

# Early onset scoliosis: current concepts and controversies

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**Abstract** Early Onset Scoliosis (EOS) may be associated with long-term pulmonary morbidity, which is not commonly seen in Adolescent Idiopathic Scoliosis. Initial evaluation is based on determining any underlying etiology related to congenital or syndromic conditions. Assessing the impact of scoliosis on thoracic development may help guide treatment, which is often required at a young age in these children to prevent irreversible pulmonary insufficiency. Treatment is based on multiple factors but may include non-surgical strategies, such as casting or bracing, along with growth-sparing surgical procedures using growing rods or chest wall expansion. Definitive fusion is rarely indicated in young patients. This chapter will cover the diagnosis, evaluation, and treatment of children with EOS.

**Keywords** Scoliosis · Early onset scoliosis · Thoracic insufficiency syndrome · Infantile scoliosis · Juvenile scoliosis · Bracing · Serial casting · Mehta casting · Risser casting · Growing rods · VEPTR · Expansion thoracoplasty · Pediatrics

## Introduction

The Scoliosis Research Society has classified idiopathic scoliosis in infants and children based on age of onset. This classification has been criticized for focusing on the spinal

deformity and age of diagnosis rather than the physiological effect on the patient. Dickson is responsible for the term “early onset scoliosis” (EOS), which not only includes idiopathic scoliosis in the child younger than 5 years of age, but also those children with neuromuscular, congenital, or syndromic scoliosis [1]. This designation places more emphasis on the patient’s physiological development and less on the curve magnitude or etiology. This review will cover the impact of EOS, its diagnosis, and treatment options including outcomes.

## Physiology of EOS

Spinal development is closely linked to both intraparenchymal and extraparenchymal pulmonary growth. Lung compliance, lung volumes, and alveolar growth may all be affected by the development of spinal deformity. Lung compliance is greatest at birth due to the cartilaginous makeup of the thoracic cage and underdevelopment of the chest wall musculature. Compliance decreases with time but is particularly depressed by external compression related to spinal or thoracic cage deformity. As lung compliance diminishes, children with severe scoliosis may have increased work of breathing and an elevated respiratory rate due to an inability to generate adequate tidal volumes during normal respiration [2]. Low lung volumes can lower pulmonary compliance and increase pulmonary resistance above levels seen with normal lung volumes. Thoracic deformity related to scoliosis may limit lung volumes, which in turn may decrease pulmonary compliance [3]. Alveolar growth in the postnatal period is linked to the growth of the child and the thorax as alveolar development is primarily peripheral in the distal aspects of the pulmonary tree. Processes that impair lung volume growth therefore inhibit alveolar development

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[4]. The process whereby neither respiratory function nor pulmonary development is supported by the thorax has been deemed Thoracic Insufficiency Syndrome (TIS) by Campbell and colleagues [5].

## Patient evaluation

### History

A careful history and physical examination is paramount to arrive at an appropriate treatment for patients with EOS. Scoliosis and thoracic insufficiency may have a profound impact on patient quality of life (QOL), with children with EOS having QOL similar to children with severe asthma or cardiac disease [6, 7]. Patient evaluation should begin with a careful birth history focusing on prenatal and perinatal complications, time spent in an intensive care setting, and hospitalizations for pulmonary issues. One should seek to understand the initial discovery of the curvature and any apparent progression noted by the parents. Since many children with EOS have associated comorbidities such as neuromuscular, dysplastic, or syndromic conditions, these comorbidities must be characterized as well.

### Physical examination

An assessment of the general health and vigor of the patient gives an early understanding of the overall effect of the disease process. Patients with EOS may range in function from essentially normal to severely cachectic requiring ventilator support. Respiratory rate is a good indicator of work of breathing. Physical examination of the lungs begins with a careful pulmonary examination focusing on air movement within each hemithorax. One should look for any associated wheezing, areas of absent air flow, or cardiac murmurs that may be related to underlying diminished pulmonary function seen later in the disease course. For the surgeon who is not as used to pulmonary auscultation, evaluation of pulmonary reserve may be performed by noting the maximum expiratory force when having the child blow on the examiner's finger as if trying to blow out a candle. The thumb excursion test evaluates the contribution of each hemithorax to rib expansion. Here, the examiner places his hands around the axillary region with the thumbs pointing towards the midline and proximally on either side of the spine. As the child breathes, the examiner's thumbs will move away from the midline. The amount of excursion may be graded from +3, when more than 1 cm is achievable, down to a score of 0, when no movement is appreciated. Finally, the use of accessory muscles, such as the strap muscles of the neck or the diaphragm, should be evaluated by looking for the "marionette" sign, retractions, or other signs of increased work of breathing.

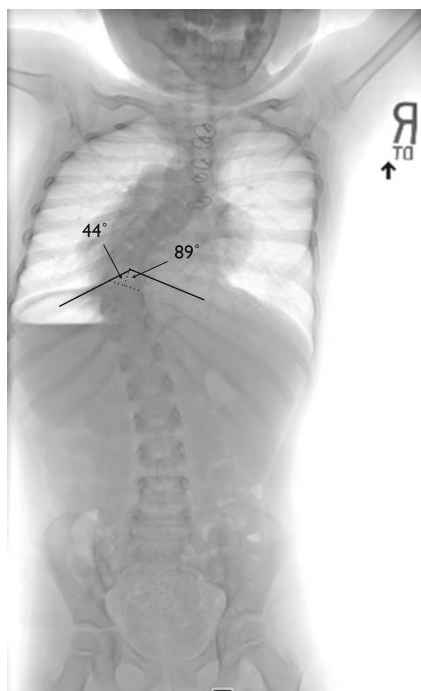
### Laboratory studies

Laboratory studies in the child with EOS are directed at evaluating the effect of the scoliosis on pulmonary function. Assessment of oxygenation may be measured directly using pulse oximetry or arterial blood gas. Oxygenation can also be measured indirectly through the hemoglobin or hematocrit levels, and serial blood draws may be beneficial to evaluate trends [8]. Pulmonary function tests may be used in children starting around the age of five as these require compliance on the part of the patient and thus are not feasible in very young children or those with developmental delays. Other techniques to evaluate total lung capacity, including total body plethysmograph or gas dilution techniques, require the assistance of an experienced pulmonary colleague. Sleep studies have been found to be very helpful in children with TIS as sleep apnea has been found in as much as 92% of children with TIS [2, 9].

### Radiographic evaluation

Radiographic examination should begin with a standard posteroanterior (PA) and lateral examination of the entire spine and thorax. Weight-bearing upright views should be used to evaluate the effect of gravity on the spinal curve whenever possible. Measurement of the Cobb angle is performed to determine the magnitude of the spinal deformity [10]. Assessment of the thoracic deformity includes an indirect determination of lung capacity. The space available for the lung (SAL) is a ratio of heights between the two hemithoraces, providing an idea as to the relative restriction of pulmonary growth imparted by the chest [5]. Both thoracic width and thoracic height, measured from T1 to T12, may be followed longitudinally to determine a trendline during management. Treatment decision should be tailored to minimize complications while maximizing thoracic height, as children with T1-T12 height of 22 cm or more may have normal pulmonary function [11]. Comparison to the width of the pelvic inlet, which does not vary significantly with pelvic tilt, may be used to evaluate growth over time. Assessment of the Risser sign and the extent, if any, of fusion at the triradiate cartilage indicates remaining spinal growth.

Mehta initially described the Rib Vertebral Angle Difference (RVAD) as a way to predict curve progression in children with infantile idiopathic scoliosis (Fig. 1). This measurement is performed by drawing a line perpendicular to the endplate of the most translated apical vertebrae and then a line down the concave and convex rib at this same level. The angle created on the convexity is then subtracted from that on the concavity to create the RVAD. Mehta found that scoliosis will resolve in 90% of children with a RVAD less than 20° while scoliosis is less likely to resolve when the RVAD is greater than 20°. While RVAD has not been



**Fig. 1** Rib Vertebral Angle Difference (RVAD). The rib vertebral angle measures the angle formed by a line perpendicular to the endplate of the most apically translated vertebrae and a line drawn down the middle of the concave and convex ribs. The RVAD is the difference between these angles. In the example above, this is 45°. The overlap of the rib heads and the lateral border of the vertebral body indicates significant rotation and a phase II rib

validated in non-infantile EOS, it continues to be used as an indicator of curve severity and progression of deformity. The rib head phase may be used as an adjunct to the RVAD in determining curve progression. The rib phase is determined by the relationship of the rib head and vertebral body at the apex of the curve with overlapping of the vertebral body and the rib head predicting curve progression [12, 13].

In addition to routine two-dimensional orthogonal imaging, computed tomography (CT) and magnetic resonance imaging (MRI) may be helpful in assessing the impact of the deformity on chest development. While each provides unique information that can be invaluable in evaluation of the spinal deformity, there are drawbacks to each. CT scans give unparalleled detail of the spine as well as the thoracic cage and lung, and they continue to play an important role in preoperatively evaluating congenital curves or curves with complex anatomy at the expense of a high radiation load. Low dose radiation protocols should be used whenever possible and may reduce the radiation exposure by 20-fold or more [14]. Three-dimensional reconstructions have been utilized to analyze lung volumes in patients with thoracic insufficiency and provide a comparison to age matched normals. If obtained in a longitudinal fashion, the response to treatment may also be documented [15, 16]. MRI evaluations avoid the risk of radiation exposure and provide extraordinary soft tissue

details, but they are poor at delineating bony anatomy and often require sedation or general anesthesia due to the time required to obtain these studies. If surgical care is anticipated, however, preoperative MRI of the entire spinal column should be obtained on all patients with EOS as approximately 20% of these children will have an underlying intraspinal anomaly [17–21]. Future applications of MRI include functional MRI and dynamic MRI, both of which may provide real-time understanding of lung function and the impact of thoracic deformity on the lung [22, 23].

## Treatment

### Historical perspective

Traditional management of EOS included both nonoperative and operative techniques. Prior to modern derotational casting techniques, a variety of translational and turnbuckle casting was performed in addition to bracing in an attempt to delay surgery. Surgical treatment often involved early limited, or sometimes more extensive, spinal fusion, which has been linked to the development of thoracic insufficiency. Karol and colleagues found a higher rate of restrictive lung disease in children treated at an average age of 3.3 years with fusion for progressive scoliosis, with 12 of 28 patients having <50% forced vital capacity when compared to age matched normals [11]. Goldberg and others also showed forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) averaging 41% of predicted values in a cohort of adults who had been treated surgically at a mean age of 4.1 years. Patients in whom surgery was delayed until age 10 had a FEV1 of 79%. Furthermore, the deformity was found to recur after early definitive surgery [24]. With the advent of improved growing spine instrumentation techniques and a resurgence of casting as a delay tactic, definitive fusion for non-congenital scoliosis is now performed infrequently in young children with EOS (Table 1).

### Nonoperative techniques

Initial treatment for patients with EOS is nonoperative if at all possible, with patients being placed in a brace or cast in order to prevent or delay the need for surgical intervention. Bracing has been a traditional treatment for EOS, although the success in preventing spinal curve progression in this patient population has been variable. No studies have evaluated bracing children with EOS. The physician, orthotist, and family should not take orthotic management lightly as the goals, expectations, and potential complications of bracing are different and may be more significant than those in older patients. Since a brace functions predominantly to stabilize rather than reverse the deformity, bracing is much

**Table 1** Comparison of treatment options used in early onset scoliosis

Treatment	Advantages	Disadvantages
Serial casting	<ol style="list-style-type: none"> <li>1. Non-surgical</li> <li>2. Not removable</li> <li>3. Allows spinal derotation</li> <li>4. May cure smaller idiopathic curve</li> </ol>	<ol style="list-style-type: none"> <li>1. May be associated with skin complications</li> <li>2. Not removable</li> <li>3. May require prolonged treatment to produce a cure</li> <li>4. Possibility of chest wall deformity related to cast application</li> </ol>
Bracing	<ol style="list-style-type: none"> <li>1. Allows curve stabilization</li> <li>2. Removable</li> <li>3. Better tolerated in most settings than a cast</li> </ol>	<ol style="list-style-type: none"> <li>1. Cannot cure scoliosis</li> <li>2. Removable—Difficulty to maintain compliance over long treatment periods</li> </ol>
Growing rods	<ol style="list-style-type: none"> <li>1. Does not require spinal fusion</li> <li>2. Allows spinal and thoracic growth</li> <li>3. May provide curve correction</li> </ol>	<ol style="list-style-type: none"> <li>1. Implant and wound problems common</li> <li>2. May result in autofusion of spine with a decrease in incremental spinal growth after multiple lengthenings</li> <li>3. Does not allow control of complex chest wall deformity</li> </ol>
Vertical Expandable Prosthetic Titanium Rib (VEPTR) ®	<ol style="list-style-type: none"> <li>1. Implants placed away from spine in many instances, limiting risk of autofusion</li> <li>2. Allows control of chest wall deformity and spinal deformity</li> <li>3. Promotes chest and spinal growth with lengthenings</li> <li>4. May be used to stabilize congenital curvature without spinal fusion</li> </ol>	<ol style="list-style-type: none"> <li>1. Incisions often placed away from midline, resulting in multiple scars</li> <li>2. Implant migration, fracture, and wound complications frequently seen</li> <li>3. Fixation to the ilium may result in abnormal gait</li> <li>4. Thoracic cage compliance may decrease with device expansion</li> </ol>

less likely to result in permanent correction of spinal curvature than serial casting in patients with infantile idiopathic scoliosis. The authors feel that casting should be used in this population whenever possible in an attempt to correct the deformity. Bracing is more commonly used in older patients with larger curves that would not be expected to correct with casting. Bracing is indicated in patients with progressive scoliosis, those who do not tolerate or could not tolerate casting, and those who are unable to undergo surgical management for medical or other reasons. A trained orthotist is absolutely necessary, as significant chest wall deformity is a documented risk when overzealous correction is attempted in the setting of a pliable thorax [25].

Serial casting has seen a resurgence as the complications associated with growing rod and VEPTR treatment have become better appreciated. Nonetheless, the literature supporting derotational casting in non-idiopathic infantile scoliosis is limited at this time. Elongation Derotation Flexion (EDF) casting has been shown to be curative in patients less than 17 months of age with smaller curvatures [26]. While some centers have reported curative casting in older children and those with larger curves, bracing after the age of two is often part of a delay tactic devised to put off surgery as long as possible rather than a curative treatment. This is particularly important given the “law of diminishing returns” noted by Sankar et al. whereby a steady decrease in spinal length is

obtained with each subsequent lengthening using growing rods [27•]. Sanders and D’Astou have shown good results with casting as a delay tactic in a large series of children with EOS [28]. Fletcher et al. found an average of a 3 year delay until surgery in patients with moderate-to-severe EOS characterized by age greater than 2.5 years and curves larger than 50°. At the five-year follow-up, 75% of patients had either undergone definitive surgery (25%) or had been converted to brace therapy (50%). Complications with serial casting occur infrequently but include skin irritation, sores, nausea or vomiting, and parental dissatisfaction. Nonetheless, the use of a cast as a “permanent” and, perhaps more importantly, non-removable brace is appealing to many physicians as brace compliance is difficult to maintain over an extended period [29]. Physicians should not undertake EDF casting without appropriate training as this technique requires a specially designed table and significant and irreversible chest wall deformity may occur if done incorrectly.

### Growing spine techniques

#### Growing rods

The concept of a rod that is lengthened at regular intervals after initial implantation is not new as Harrington, Luque,



and Moe all contributed early proof-of-concept over 25 years ago [30–33]. Current growing rod techniques combine the principle of fusionless surgery to control curve magnitude while achieving spinal growth using modern implant systems. Akbarnia and Marks published their results of submuscular dual-growing rods in the management of progressive scoliosis in 2000, and enormous advances have occurred since then [34]. This technique employs short segments of spinal fusion at the proximal and distal aspects of the involved curve using a combination of hooks or screws. These areas are then linked with a rod passed in an extrapariosteal but submuscular manner. Through the use of a tandem or side-to-side connectors, the rods can then be lengthened through a small incision every 6 months until definitive fusion is needed.

Growing rods have revolutionized the treatment of EOS. Previously, children were observed while their curves either progressed despite bracing or fused with the resultant short spine and thoracic hypoplasia [11]. Akbarnia has reported the results of a multicenter study of 23 patients with 2 year follow-up. Initial surgery was at 5 years 5 months of age with an average of 6.6 lengthenings. Curve magnitude decreased from 82° to 38° at initial surgery with no significant loss of correction over time. Spinal growth averaged 1.21 cm per year with similar improvements in the space available for the lung. Eleven of twenty-three patients suffered a complication during treatment [32]. Thompson et al. also found that dual rods resulted in fewer complications and provided better correction due to the increased rigidity in the system when compared to single rods [35].

Despite the apparent successes with this technique, significant obstacles still limit its overall effectiveness in managing scoliosis in the very small or young child. The implant load is often not tolerated in young children as the screws and hooks are proportionally large in this population. Thin body habitus or malnourishment often results in poor implant coverage, and the repeated lengthenings increase the risk of skin problems and infection. Families often become disillusioned with the process and may resist the need for repetitive surgical interventions. Bess et al. reviewed complications on 910 growing surgeries and found the risk of complications per surgery to be roughly 20%, although using submuscular versus subcutaneous and dual rod as opposed to single rod systems decreased this complication rate [36]. Perhaps more concerning is evidence provided by Sankar et al. who demonstrated a “law of diminishing returns” that crescendos after seven lengthenings due to autofusion and spinal noncompliance [27•]. Nordeen et al. similarly found that the force required to distract the spine doubles by the fifth lengthening procedure with less than 8 mm of spinal growth achieved with each lengthening after this point. Distraction forces were 40% higher in patients

with apical fusions in addition to growing rods [37•]. Children who undergo implantation at 3 or 4 years of age may therefore reach the limits of growing rod surgery within 2.5–3.5 years and prior to sufficient thoracic and pulmonary development.

The authors tend to favor the use of growing rods in older juvenile children (5–8 years of age) with curves greater than 60° where the primary deformity is spinal with limited pulmonary compromise [38]. Bess and colleagues noted that complications were decreased by 13% with each year that surgery was delayed [36]. Proximal and distal fusion blocks, including a minimum of four points of fixation, are recommended in all children, and hybrid spine-to-rib techniques may be used to decrease proximal hardware failure [39]. Pedicle screws are used for distal fixation; hook-claw or nonconvergent pedicle screw constructs are used proximally to limit the possibility of posterior pull-off and spinal cord injury. Careful preoperative evaluation of the sagittal profile is paramount to minimize complications related to excessive kyphosis, however, proximal junctional issues continue to be problematic even with proper surgical techniques [40, 41]. Lengthenings are performed every 6 months through a small midline incision over the tandem connector [38].

#### Expansion thoracoplasty using the Vertical Expandable Prosthetic Titanium Rib (VEPTR®)

The pulmonary implications of spinal deformity, and vice versa, have been increasingly well elucidated over the past decade since Thoracic Insufficiency Syndrome (TIS) was first characterized [5]. Campbell initially described expansion thoracoplasty in 2003 for TIS in skeletally immature patients. However, the indications have continued to evolve to include patients with absent ribs, thoracic constriction related to rib fusions, thoracic hypoplasia, and progressive scoliosis [42]. The VEPTR® is produced by Synthes Spine Company of West Chester, PA and is available under the FDA Humanitarian Device Exemption with Institutional Review Board approval.

VEPTR® offers control of the thoracic component of spinal deformity, a feature which has not been present in traditional spine based implants. In complex chest wall pathology such as that seen in multiple rib fusions, absent ribs, or thoracic hypoplasia, the chest wall can be reconstructed and then supported by a vertical expandable implant [43]. Expansion thoracoplasty also offers the ability to control the spinal deformity in severe scoliosis with pulmonary hypoplasia by producing a seemingly more biomechanically sound lateral expansive force on the ribs, thus increasing the functional lever arm of the corrective implant. VEPTR® with expansion thoracoplasty can also permit growth across a unilateral bar in the setting of congenital

scoliosis, although its use in children with stiff congenital scoliosis is still limited [42]. Another benefit of the VEPTR® system is the manner in which it can be implanted with minimal direct impact on the spine.

Surgical indications for use of chest expansion have expanded as the use of VEPTR® has become more widespread. As such, it is often difficult to compare results or apply specific principles across patient groups. Campbell has attempted to classify the various types of volume depletion deformities (VDD) based on etiology, with subsequent treatment strategies based on the type of deformity [44]. Vitale and colleagues surveyed members of the Chest Wall Study Group and found a wide range of opinions regarding indications for use of VEPTR® versus growing rods [45].

The use of VEPTR® is perhaps best supported in conditions such as scoliosis with multiple rib fusions, absent ribs, or severe thoracic hypoplasia, which were all previously associated with a high risk of early mortality and otherwise not amenable to more traditional bracing, casting, or even growing rod techniques. Campbell and others reported on 27 patients treated with VEPTR® opening wedge thoracoplasty who were followed for an average of 5.7 years. Curve correction improved by 25°, and the space available for the lung increased from 63% to 80%. Complications included 1.9% having infections, 15% having skin sloughing requiring rotational flaps, two patients having brachial plexopathy, and one patient dying of early post operative pneumonia. It was also noted that early intervention in this population was crucial when evaluating long-term pulmonary outcomes. Patients operated on before the age of two had a vital capacity of 58% at follow-up compared with 44% in those operated on after the age of two [42]. Using CT scans to follow pulmonary development prospectively, Emans et al. also studied 31 patients who had fused ribs and scoliosis that had caused TIS. Spinal growth, pulmonary function, and lung volumes all improved using VEPTR® expansion thoracoplasty [46]. VEPTR® use in myelomeningocele has also been supported, both for neuromuscular scoliosis and distal kyphosis (gibbus) deformity [47–49]. Perhaps the most controversial use of VEPTR® continues to be in the setting of purely idiopathic scoliosis, particularly with associated kyphosis. Proponents of its use in this setting note the positive impact on pulmonary growth as measured by space available for the lung and a lower complication rate than in sicker patient populations [50]. Critics have noted that early implantation in healthy children may lead to decreased chest compliance as the thoracic cage stiffens. Others have noted the high level of complications seen in some series and continue to emphasize the need for delayed surgery in an attempt to minimize the number of procedures [29]. The use of VEPTR® in kyphoscoliosis has also been fraught with complications as proximal junctional

kyphosis often develops and proves extremely difficult to treat. Use of hybrid systems with proximal up-going rib hooks or proximal fixation on the second rib may prove to be more suitable in this situation [39, 49–51]. Future research is still required to define the use of chest wall procedures in this patient population.

The clinical benefits anticipated following chest wall expansion have been surprisingly difficult to characterize due to the difficulty in accurately measuring pulmonary function in small children. Surrogate markers for improved oxygenation and less energy expenditure, such as a normalization in preoperatively elevated hemoglobin [8], improvement in weight [52], or change in chest wall anatomy on CT scans [46] after chest wall expansion, have been described. However, direct measures of pulmonary function improvement after chest wall expansion have been lacking. Furthermore, no evidence exists to suggest that straightening of the spine through chest wall expansion as measured using the Cobb angle results in real improvements in pulmonary function [53•]. Mayer and colleagues have shown that early changes in pulmonary function after chest wall expansion may be related to stretching of the lung and an increase in residual volume rather than allowing the lung to grow into the chest cavity and increase FVC [54].

The authors favor the use of extra-spinal expansion thoracoplasty in the young patient (<5 years old) so as to minimize autofusion of the spine at this young age and allow for prolonged spinal expansion. Careful surgical technique is required during implantation to avoid periosteal stripping of ribs not involved in proximal rib fixation, thereby minimizing rib autofusion. This is often a problem seen in the setting of congenital rib fusions reconstructed with rib lysis. Surgeons must also take future spinal surgeries into account when planning skin incisions. VEPTR® implantation may be performed in either the lateral position, when a thoracostomy is planned [55], or the prone position when used for rib-to-spine or rib-to-pelvis fixation in the setting of neuromuscular scoliosis with-or-without pelvic obliquity [56].

### Alternative techniques and future directions

Patients and physicians continue to seek surgical options that do not require regular lengthening procedures. Guided growth techniques include traditional hemiepiphysiodesis, spinal tethers, Shilla, and self-expanding rods. Convex hemiepiphysiodesis, commonly used for multilevel congenital deformities, is a safe but somewhat unpredictable method of “guiding” spinal growth. The concept of hemiepiphysiodesis is to arrest spinal growth on the convexity of the curve, allowing the concave side to grow and slowly straighten the

spine. Hemiepiphysiodesis has somewhat fallen out of favor due in part to the inability to predict curve correction and the development of other techniques. Hemivertebrectomy is a more predictable method of curve correction, although the neurologic risk is higher than that seen with hemiepiphysiodesis [57–59]. Betz and others have reported on the use of vertebral body stapling to guide growth, borrowing from the principle of temporary hemiepiphysiodesis used in long bone deformity. This technique has been successful at reversing deformity in flexible curves measuring 25–35°, however, spinal response remains somewhat unpredictable, and the long-term impact on the instrumented disc spaces is unknown. Stapling may represent an alternative to bracing in certain situations. Guided growth using a flexible spinal tether is another option whose efficacy has been shown in animal models [60–66]. It appears that some type of tether or staple-based deformity correction will have a place in the management of early onset scoliosis.

One of the classic guided growth techniques, the Luque trolley, has been updated using modern pedicle screw fixation by McCarthy in the Shilla method [30, 67, 68]. Shilla utilizes an apical fusion with non-locking polyaxial screws proximally and distally to guide a rod that is purposefully left long to minimize the need for subsequent surgery. As spinal growth occurs, the rod slides through the non-locking screws. This technique has not met FDA approval, but the originators hope to seek approval in the near future. Early results with this technique have been very promising [69, 70]. Externally controlled expandable devices, including implantable magnetically controlled growing rods, represent perhaps one of the most exciting future prospects but are currently unavailable in the United States [71].

## Conclusions

Early onset scoliosis continues to present a formidable challenge to physicians as the potential for long-term morbidity warrants early intervention in many cases. Multidisciplinary coordination is often required to develop an understanding of the patient's condition. Early treatment may be required in those children with progressive curves or evidence of thoracic insufficiency syndrome. Non-surgical options, including bracing and serial casting, may be used to “buy time” before surgical intervention is undertaken. Casting may have the potential to treat these conditions definitively in very young children. Definitive fusion for EOS is rarely indicated other than in those children who are near skeletal maturity and have adequate pulmonary development. Growing spine techniques including growing rods

and VEPTR® allow continued growth of the spine but require multiple lengthenings and carry a reasonably high risk of complications. Future options may include fusionless techniques that do not require multiple surgical lengthenings.

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