrumentation than those with infantile idiopathic variants.
- A foundation is defined as an assembly of at least four anchors at two or three vertebrae along with one or two rods. This construct must be stable and strong enough to accept corrective loads and to resist deforming loads without dislodgment of the anchors.
- The proximal foundation generally involves placing anchors at T2-T4 with a hook construct in a claw fashion with a cross-connector (Figs. 1-C and 1-D) or bilateral pedicle screws across

one or two motion segments on the basis of the anatomy, bone quality, and age at surgery. Do not use the cross-connector when pedicle screws are used at the foundation.

Step 5 (Initial Surgery): Choosing the Anchors

Use hooks or pedicle screws for the proximal foundation and use bilateral pedicle screws (a four-anchor construct) for the distal foundation.

- Use hooks or pedicle screws for the proximal foundation.
- Critically review your anchor placement on fluoroscopic anteroposterior and lateral images.
- If you choose hooks for the proximal foundation, insert bilateral supralaminar hooks at the cephalad vertebra (e.g., T2) and bilateral sublaminar hooks at the caudad vertebra (e.g., T4) in a "claw" fashion (Fig. 2).
- The hooks can be staggered over two or three levels to avoid crowding the spinal canal and to decrease the stress at the cephalad foundation in an effort to avoid hook pull-out. Staggering hook levels may interfere with the use of a cross-connector at the foundation level, but whenever a four-hook construct is used, place a cross-connector to create a construct biomechanically equal to bilateral pedicle screws. It is crucial to build a stable foundation at the index surgery to reduce failure rates, even at the expense of exposing an additional level. Mahar et al. demonstrated the equivalence of an all-screw construct with the "claw" hook construct plus a cross-connector⁸. Furthermore, they found these two foundations to be superior to hooks alone and demonstrated the importance of adding a cross-connector if an all-hook construct is used.
- Use bilateral pedicle screws (a four-anchor construct) for the distal foundation.
- The distal foundation is typically two or three levels below the lower end vertebra of the major curve⁵. In the presence of pelvic obliquity, such as in neuromuscular scoliosis, the distal foundation may be extended to the sacrum or to the ilium with bilateral intra-ilium fixation; however, there is still debate about utilization of instrumentation to the pelvis in patients who can walk⁹.

Step 6 (Initial Surgery): Rod Contouring and Rod Assembly (Figs. 1-A and 1-B)

Cut two 4.5-mm rods and contour them to the appropriate sagittal and coronal alignment, being careful not to overcorrect in the sagittal and coronal planes.

- Use the skin surface to plan the rod contouring and the placement of the tandem connector. Mark the skin and the rods to avoid contouring the rod across the area of the tandem connector.
- Cut two 4.5-mm rods (stainless steel or titanium) and contour them to the appropriate sagittal and coronal alignment. Other rod sizes (e.g., 5.0 mm and 5.5 mm) have also been used with different systems and may be stronger; however, we prefer to keep these sizes for larger children or in the revision setting. Contouring will aid in deformity correction when the deformity is flexible.
- Be careful not to overcorrect in the sagittal and coronal planes, especially with rigid curves, to avoid anchor failure.

Step 7 (Initial Surgery): Tandem Connector Attachment

Place a tandem connector at the thoracolumbar junction to allow for future lengthening.

- Once the rods are contoured, cut them at the site where the planned lengthening will occur—i.e., cut the rods at the thoracolumbar junction (Fig. 1-B) and at the distal end of the tandem connector.
- As lengthening is usually performed by loosening the screw for the proximal rod, leave more room for that rod inside the connector.
- Do not contour the segments of the rod that will be inside the connector as that would prevent entry into the straight connector.
- Assemble the newly cut rod with the longest tandem connector feasible.
- Tighten the set screws to recreate a single rod.

Note: Set screws can be placed facing either medially or laterally. Turning the tandem connectors medially (with the set-screw heads facing medially) results in easier access to the screws and allows for minimally invasive access for subsequent lengthening procedures through a single mid-line incision.

Step 8 (Initial Surgery): Final Implant Assembly

Pass the preassembled rods and tandem connector from caudad to cephalad beneath the fascia, securing them to the foundation and performing the first lengthening.

- Pass the rods from distal to proximal and sub-fascially under the intact skin bridge. Beware of the sagittal orientation of the rod during this maneuver to avoid incidental thoracic penetration with forceful passage of the rod.
- Secure the rods to their respective proximal anchors, perform the final tightening of the set screws, and follow this by placing a cross-link when hooks are used.
- Do this BEFORE reducing the distal foundation. The idea is to create a solid proximal foundation that will distribute the load when the rods (and the spine) are reduced to their distal anchors. Implant-specific reduction tools are used to gently reduce the distal foundation.
- Perform an initial correction and lengthening at this point, being very careful not to overlengthen the spine on the first attempt. We recommend building the first lengthening into the rod (adding 5 mm of length to the rod). The first lengthening is then performed outside the tandem connector against the distal foundation.
- Pack the foundations, including the prepared facet joints and interlaminar and interspinous spaces, with locally obtained autograft.
- Augment the fusion with allograft and appropriate bone substitute if necessary.

Step 9 (Initial Surgery): Wound Closure

Gentle handling of the skin and associated deeper tissues is essential to avoid complications.

- As the child will undergo numerous surgical interventions through the same skin incisions, pay extra attention to this important step. Gentle handling of the skin and associated deeper tissues is essential to avoid complications.
- Close the fascia with number-1 Vicryl and the dermal layer with 2-0 Vicryl, use 3-0 Monocryl in a running subcuticular fashion, and apply DERMABOND to provide a layered barrier.
- After the DERMABOND dries, place a narrow strip of Telfa followed by a clear adhesive dressing.

- As many of these children have allergies, make sure to document if they had a previous reaction to suture or tape. The operative note should reflect if you deviated from this closure protocol, so that it can be referenced at the time of future surgery.

Note: Management of early-onset scoliosis with growth-modulating techniques such as growing rods demands that the surgeon be familiar with complex wound closure techniques such as the use of myocutaneous flap closure and the use of tissue expanders, which can be very helpful in the setting of tissue deficiency, infection, and myelomeningocele.

Steps 1 and 2 (Lengthening): Positioning and Neuromonitoring

These are the same as those for the initial surgery.

Step 3 (Lengthening): Exposure

Make one incision between the two connectors on or in line with the original incision.

- Palpate and mark the tandem connectors and upper set screws on the skin using fluoroscopy when necessary.
- Depending on the orientation of the set screws, make one incision between the two connectors on or in line with the original incision. The incision must be long enough to reach the set screws and accommodate a rod holder.
- Complete the exposure on both sides prior to lengthening. It is important to note that the size of the incision is not what makes this procedure less invasive. If a slightly larger incision results in gentler soft-tissue handling and less tissue damage then by definition it makes the procedure less invasive.

Step 4 (Lengthening): Lengthening Inside Versus Outside the Tandem Connector (Figs. 3-A, 3-B, and 3-C)

Lengthening can be performed inside or outside the tandem connector.

- In general, the side of the concave major curve is lengthened first unless there is an associated coronal imbalance to the contralateral side.

- If you choose to lengthen outside the tandem connector, loosen the convex set screw first and then redirect your attention to the concave side. Place a rod holder with enough room to allow the distractor to fit between the rod holder and the tandem connector.
- While maintaining the length with the distractor, loosen the set screw and lengthen the rod 5 to 10 mm.
- Tighten the set screw and repeat the process on the contralateral side. This technique is useful when the rods are too close to each other within the connector and the distractor will not fit or when the rods are too far away from each other.
- For lengthening inside the tandem connector, place the distractor in the tandem connector slot.
- While opening the distractor widely and holding it firmly against the rod tips, gently loosen the upper set screw.
- Obtain the desired length and then tighten the set screw again.
- Avoid excessive distraction force especially at the first lengthening, to prevent anchor and implant-related complications. A change in SSEP of >50% or any change in MEP from baseline warrants surgeon intervention.
- When the side-to-side connector is used, the rods can be lengthened by tightening the appropriate set screws of each connector and distracting between the connectors to distract the rods. Based on the two screws tightened, distraction or compression can be achieved using only distraction between two connectors.
- If the distance between the rods within the tandem connector is too great to accommodate the distractor, place a small free piece of rod within the connector to effectively reduce the distance between the rods for distraction and to avoid a larger skin incision or unnecessary skin retraction.
- The timing of lengthening is universally at six-month intervals.

Step 5 (Lengthening): Closure *See Step 9 for the initial surgery.* Postoperative Brace Application

- The patient is fitted with a custom thoracolumbosacral orthosis (TLSO), which is worn for six to twelve weeks after the initial growing-rod surgery (depending on the sur-

geon's preference) or until the fusion mass in the proximal and distal foundations is mature. Bracing after routine lengthening is unnecessary.

Results

The quantity and quality of research on growth-sparing techniques for early-onset scoliosis have increased substantially in the past three years. Simultaneously, there has been growing interest in clinical outcome measures as well as the impact of the spine and chest wall deformities on pulmonary development and function.

One of us (B.A.A.) and colleagues⁵ were the first to report, in 2005, the clinical outcomes following dual growing-rod surgery with a minimum two-year postoperative follow-up. An average of 6.6 lengthening procedures per patient, performed at 7.4-month intervals, resulted in the mean Cobb angle improving from 82° preoperatively to 38° after the initial surgery and 36° at the time of last follow-up (after the final fusion). T1-S1 length increased by a mean of 1.21 cm/yr. The complication rate was 48%. In 2008, one of us (B.A.A.) and colleagues reported on thirteen patients with no previous surgery and non-congenital curves who underwent dual growing-rod surgery and were followed to final fusion¹⁰. The average Cobb angle improved from 81° before the initial surgery to 36° postoperatively and 28° after final fusion. The patients underwent an average of 5.2 lengthening procedures at 9.4-month intervals. The average growth was 1.46 cm/yr, for a total of 5.7 ± 2.9 cm over 4.37 ± 2.4 years. A cohort of children with more frequent lengthening procedures (at intervals of six months or less) had a significant improvement in growth rate (1.8 cm/yr versus 1 cm/yr in the patients with less frequent lengthening procedures) and Cobb correction (79% versus 48%).

The results of a recent comparison of dual versus single-rod constructs by Thompson et al. convincingly favor dual growing rods¹¹. Although the overall complication rate was slightly higher (three of sixteen versus two of seven), the amount of initial correction obtained and final correction sustained as well as an improved growth rate and T1-S1 length made dual rods the more effective treatment. The presence of a second rod prevents the need for urgent revision when one rod breaks or undergoes plastic deformation. In the single-rod construct, a broken rod or implant complication is usually something that cannot wait until the next scheduled lengthening.

Sponseller et al. reported the outcomes associated with growing rods fixed to the pelvis¹². Among

the six patients with final fusion, the mean gain in T1-S1 length was 8.6 cm, of which 4 cm occurred during the lengthening period. Dual-rod iliac fixation provides a significant advantage over single-rod fixation for correction of coronal deformity (47% versus 25%) and pelvic obliquity (67% versus 44%). The authors concluded that pelvic fixation can be safely applied to a growing rod in cases in which distal fixation is appropriate. Dual iliac screws with a caudal cross-link provided the best outcome.

Sankar et al. studied spinal growth with serial lengthening procedures and concluded that there was a "law of diminishing returns."¹³ They reported that, after a mean of seven lengthening procedures, each subsequent lengthening resulted in a diminished amount of spinal (T1-S1) growth compared with expected growth. There was also a significant decrease in T1-S1 gain over time. This phenomenon may be due to autofusion of the spine resulting from prolonged immobilization. Myung et al.¹⁴ showed that, following treatment of early-onset scoliosis with growing-rod surgery, there was significant improvement in nutritional status in approximately 50% of patients, a finding similar to that reported with the VEPTR (Vertical Expandable Prosthetic Titanium Rib). They concluded that improved nutritional status may be an indirect indication of improvement in pulmonary function.

McElroy et al. reviewed the results of growing-rod treatment in twenty-four patients with cerebral palsy¹⁵. The mean Cobb angle was $85.8^\circ \pm 22.5^\circ$ preoperatively and $48.6^\circ \pm 21.2^\circ$ at the time of latest follow-up, yielding a mean curve correction of $42.8\% \pm 24.2\%$. Fusion was extended to the pelvis in eleven patients. T1-S1 height increased by 7.7 ± 0.4 cm over the average follow-up period of 53 ± 31 months. Complications from a total of 109 operations included two superficial wound infections, nine deep wound infections, two rod fractures, three anchor dislodgments, and one wound dehiscence. Seven patients underwent final fusion at mean age of 12.4 ± 3.6 years, and the final Cobb correction averaged $36.1\% \pm 30.7\%$. The authors concluded that growing rods are indicated for patients with cerebral palsy who develop severe early-onset scoliosis; however, the burden of care remains substantial. McElroy et al. also analyzed growing-rod treatment in fifteen patients with spinal muscular atrophy¹⁶. Their study showed that growing rods improved mean trunk height (T1-S1 growth of 8.7 ± 3.2 cm) and the average space-available-for-lung ratio (from 0.86 ± 0.15 preoperatively to 0.94 ± 0.21 at the time of follow-up) while controlling the curve (from $89^\circ \pm 19^\circ$ to $55^\circ \pm 17^\circ$) and pelvic obliquity (from $31^\circ \pm 14^\circ$ to $11^\circ \pm 10^\circ$). This form of treatment, however, did not halt rib collapse.

The outcomes of the growing-rod technique in 134 patients who had early-onset scoliosis with different etiologies were reviewed by one of us (B.A.A.) and colleagues to evaluate the effect of etiology on growing-rod treatment¹⁷. Patients with idiopathic scoliosis showed the greatest curve correction and the least loss of correction. Patients with congenital scoliosis had the least overall correction and the greatest loss of correction. Patients with idiopathic scoliosis had the greatest spinal growth, and those with congenital scoliosis had the least. The complication rate per surgical procedure and the implant-related complication rate were highest in the idiopathic group secondary to their level of activity and higher rate of operations.

In a recently published multicenter study of complications from growing-rod surgery, Bess et al. found that eighty-one (58%) of 140 patients with early-onset scoliosis had at least one complication¹⁸. The mean number of complications per patient was 2.2 (range, one to seven) and the mean complication rate per procedure was 20%. Implant-related problems and wound infection were the two major sources of complications. The authors demonstrated an increasing risk of wound complications with an increasing number of surgical procedures. With six procedures, the wound-complication-free rate was >95%. However, with eleven and thirteen procedures, the wound-complication-free rate decreased to 60% and 40%, respectively. The authors concluded that delaying the implantation of the growing rod, placing dual growing rods submuscularly, and limiting the number of lengthening procedures could reduce complications.

Yang et al. reviewed Growing Spine Study Group (GSSG) data and found that forty-nine of 327 patients had rod fractures¹⁹. Risk factors for rod fractures included prior fracture, use of a single rod, stainless-steel rods, small-diameter rods, proximity to tandem connectors, short tandem connectors, and preoperative walking, but neither the magnitude of preoperative scoliosis nor kyphosis was a risk factor for fracture. The length of instrumentation, anchor type, and pelvic fixation also had no significant effect on fracture rates.

Preliminary results of a non-invasive “magnetically controlled growing rod” (MCGR) in a small cohort of fourteen patients with early-onset scoliosis with different etiologies and a mean age of eight years and ten months showed the safety and efficacy of a remotely driven telescopic growing rod²⁰. All patients had one open index growing-rod surgery, and all of the distractions were achieved in an outpatient noninvasive setting. Through the mean follow-up period of ten months, the patients achieved a mean correction of 39% (from a preoperative Cobb angle of 57° to an-

gle of 35° at the time of latest follow-up). The mean monthly growth in thoracic (T1-T12) height was 0.5 mm in the single-rod group and 1.39 mm in the dual-rod group, which was comparable with the findings in previous studies.

What to Watch For

Indications

- “Potential” candidate: a child with documented progressive early-onset scoliosis (i.e., an initial diagnosis of early-onset scoliosis at the age of ten years or younger²¹) of any etiology with substantial growth potential.
- “Ideal” candidate: the above-described patient with no or minimal chest wall anomalies.
- An absolute Cobb angle of >35° to 40°; a rib-vertebral angle difference (RVAD), as defined by Mehta, of >20°; and rib-head phase II serve as red flags for imminent rapid progression rather than as a clear-cut indication for operative treatment of infantile idiopathic scoliosis.

Contraindications

- Minimal or no spinal growth potential is the main contraindication for the dual growing-rod technique.
- Severe rib-cage anomalies or multiple rib fusions that may need additional procedures (e.g., rib osteotomy) will benefit from rib-based growth-modulating techniques (e.g., VEPTR).

Pitfalls & Challenges

- Poor soft-tissue handling: This will deprive the soft tissue of its microvascular bed and increase the risk of wound complications and the need for unplanned surgery.
- Autofusion: Levels intended for growth must not be surgically exposed. A subperiosteal dissection will increase the risk of autofusion. Limiting this type of exposure to the foundations is essential to keep the spine growing.
- Foundation failure: Since the foundations serve as a fulcrum for exerting distraction forces, they have to be prepared with rigidly implanted anchors and a solid arthrodesis. The anchor selection should be hooks in a claw construct with a cross-connector or bilateral pedicle screws.
- Sagittal imbalance: Careful review of the sagittal profile of the spine is of utmost importance. Vigorous initial correction of the sagittal deformity can lead to implant failure and other

complications. We recommend gradual correction of the sagittal spinal deformity with subsequent lengthening procedures to avoid proximal and distal junctional problems. There is still a wide debate about the incidence and etiology of proximal junctional kyphosis after distraction-based techniques. Both technical and patient-related factors can play a role. In a few small studies, older age at the initial surgery, preoperative thoracic hyperkyphosis, and postoperative positive sagittal imbalance were found to be risk factors^{22,23}.

- **Overdistraction:** The average lengthening results in 5 to 10 mm of distraction. Overdistraction may lead to neural element traction and major neurologic complications. Ensure that neuromonitoring is present to detect a potentially reversible neurologic injury.
- **Unplanned revisions:** Rod breakage, implant failure, and deep infection can all lead to unplanned trips to the operating room. Dual growing rods may allow the surgeon to delay revisions until the time of the next lengthening.
- **Deep surgical site infection:** This is a serious complication. Early irrigation and debridement and culture-guided antimicrobial therapy are the mainstays of treatment. Irrigation and debridement should be appropriately repeated according to the patient's clinical and laboratory

response to treatment. Total removal of all implants is generally not advisable especially if the deep surgical site infection is diagnosed and appropriate treatment is started early. It is our common practice to retain at least one longitudinal implant (e.g., one rod and tandem connectors) to maintain the spinal height and curve correction achieved previously. Fifty percent of patients with deep surgical site infection who had total implant removal also had the growing-rod treatment terminated, whereas the termination rate was <33% with no or partial removal²⁴.

Clinical Comments

- Is there a role for remote lengthening to avoid serial open lengthening procedures every six months?
- Is there an ideal age at which to initiate distraction-based growing-rod constructs to avoid the law of diminishing returns?
- Does increasing thoracic height predict improvement in pulmonary function?
- Should the treatment or surgical approach differ on the basis of curve location or thoracic versus thoracolumbar/lumbar involvement?

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Figures

Fig. 1-A

Schematic posterior view of dual growing-rod instrumentation. Note that subperiosteal exposure is performed only at the foundation sites and both rods are passed subfascially after contouring and assembly of the tandem connectors.

Fig. 1-B

Schematic lateral view of dual growing-rod instrumentation with pedicle screws at both the upper and the lower foundation. Note the location of the tandem connectors at the thoracolumbar junction and the rod contour in the sagittal plane.

Fig. 1-C

Close-up of the upper foundation site consisting of bilateral supralaminar and infralaminar hooks in a claw construct.

Fig. 1-D

Close-up of the lateral view of the upper foundation site consisting of supralaminar and infralaminar hooks.

Fig. 2

Clockwise rotation of the hook holder to insert the infralaminar and supralaminar hooks.

Fig. 3-A

Lengthening of the dual growing rods from within the tandem connector.

Fig. 3-B

Lengthening performed cephalad to and outside of the tandem connector.

Fig. 3-C

Lengthening of the growing rods connected with side-to-side connectors (wedding band) on either side of the spine. The distractor is placed between cephalad and caudad wedding bands.

Fig. 1-A

Fig. 1-B

Fig. 1-C

Fig. 1-D

Fig. 2

Fig. 3-A

Fig. 3-B

Fig. 3-C