When Is a Growth-friendly Strategy Warranted? A Matched Comparison of Growing Rods Versus Primary Posterior Spinal Fusion in Juveniles With Early-onset Scoliosis

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Background: In 7 to 11-year-old juveniles with severe early-onset scoliosis (EOS) the optimal surgical option remains uncertain. This study compares growing rods (GRs) followed by definitive posterior spinal fusion (PSF) versus primary PSF in this population. We hypothesized that the thoracic height afforded by GRs would be offset by increased rigidity, more complications, and more operations.

Methods: This retrospective comparative study included EOS patients aged 7.0 to 11.9 years at index surgery treated with GR→PSF or primary PSF during 2013 to 2020. Primary outcomes were thoracic height gain (ΔT1-12H), major curve, complications, and total operations. Primary PSFs were matched with replacement 1-to-n to GR→PSFs by age at index, etiology, and major curve.

Results: Twenty-eight GR→PSFs met criteria: 19 magnetically controlled GRs and 9 traditional GRs. Three magnetically controlled GRs were definitively explanted without PSF due to complications. The remaining 25 GR→PSFs were matched to 17 primary PSFs with 100% etiology match, mean Δ major curve 1 degree, and mean Δ age at index 0.5 years (PSFs older). Median ΔT1-12H pre-GR to post-PSF was 4.7 cm with median deformity correction of 37%. Median ΔT1-12H among primary PSFs was 1.9 cm with median deformity correction of 62%. GR→PSFs had mean 1.8 complications and 3.4 operations. Primary PSFs had mean 0.5 complications and 1.3 operations. Matched analysis showed adjusted mean differences of 2.3 cm greater ΔT1-12H among GR→PSFs than their matched primary PSFs, with 25% less overall coronal deformity correction, 1.2 additional complications, and 2.2 additional operations per patient.

Conclusions: In juveniles aged 7 to 11 with EOS, on average GRs afford 2 cm of thoracic height over primary PSF at the cost of poorer deformity correction and additional complications and operations. Primary PSF affords an average of 2 cm of thoracic height gain; if an additional 2 cm will be impactful then GRs should be considered. However, in most juveniles the height gained may not warrant the iatrogenic stiffness, complications, and additional operations. Surgeons and families should weigh these benefits and harms when choosing a treatment plan.

Level of Evidence: Level III—retrospective comparative study.

Key Words: early onset scoliosis, growing rods, magnetically controlled growing rods (MCGRs), posterior spinal fusion

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For patients with early-onset scoliosis (EOS) in whom nonoperative treatments fail, all surgical options have limitations, and experts seldom agree on the best treatment plan.[1,2] Traditional and magnetically controlled growing rods (TGRs and MCGRs) afford some correction and avoidance of progression while allowing growth. Unfortunately, their use can be fraught with numerous, often severe complications (Supplemental Fig. 1, Supplemental Digital Content 1, http://links.lww.com/BPO/A408).[3] MCGRs may also cause titanium metallosis.[4,5] Primary posterior spinal fusion (PSF) in young patients may limit thoracic growth and pulmonary development and allow the crankshaft phenomenon,[6] although this is less common with modern 3-column instrumentation.[7–9] Previous matched cohort studies have included only 1 etiology of EOS and have included relatively few GRs.[10–12] This study compares growing rods (GRs) followed by definitive PSF (GR→PSF) versus primary PSF in juveniles aged 7 to 11 years old with EOS. Groups were matched for age, etiology, and major curve, and outcomes included thoracic height increase, deformity correction, complications, and total and unplanned operations.

METHODS

This retrospective comparative cohort study included all EOS patients aged 7.0 to 11.9 years at index surgery treated with GRs followed by definitive management with primary PSF. This study was approved by the local Institutional Review Board. We used Current Procedural Terminology codes to identify all patients treated with GRs or primary PSF at the authors' institution between January 1, 2013 and March 31, 2020. It is routine at this institution to perform segmental posterior instrumentation and fusion when GR treatment is complete. We reviewed all patients who had completed GR treatment, and excluded those with GRs still in place on March 31, 2020 with no plan for revision PSF.

Primary PSFs were matched using optimal matching with replacement 1-to-n to GR→PSFs by age at index (adjusted for skeletal age if abnormal), etiology, and major curve. Matching with replacement up to 1-to-3 maximized match quality without allowing undue statistical influence of any individual (Supplemental Fig. 2, Supplemental Digital Content 1, http://links.lww.com/BPO/A408). Preindex parameters were compared using standardized absolute mean differences.[13]

Primary outcomes were thoracic height gain (ΔT1-12H), coronal deformity (major curve), complications,[14] and total and unplanned operations. Other outcomes included kyphosis and coronal spine length (CSL)/sagittal spine length (SSL).[15] Radiographic outcomes in the primary PSF group were measured (1) pre-PSF and (2) post-PSF. In the GR→PSF group, outcomes were measured (1) pre-GR, (2) post-GR implantation, (3) post-growth phase/pre-PSF, and (4) post-PSF.

We used a linear mixed effects model to adjust for dependency introduced by 1-to-n matching and for remaining age differences between matched pairs. Multivariate logistic regression was performed to identify possible predictors of T1-12H increase from GR→PSF versus primary PSF.

RESULTS

Current Procedural Terminology code search returned 45 patients treated with GRs implanted when they were 7.0 to 11.9 years of age and 60 primary PSFs in this age group. Twenty-eight patients with GRs (19 with MCGRs, 9 with TGRs) were determined to have completed GR treatment. Three MCGRs were definitively explanted due to complications and family and surgeon elected to forego PSF; all subsequently developed deformities >100 degrees (Supplemental Fig. 3, Supplemental Digital Content 1, http://links.lww.com/BPO/A408). These were excluded from matched analysis as it was felt they would significantly limit meaningful comparison of groups. The remaining 25 GRs who had undergone GR removal with revision PSF compose the GR→PSF cohort. Seventeen primary PSFs met optimal matching criteria and were selected for analysis. Optimal matching with replacement yielded 3 PSFs who were matched in triplicate and 2 PSFs matched in duplicate.

Demographics of GR→PSFs and primary PSFs were similar (Table 1). All patients were matched for etiology. Among 25 GR→PSFs, median age at index was 10.0 years. Among 25 primary PSFs (17 patients with duplicates as described above), median age at index was 10.3 years. Matches had mean difference in (Δ) major curve of 1 degree and mean Δ age of 0.5 years (PSFs older, Supplemental Table, Supplemental Digital Content 1, http://links.lww.com/BPO/A408). Mean follow-up in the GR→PSF cohort was 4.8 years post-GR implantation (SD 2.3, range 2.3 to 10.9) and 1.2 years post-PSF (SD 2.0, range 0.1 to 8.9). Mean follow-up in the primary PSF cohort was 2.8 years post-PSF (SD 1.7, range 0.3 to 7.1).

Thoracic Spine Height

Among GR→PSFs median T1-12H at index was 18.5 cm. It increased by median 1.8 cm at GR implantation, median 1.3 cm during growth phase (median 34 mo), and median 1.7 cm following revision PSF. Overall increase pre-GR to post-PSF was 4.7 cm. Among primary PSFs median T1-12H at index was 19.9 cm. It increased by median 1.9 cm following PSF.

Coronal Deformity

Among GR→PSFs median major curve at index was 73 degrees. Median coronal deformity correction at GR implantation was 47%. Coronal deformity recurred during growth phase by median 33% of the pre-GR

TABLE 1. Baseline Characteristics of Growing Rods (GRs) Followed by Definitive Posterior Spinal Fusion (PSF) Versus Primary PSF, Values Expressed as Median (IQR) Unless Otherwise Specified

	GR→PSF (n = 25)	Primary PSF (n = 25)*	Standardized Absolute Mean Difference†
Age preindex (y)	10.0 (1.8)	10.3 (1.3)	0.28
Sex [n (%)]			
Female	15 (60)	13 (52)	NA
Male	10 (40)	12 (48)	
Etiology [n (%)]			
Idiopathic	5 (20)	5 (20)	NA
Neuromuscular	15 (60)	15 (60)	
Thoracogenic/syndromic	4 (16)	4 (16)	
Congenital	1 (4)	1 (4)	
T1-T12 height preindex (cm)	18.5 (3.1)	19.9 (4.7)	0.33
T1-S1 height preindex (cm)	29.3 (2.8)	31.0 (8.1)	0.32
Major curve preindex (deg.)	73 (18)	72 (24)	0.07
Coronal balance preindex (cm)‡	1.3 (1.6)	2.6 (3.7)	0.73
Maximum kyphosis preindex (deg.)	40 (17)	44 (16)	0.05
T1-T5 kyphosis preindex (deg.)	12 (14)	14 (12)	0.26

*With duplicates for 1-to-n optimal matching with replacement up to 3 times, see Supplemental Table (Supplemental Digital Content 1, http://links.lww.com/BPO/A408).

†Absolute difference between sample means divided by pooled SD, Cohen considered values of 0.2, 0.5, and 0.8 to represent small, medium, and large differences, respectively.

‡Absolute value of coronal imbalance.

IQR indicates interquartile range; NA, not applicable.

curve. This recurrence of deformity was not fully corrected by the median 31% correction achieved at revision PSF. This produced median net deformity correction pre-GR to post-PSF of 37%, yielding a median major curve post-PSF of 47 degrees. Among primary PSFs median major curve was 72 degrees. Median deformity correction at primary PSF was 62%, yielding a median major curve post-PSF of 25 degrees.

Complications and Operations

At least 1 complication occurred in 80% of GR→PSF patients compared with 28% of primary PSF patients. GR→PSFs had mean 1.8 complications per patient and required mean 3.4 total operations and 0.4 unplanned operations per patient. Primary PSFs had mean 0.5 complications per patient and required mean 1.3 total operations and 0.2 unplanned operations per patient (Table 2).

Matched Analysis

Matched analysis showed mean 2.3 cm greater ΔT1-12H and mean 3.8 cm greater ΔT1-S1H among GR→PSFs than their matched primary PSFs. GR→PSF treatment was more kyphogenic than primary PSF, with maximum kyphosis post-PSF of 50 versus 38 degrees, respectively. GR→PSFs had mean 25% less overall coronal deformity correction for a mean 18 degrees larger major curve post-PSF than their matched primary PSFs. GR→PSFs had

TABLE 2. Complications Among Patients Treated with Growing Rods (GRs) Followed by Definitive Posterior Spinal Fusion (PSF) Versus Primary PSF

	GR→PSF (n = 25)	Primary PSF (n = 25)*
Patients with ≥ 1 complication [n (%)]	20 (80)	7 (28)
Complications per patient among those with ≥ 1 complication [mean (SD)]	2.3 (1.4)	1.7 (1.1)
Complications per patient among all patients [mean (SD)]	1.8 (1.5)	0.5 (1.0)
Complications by type (n)	46	12
Instrumentation migration/failure	17	2
Junctional kyphosis or severe curve progression	8	4
Wound/skin breakdown or infection	6	4
Sepsis	1	0
Postoperative pneumonia/respiratory failure	9	1
Pneumothorax	1	0
Rib fracture	1	0
Intraoperative neurological compromise	1	0
Dural tear	1	0
Symptomatic implant prominence	1	0
Occipital pressure ulcer	0	1
Complications by severity (n)†	46	12
Grade I—required additional outpatient medical management only	18	4
Grade II—required inpatient medical management	11	1
Grade IIA—required 1 unplanned surgery	9	7
Grade IIB—required multiple unplanned surgeries	3	0
Grade III—required aborting GR treatment	5	NA
Grade IV—caused death	0	0

*With duplicates for 1-to-n optimal matching with replacement up to 3 times, see Supplemental Table (Supplemental Digital Content 1, http://links.lww.com/BPO/A408).

†According to Smith classification of complications in growing spine surgery.

NA indicates not applicable.

TABLE 3. Changes in Spine Length and Deformity, Complications, and Reoperations of Growing Rods (GRs) Followed by Definitive Posterior Spinal Fusion (PSF) Versus Primary PSF, Values Expressed as Median (IQR) Unless Otherwise Specified

	GR→PSF (n = 25)	Primary PSF (n = 25)*	Adjusted Difference Between Matched Pairs (n = 25)†
T1-T12 height increase (cm)			
GR implantation	1.8 (1.5)	1.9 (1.4)	**2.3 (0.9 to 3.6, GRs greater)**
Growth phase	1.3 (3.8)		
Overall (preindex to post-PSF)	4.7 (3.0)		
T1-T12 height post-PSF (cm)	22.6 (3.6)	21.6 (6.1)	0.9 (−2.1 to 3.8, GRs greater)
T1-S1 height increase (cm)			
GR implantation	3.9 (2.6)	3.6 (4.0)	3.8 (−1.0 to 8.7, GRs greater)
Growth phase	0.6 (5.2)		
Overall (preindex to post-PSF)	7.9 (4.5)		
T1-S1 height post-PSF (cm)	37.3 (5.1)	34.3 (7.9)	2.5 (−2.7 to 7.6, GRs greater)
Major curve % correction			
GR implantation	47 (26)	62 (21)	**−25 (−38 to −11, GRs less)**
Growth phase‡	−33 (29)		
Overall (preindex to post-PSF)	37 (26)		
Major curve post-PSF (deg.)	47 (22)	25 (18)	**18 (7 to 30, GRs larger)**
Coronal balance post-PSF (cm)§	1.7 (2.3)	1.8 (3.2)	−0.1 (−1.6 to 1.5, GRs less)
Maximum kyphosis change (deg.)∥	+9 (40)	−16 (7)	**21 (2 to 40, GRs more)**
Maximum kyphosis post-PSF (deg.)∥	50 (25)	38 (10)	14 (−2 to 30, GRs more)
T1-5 kyphosis change (deg.)∥	+5 (18)	0 (13)	**16 (8 to 25, GRs more)**
T1-5 kyphosis post-PSF (deg.)∥	15 (20)	11 (7)	5 (−6 to 16, GRs more)
Complications per patient [mean (SD)]	1.8 (1.5)	0.5 (1.0)	**1.2 (0.1 to 2.4, GRs more)**
Total operations per patient [mean (SD)]	3.4 (1.8)	1.3 (0.6)	**2.2 (1.1 to 3.2, GRs more)**
Unplanned operations per patient [mean (SD)]	0.4 (0.8)	0.2 (0.4)	0.2 (−0.3 to 0.7, GRs more)

Key outcomes noted in bold.

*With duplicates for 1-to-n optimal matching with replacement up to 3 times, see Supplemental Table (Supplemental Digital Content 1, http://links.lww.com/BPO/A408).

†Linear mixed effects model with random intercept, adjusted for age difference between matched pairs and clustering, with 95% confidence intervals.

‡Recurrence of deformity.

§Absolute value of coronal imbalance.

∥Adjusted differences affected by matched pairs dropped from analysis of this outcome when lateral radiographs were not obtained for both patients (not an issue for parameters measured on anteroposterior or posteroanterior radiographs).

IQR indicates interquartile range.

mean 1.2 additional complications, 2.2 additional total operations, and 0.2 additional unplanned operations per patient (Table 3). Figure 1 illustrates a matched pair with typical outcomes.

CSL and SSL

Among GR→PSFs, at GR implantation median CSL was unchanged (Δ 0.0 cm), and SSL increased by median 1.9 cm. During growth phase CSL increased by median 2.5 cm and SSL by median 2.3 cm. At revision PSF, CSL increased by median 1.0 cm and SSL by median 0.9 cm. Overall pre-GR to post-PSF, CSL increased by median 2.5 cm and SSL by median 4.6 cm. Among primary PSFs, CSL was essentially unchanged at PSF with median Δ −0.1 cm, and SSL increased by median 2.4 cm.

Subgroup Analysis by GR Type

Subgroup analysis showed similar ΔT1-12H from MCGRs and TGRs (4.0 vs. 5.1 cm, respectively). Compared with TGRs, MCGRs had better overall deformity correction (48% vs. 28%) with fewer complications (mean 1.3 vs. 2.9) and fewer total operations (mean 2.3 vs. 5.6) and unplanned operations (mean 0.3 vs. 0.7). This study was not designed to statistically compare GR types. Compared with primary PSFs, MCGR→PSFs still had poorer overall deformity correction (mean 48% vs. 62%), more complications (mean 1.3 vs. 0.5), and more total operations (mean 2.3 vs. 1.3) and unplanned operations (mean 0.3 vs. 0.2, Table 4).

Possible Predictors of T1-12H Increase From Primary PSF

Logistic regression showed thoracogenic/syndromic patients treated with primary PSF (n = 4) had less ΔT1-12H from primary PSF than patients with other etiologies (median 1.3 vs. 1.9 cm, respectively, Table 5). In graphical analysis primary PSF afforded greater ΔT1-12H when patients had larger deformities, suggesting a smaller projected benefit of GRs over primary PSF as major curve increases (Fig. 2). Supine or gravity traction views were not consistently available.

DISCUSSION

The goals of treatment for severe EOS are arresting progression and ideally correcting deformity while allowing adequate spinal growth and pulmonary development. Primary PSF prioritizes deformity correction at the expense of further growth, while GRs prioritize growth though with unclear effects on meaningful pulmonary development. We undertook this study to help delineate whether the risk-benefit ratio favors GRs or primary PSF in juveniles aged 7 to 11 with EOS. Our findings suggest that the risks of GR therapy appear to outweigh the incremental benefits for many patients in this population.

To our knowledge this is the first matched comparison of GR→PSF versus primary PSF in juveniles with EOS of all etiologies. A few recent studies have investigated this topic in specific etiologies. Pawelek et al[10] compared 11 TGRs to primary PSF in idiopathic EOS and found better overall deformity correction with fewer operations from primary PSF with similar complications rates from the 2 strategies. Many of our results are consistent with this study, although we observed higher complication rates in our mixed-etiology cohort. Published rates of infection and implant removal are higher in nonidiopathic EOS.[16] Li et al[11] studied neuromuscular EOS patients including 3 MCGRs and 12 TGRs and found that the growth afforded by GRs may not justify the complications and decreases in quality of life measures. Xu et al[12] studied congenital scoliosis including 9 TGRs and found improved deformity correction with fewer complications from primary PSF than from distraction-based therapy. To our knowledge this is the first to closely match patients for age, etiology, and deformity. This study

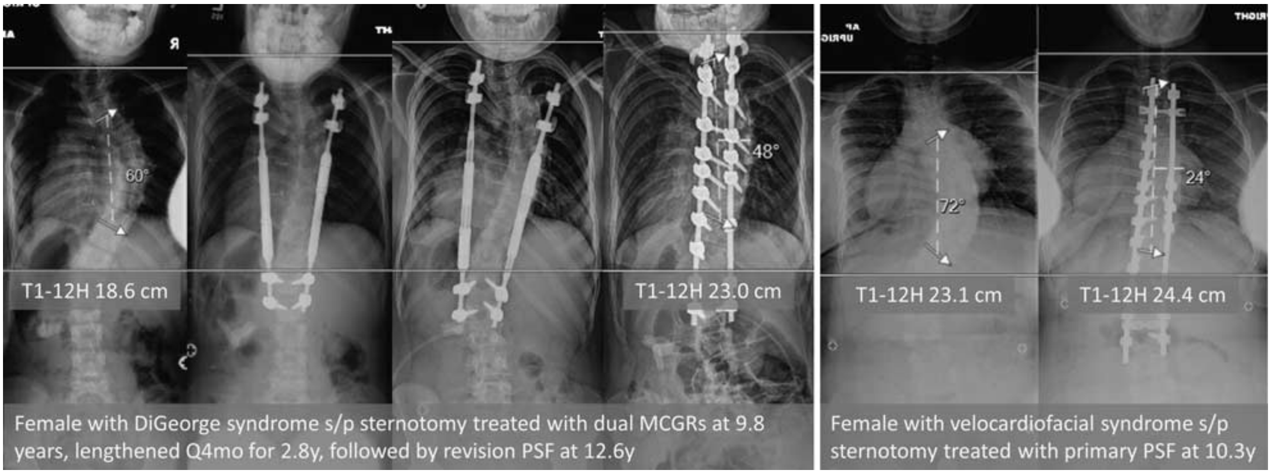

FIGURE 1. Matched patients with syndromic/thoracogenic scoliosis with typical outcomes displayed. On average growing rods afforded about 2 cm more thoracic height with 25% worse correction of major curve, similar final coronal balance, 1 more complication, and 2 more operations per patient. MCGR indicates magnetically controlled growing rods; PSF, posterior spinal fusion.

TABLE 4. Subgroup Analysis of Magnetically Controlled Growing Rod (MCGR) and Traditional Growing Rods (TGRs) Followed by Definitive Posterior Spinal Fusion (PSF) Versus Primary PSF, Values Expressed as Median (IQR) Unless Otherwise Specified

	MCGR→PSF (n = 16)	TGR→PSF (n = 9)	Primary PSF (n = 25)*
T1-T12 height increase (cm)			
Growing rods implantation	1.8 (1.4)	2.1 (1.5)	1.9 (1.4)
Growth phase	1.3 (2.9)	1.3 (4.0)	
Overall (preindex to post-PSF)	4.0 (2.7)	5.1 (3.5)	
T1-T12 height post-PSF (cm)	23.0 (4.4)	22.0 (2.7)	21.6 (6.1)
T1-S1 height increase (cm)			
Growing rods implantation	3.6 (2.8)	4.0 (1.6)	3.6 (4.0)
Growth phase	1.1 (4.2)	−0.8 (5.3)	
Overall (preindex to post-PSF)	5.8 (4.0)	8.4 (6.0)	
T1-S1 height post-PSF (cm)	36.9 (6.3)	37.7 (4.1)	34.3 (7.9)
Major curve % correction			
Growing rods implantation	49 (13)	26 (34)	62 (21)
Growth phase†	−28 (30)	−37 (33)	
Overall (preindex to post-PSF)	48 (16)	28 (12)	
Major curve post-PSF (deg.)	37 (16)	53 (15)	25 (18)
Maximum kyphosis change (deg.)	+7 (24)	+21 (59)	−16 (7)
Maximum kyphosis post-PSF (deg.)	44 (22)	59 (27)	38 (10)
T1-5 kyphosis change (deg.)	0 (13)	+13 (15)	0 (13)
T1-5 kyphosis post-PSF (deg.)	13 (12)	24 (23)	11 (7)
Complications per patient [mean (SD)]	1.3 (1.2)	2.9 (1.5)	0.5 (1.0)
Total operations per patient [mean (SD)]	2.3 (0.8)	5.6 (0.9)	1.3 (0.6)
Unplanned operations per patient [mean (SD)]	0.3 (0.8)	0.7 (0.9)	0.2 (0.4)

*With duplicates for 1-to-n optimal matching with replacement up to 3 times, see Supplemental Table (Supplemental Digital Content 1, http://links.lww.com/BPO/A408).

†Recurrence of deformity.

IQR indicates interquartile range.

also includes a higher percentage (68%) of MCGRs, reflecting modern surgical trends.

Literature on growth-friendly instrumentation lacks standardized radiographic outcomes,[17] and much reported "growth" occurs at GR implantation or PSF. Our results confirm this, with little T1-12H gained during growth phase. However, the increases in CSL and SSL and recurrence of deformity during lengthening indicate curvilinear spinal growth which can be translated into thoracic height at revision PSF, if spinal flexibility and osteotomies permit.

We found that 3/28 GRs (11%) underwent definitive explantation without PSF due to complications and family preference. This may occur more commonly than previously reported,[18] and the curve progression in these patients confirms that explantation without PSF affords unacceptably poor outcomes.[19,20] A similar suboptimal outcome may be encountered when patients are lost to follow-up with GRs retained indefinitely, although in some institutions this strategy is intentional. Potential drawbacks

TABLE 5. Multivariate Logistic Regressions of Possible Predictors of Overall T1-12H Increase Among Patients Treated With Growing Rods (GRs) Followed by Definitive Posterior Spinal Fusion (PSF) Versus Primary PSF

	GR→PSF		Primary PSF	
	Coefficient (β)	95% Confidence Interval	Coefficient (β)	95% Confidence Interval
Age preindex	−0.26	−1.10, 0.58	0.24	−0.49, 0.97
Sex	0.36	−1.85, 2.57	0.65	−0.89, 2.19
Etiology				
Idiopathic	Reference		Reference	
Neuromuscular	−2.02	−4.61, 0.58	−0.96	−2.22, 0.30
Thoracogenic/syndromic	−1.45	−4.78, 1.88	−1.57	**−2.87, −0.27**
Congenital	−4.71	−11.2, 1.76	−0.88	−3.77, 2.01
T1-T12 height preindex	0.04	−0.48, 0.56	0.13	−0.07, 0.32
Major curve preindex	−0.02	−0.10, 0.06	0.02	−0.01, 0.05
Model fit (R^2)	0.204		0.740	

Key outcomes noted in bold.

of retained GRs include ongoing titanium wear and risk of metallosis, as well curve progression given the incomplete fusion.[4,5] These scenarios highlight potential advantages of a single "definitive" surgery over a GR treatment plan in particularly poor operative candidates or those whose socioeconomic status limits regular follow-up.

This study has several limitations. Due to the paucity of primary PSFs performed under 9 years of age, we had to match 5 PSF patients in triplicate or duplicate. This optimal matching with replacement provides the most similar pairs when a few controls (PSFs) are most similar to > 1 treated individual (GR→PSFs), as was the case in our cohort (Supplemental Table, Supplemental Digital Content 1, http://links.lww.com/BPO/A408, Supplemental Fig. 2, Supplemental Digital Content 1, http://links.lww.com/BPO/A408). This matching scheme takes into account the entire data set before making individual matches unlike nearest neighbor matching.[21–23] Confounding and selection biases are inherent to observational research but are reduced by this matching scheme. Thoracic height is only a surrogate of pulmonary function, and the lack of pulmonary function tests and patient reported outcomes is another limitation to be addressed with prospective study. Finally, the short duration of follow-up post-PSF for some patients particularly in the GR→PSF cohort is a limitation. Patients with < 2 years of follow-up post-PSF were not excluded, as data to guide surgeons in choosing GR therapy versus primary PSF in juveniles with EOS is sparse, and given the relatively recent development of MCGRs, patients are just beginning to "graduate" from MCGRs to revision PSF in adequate numbers to be rigorously studied. This study focuses on acute complications and radiographic outcomes; long-term follow-up is needed and may demonstrate further differences.

To conclude, for juveniles aged 7 to 11 with EOS, GR→PSF treatment affords 2.3 cm of thoracic height gain over primary PSF at the cost of 25% loss of deformity

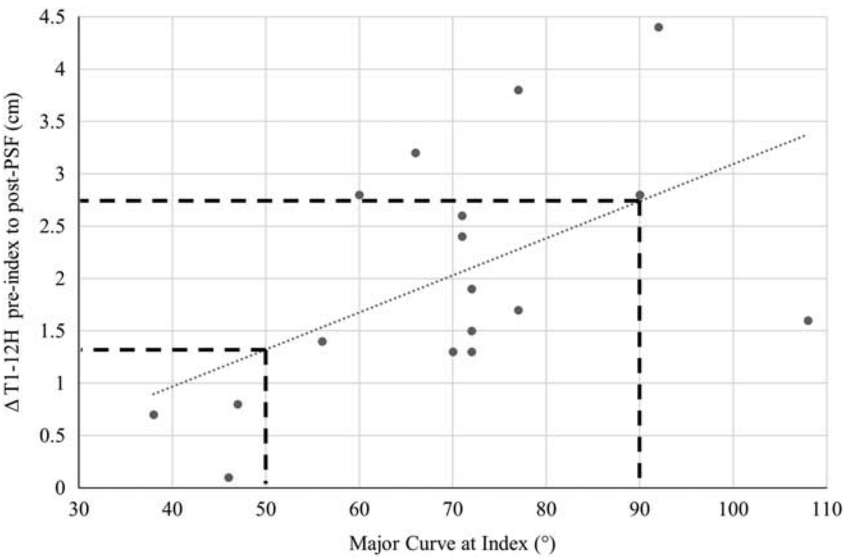

FIGURE 2. As major curve increased, more height gain from primary posterior spinal fusion (PSF) led to less projected benefit from growing rods. For example, a patient with a 90 degrees deformity has more coronal spine length that can be straightened to gain 3 to 4 cm of thoracic height from PSF alone, while a patient with a 50 degrees deformity will gain very little.

correction and an additional 1.2 complication and 2.2 operations per patient. Primary PSF affords an average of 2 cm of thoracic height gain; if an additional 2.3 cm will be impactful then GRs should be considered. However, for many patients in this population, the height gained may not warrant the iatrogenic stiffness, complications, and additional operations. Surgeons and families should weigh these benefits and harms when choosing a treatment plan.

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