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ABSTRACTS

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Paper #01

Longitudinal pulmonary function after surgery in early onset scoliosis: we need to do better

Scott Yang; Michael Trask; Natalie Maharaj; Apeksha Gupta; Anna Faino; Sean Pirkle; Kelson Adcock; Jennifer M. Bauer; Burt Yaszay; Gregory Redding

Introduction: Longitudinal pulmonary outcomes after surgical treatment of early onset scoliosis (EOS) are not well reported. Prior understanding of pulmonary function after surgical treatment of EOS is limited to a few studies, none of which report on multiple serial pulmonary function tests during treatment.
Aims/objectives: This study aims to evaluate change in serial pulmonary function tests (PFTs) in children with EOS who had surgical treatment of scoliosis.
Methods: A retrospective review was performed at a single academic hospital. All patients who had surgical treatment of EOS and repeated PFT data were included in the study. PFT measures included forced vital capacity (FVC) and FVC % predicted. To determine if the time since surgery impacted PFTs, a random effects mixed model was used adjusting for age at each PFT, sex, race, scoliosis etiology, and stage of treatment (i.e. pre-surgery, during growth-friendly treatment, and post-fusion). Predicted marginal means were calculated (LSMEANS) and Bonferroni adjusted p-values were reported.
Results: Fifty-one patients were included for analysis (66.7% female), with etiology of 45% syndromic, 21% congenital, 12% neuromuscular, 12% idiopathic, and 10% thoracogenic. Mean age was 7.2 ± 2.8 years at index surgery. Index surgery was 56.9% VEPTR, 21.6% traditional growing rod, 17.7% magnetically controlled growing rod, 1.9% hybrid construct, and 1.9% early fusion. 45.1% underwent eventual final fusion. Median duration from the first PFT to the most recent PFT was 44 months (IQR 17–75 months), with 37.3% of patients having pre-surgery PFTs. Mean radiographic measures pre-surgery, most recent after growth-friendly surgery, and after final fusion were Cobb angle (degrees) 77.8 ± 14.6, 66.2 ± 17.8, 57.5 ± 16.9 respectively, and T1–T12 length (cm) 15.3 ± 3.6, 19.3 ± 2.7, 20.2 ± 2.5 respectively. The random effects model for the cohort predicted no significant change in FVC and FVC% over time since surgery. When changes in PFTs were analyzed by stage of treatment and scoliosis etiology together, there was no significant change in FVC or FVC % predicted after surgical treatment with any etiology. However, in patients with congenital scoliosis, FVC% predicted significantly decreased by 15% and 18% after growth-friendly treatment and fusion respectively compared to before surgery (Adj. p = 0.005). Other etiologies did not demonstrate a significant change in FVC or FVC% with surgery (Fig. 1).
Conclusions: In our cohort with only moderate scoliosis correction, patients with congenital scoliosis continue to decline in pulmonary function despite growth-friendly treatment and final fusion. EOS surgery does not predict improved pulmonary function, but at best prevents further pulmonary decline in children except in congenital scoliosis. This study is one of the largest studies reporting on changes in serial PFTs in patients undergoing treatment.

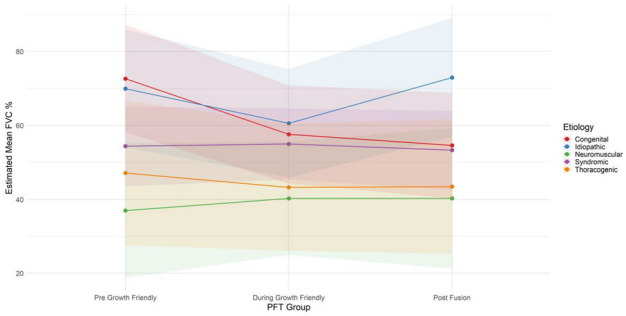


Figure 1 Forced Vital Capacity (% Predicted) based on stage of treatment and scoliosis etiology

Paper #02

Increases in three-dimensional spine length during growth friendly treatment for early onset scoliosis are moderately correlated with improved pulmonary function

Jennifer Hurry; Matthew Holloway; Amir Mishreky; Todd Ritzman, MD; Lorena Floccari, MD; Richard Steiner, PhD; Pediatric Spine Study Group; Ron El-Hawary, MD

Introduction: Severe early onset scoliosis (EOS) contributes to chest wall deformation and rigidity and impaired respiratory muscle function leading to restrictive lung disease and thoracic insufficiency syndrome (TIS). Growth friendly EOS surgery aims to control curve progression, preserve chest wall motion and function, and sustain spinal growth until adequate height is achieved to avoid TIS. Traditional one-dimensional coronal height measurements overlook out-of-plane growth and leads to an underestimation of the effects of surgical intervention. 3D True Spine Length (3D-TSL) has been validated to capture out-of-plane growth.
Aims/objectives: To examine if 3D-TSL measurements (T1-L1) correlate with pulmonary function tests forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), and their percentage of expected values post-operative definitive fusion.
Methods: A pediatric spine registry contained prospectively and retrospectively collected radiographic and PFT data from EOS patients. Those with both post-definitive fusion radiographs and PFT data available, excluding neuromuscular and syndromic, had 3D-TSL measured (n = 42). Pearson correlations between PFT data and 3D-TSL were analyzed.
Results: Forty-two EOS participants with a mean pre-operative scoliosis of 74° (28°–106°) and kyphosis of 50° (4°–99°) who underwent growth friendly treatment for 6 (2–10) years before fusion were included. They had an average post-definitive scoliosis of 43° (13°–81°) and kyphosis of 55° (16–141). Actual FEV1 and FVC had moderate positive correlations with 3D-TSL (FEV1 r = 0.36 p = 0.02; FVC r = 0.39 p = 0.01). Percent predicted and the FEV1/FVC ratio were not significantly correlated to spine length (Table 1).
Conclusions: This study confirms the hypothesis that a positive correlation exists between 3D-TSL and postoperative actual FEV1 and FVC. Further long term PFT follow up evaluation of a larger population of post-definitive fusion EOS patients has potential to clarify a definitive ideal thoracic length as measured by 3D-TSL that could indicate better outcomes in regard to TIS.

Table 1 Pearson Correlations (r) between T1-L1 spine length (3D-TSL) and pulmonary function variables

Pulmonary Function Variable	Correlation with 3D-TSL (n)	P-value
FEV1 (Actual)	0.36 (42)	0.02*
FEV1 (Predicted)	0.26 (42)	0.10
FVC (Actual)	0.39 (42)	0.01*
FVC (Predicted)	0.28 (42)	0.07
FEV1/FVC	0.056 (35)	0.75

Table 2 Mean PFT values for participants below or above a 3D-TSL T1-S1 spine length of 24 cm (23.7 mm is the mean for the whole group)

Pulmonary Function Variable	Mean value for those with <24cm 3D-TSL T1-S1	Mean value for those with >24cm 3D-TSL T1-S1
FEV1 (Actual)	1.8 L	2.2 L
FEV1 (Predicted)	59%	70%
FVC (Actual)	2.1 L	2.6 L
FVC (Predicted)	64%	73%
FEV1/FVC	85%	87%

Paper #03

Dynamic 4D computed tomography: measured increased ventilation heterogeneity in a thoracic insufficiency syndrome rabbit model

Mostafa Ismail; Madeline Boyes; Hooman Hamedani; Klaus Hopster; Luis Loza; Fazaz Amzajerdian; Stephen Kadlecek; Kai Ruppert; Rahim Rizi; Thomas Schaer, VMD; Patrick Cahill, MD; Brian Snyder, MD/PhD

Introduction: Thoracic insufficiency syndrome (TIS) due to constricted thoracic pathoanatomy causes restrictive lung disease, chronic respiratory failure and cor-pulmonale, with 300% increased mortality. Treatment is predicated on expanding the thorax to improve ventilatory mechanics and the space available for the lung to grow. Pulmonary function tests (PFTs) are used to evaluate TIS severity and efficacy of treatments, but provide a global, rather than anatomically specific measure of changes in ventilation (pCO2) and respiration (pO2).
Aims/objectives: In this pilot study, using our previously established rabbit model for TIS (Olsen et al. 2015; Olsen et al. 2018), we analyzed the ability of dynamic 4DCT of the thorax to identify the impact of thoracic pathoanatomy on ventilatory function by mapping ventilation heterogeneity.
Methods: 1-month old New-Zealand-White rabbits (control vs. tethered right hemithorax to induce TIS) were serially imaged during free-breathing using 4D high resolution CT (Fig. 1). Correcting for rabbit position, images were reconstructed to represent the phases of the respiratory cycle. Using custom software to track voxel by voxel trajectories, the local parenchyma volumetric strain was calculated from the local voxel-based trajectories (ΔV) normalized by the initial aerated lung volume (V0); Functional Residual Capacity (FRC) was calculated at end-exhalation. FRC heterogeneity was measured by 1) interregional heterogeneity, elucidating parenchymal atelectasis(Slinky effect: Hopkins et al. 2007); 2) intraregional heterogeneity, highlighting inhomogeneities among adjacent regions with asymmetrical function (Paiva et al. 1984).
Results: Regional FRC mapped for control and TIS rabbit during growth (Fig. 1b) demonstrated that position (prone) dependent atelectasis lowers the FRC for both rabbits, but the postural gradient in parenchymal strain induced by prone position was limited in the tethered lung vs. normal (Fig. 1c). Intraregional FRC heterogeneity was increased in the tethered hemithorax throughout growth (Fig. 1.D).
Conclusions: Thoracic deformity and scoliosis created by unilateral rib tether in a rabbit model of TIS induces post-natal pulmonary hypoplasia where deformity @ 6 wks. influenced lung volume and respiratory function @ 28 wks. (adult). Restricting the hemithorax produced heterogeneity in FRC and diminished the posture dependent gradient for lung expansion. 4DCT offers the clinical potential to quantify regional pulmonary impairment for TIS patients and to better evaluate the effectiveness of interventions to improve FRC.

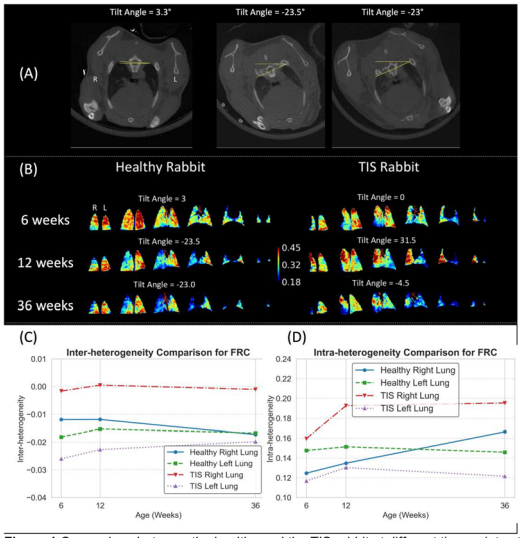


Figure 1 Comparison between the healthy and the TIS rabbit at different time points at 6, 12, and 36 weeks of age (tethering operation was performed at 4 weeks of age). (A) The lung under more pressure (from the tilt) has lower functional residual capacity (FRC) as illustrated in (B). The tethered right lung of the TIS rabbit exhibits loss of gravitational gradient as shown in (C) and more ventilation heterogeneities (D) compared to the left lung and both lungs of the healthy rabbit

Paper #04

Serial changes in respiratory muscle function among children with EOS

Gregory Redding; Michael Trask; Natalie Maharaj; Sean Pirkle; Kelson Adcock; Apeksha Gupta; Jennifer M. Bauer; Burt Yaszay; Scott Yang

Introduction: Children with early onset scoliosis (EOS) have reduced respiratory muscle strength which correlates with reduced forced vital capacity (FVC). Changes in respiratory muscle strength as measured by Maximum Inspiratory Pressure (MIP) and Maximum Expiratory Pressure (MEP) and their relationship to changes in FVC over time have not been described.
Aims/objectives: We hypothesized that a loss of MIP% and/or MEP% would result in decline of FVC% over time. We studied how changes in the values of MIP%, MEP%, and FVC% correlated over a period of > 3 years.
Methods: We reviewed serial pulmonary function data collected over > 3 years in children undergoing EOS treatment to describe longitudinal changes in respiratory muscle strength and FVC at a single spine center. MIP and Mep are reported % predicted (MIP% and MEP%) based on age and gender norms; FVC was recorded as % predicted (FVC%) using arm span. When more than two tests were recorded, first tests were excluded as children were learning to perform the tests. Spearman correlations between changes in FVC% and changes in MIP% and MEP% as well as between changes in MIP% with MEP% were performed.
Results: 32 children aged $10.5/-$ 2.3 years at initial assessment had FVC%, MIP% and MEP% measured over a period of 46 ± 22 months. Each child performed an average of 4.7 ± 1.9 measurements over time. Twenty-three were female; etiologies included 7 congenital, 3 neuromuscular, 12 syndromic, 3 idiopathic, and 4 with thoracogenic scoliosis. 24/32 had undergone spine surgery before the first tests. Initial FVC%, MIP%, and MEP% were abnormally low (< reduced80% predicted values) in 93%, 69%, and 73% of the groups respectively. Over time, FVC% increased by $> 5\%$ in 3/32 (9%) and decreased by $> 5\%$ in 13/32 (41%) of the children.

MIP% increased > 10% in 12/32 (38%) and decreased by > 10% in 12/32 (38%) of the group. MEP% increased by > 10% in 7/32 (22%) and decreased in 12/32 (41%). Changes in FVC% ranged from + 10 to − 33%, in MIP$ + 41% to − 38%, and in MEP from + 20 to − 71%. There was no correlation between changes in FVC% with changes in MIP% (r = 0.48, p = 0.28) or MEP% (r − 0.28, p = 0.12).over time. However, changes in MIP% correlated with MEP%% (r = 0.61, p < 0.001).

Conclusions: Declines in FVC% over time are not consistently associated with loss of respiratory muscle strength in children with EOS. Both Inspiratory and expiratory respiratory muscle strength increase in some children with EOS. We speculate that those children with greater work of breathing due to ongoing chest wall stiffness may strengthen their respiratory muscles over time.

Paper #05

Relevant basic science supporting extraspinal fixation for severe pediatric spinal deformity

Richard Gross; Yongren Wu; Mohammed Alshareef; Daniel Bonthius; Kristi Helke, DVM, PhD; Hai Yao

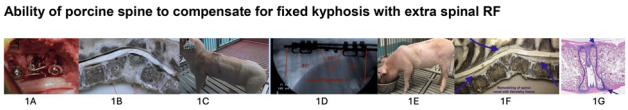
Introduction: This work supports considering adjustments to current accepted management of pediatric spinal deformity. Extraspinal sites that influence spinal and trunk posture include the thorax and scapula. Hyperkyphosis has been especially difficult to control and is associated with a higher complication rate. Currently, MAGnetic Expansion Control (MAGEC) and growing rods (GR0 are commonly used for superior fixation when treating EOS, both use 4 pedicle screws (PS) placed in adjacent upper thoracic vertebra. Rib fixation (RF) hooks are placed on ribs 2–5 in a claw configuration, 2 downgoing on ribs 2–3, and 2 upgoing on ribs 4–5.

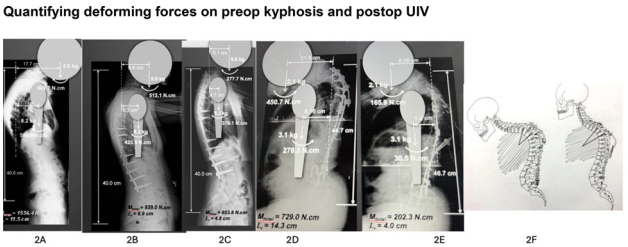
Aims/objectives: Substantiate the basic science that supports extraspinal (RF) and scapulopexy (SP) for EOS.

Methods: The first study compared resistance to kyphotic pullout forces on the immature porcine spine, 6 with PS, and 6 with RF. The second study described a method to create a structural kyphosis at T9–11 in the growing pig. The third study evaluated the ability of extraspinal RF to induce compensatory remodeling of the spine with a fixed kyphotic deformity corresponding to the instrumented levels. A separate study created a method to quanmtiate the kyphogenic forces on the preoperative (PO) and postoperative (POS) upper instrumented vertebra (UIV).

Results: Resistance to kyphotic pullout forces with RF was clearly superior to PS fixation. Subsequent studies are illustrated in Fig. 1. A structural kyphosis was created by excising an anterior wedge from the pig's T10 vertebral body, followed by compression of T9 and T11 on the defect created by the wedge excision. Necropsy at 8 weeks documented early pressure on the cord. A further study examined the capability of extraspinal RF to induce growth modulation in the spine. Slab sections and histology revealed that the posterior groove of Ranvier was attenuated, with extensive disruption of growth, while the anterior groove was growing normally. The resulted in a compensatory lordosis of the instrumented segment, compensating for the structural kyphosis Standard radiographs provide essential data to quantitate kyphogenic forces where L_h and L_s are distance from head and shoulders to apex or UIV; W_h and W_s are weight, and M_h and M_s are momentum. Total bending moment = $M_h + Ms = W_h*L_h + W_s*L_s$.

Conclusions: The basic science work presented demonstrates the effectiveness of extraspinal fixation on remodeling of the immature spine and a method for analyzing the effect of head and shoulder position on the sagittal deforming forces on the spine.





Paper #06

The biological responses to titanium alloy debris using a pediatric animal model

Ying Li, MD; Brandon Henry, DO; Paige Cordts, BS; Conor Locke, MSE; Adam Abraham, PhD; Karl Jepsen, PhD; Megan Killian, PhD

Introduction: Patients with early onset scoliosis treated with traditional growing rods, magnetically controlled growing rods, and vertical expandable prosthetic titanium rib were shown to have persistently elevated serum titanium (Ti) levels with no evidence of renal excretion. Ti implant studies revealed metal debris deposition in the spleen, lungs, kidneys, heart, and liver in an adult animal model, but this has not been studied during growth nor has the impact of debris on bone strength development been assessed.

Aims/objectives: We used a pediatric mouse model to (1) assess if presence of Ti debris affects vertebral body structure and strength, and (2) evaluate systemic accumulation of Ti debris in organs. We hypothesized that Ti debris deposited in paraspinal muscles during growth leads to systemic accumulation of Ti debris in organs.

Methods: Ti debris suspension or saline was injected into paraspinal muscles of 4-week-old mice (Ti-mice, Control-mice; n = 40/group). Mice were euthanized at 4- and 24-weeks post-injection. L1 vertebrae, femurs, paraspinal muscles, and organs were evaluated using nano-computed tomography (nanoCT).

Results: Weight did not differ between control and Ti-mice at either time point. NanoCT showed a significantly smaller L1 vertebral body total area (mean 1.40 mm^2 vs. 1.52 mm^2, p = 0.011) and cortical area (mean 0.37 mm^2 vs. 0.48 mm^2, p = 0.0005) but no difference in trabecular bone at 28 weeks in Ti-mice compared to controls (Fig. 1). Ti debris was observed in lung nanoCT images after 28 weeks in Ti-mice (Fig. 2).

Conclusions: The smaller vertebral bodies in young mice exposed to Ti debris suggested that metal debris has a negative effect on periosteal expansion and mass accumulation of the vertebral body during growth. Finding that metal debris accumulates in the lungs indicated Ti debris adjacent to the spine can lead to its accumulation in organs. Future work will histologically evaluate the vertebrae and organs to further characterize Ti debris deposition and its effects on cell and tissue quality, including presence of inflammation.

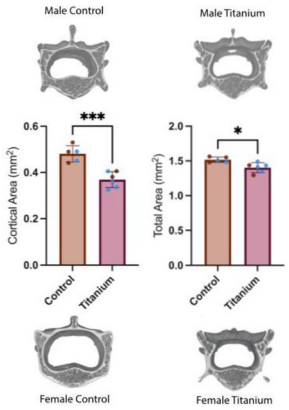


Figure 1 Comparison of vertebral body cortical area and total area between control mice and Ti-mice, and cross-sectional imaging from both groups

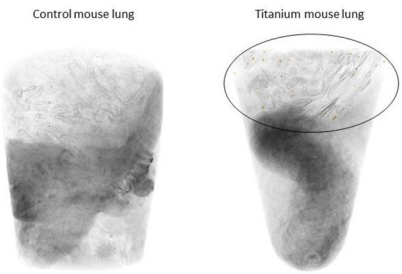


Figure 2 Lung nanoCT images demonstrating Ti debris deposition in the Ti-mouse lung tissue

Paper #07

Flexion/extension MR is safe in infants and children

Jeffrey Campbell, MD, MS, MBA; Stuart Mackenzie

Introduction: Cervical spine MR imaging with flexion and extension views have been used for over twenty years for evaluation of cervical stenosis or instability, to better understand the dynamic nature of spinal cord. This technique in younger patients is debated because of the confounding issue of sedation often required to obtain imaging and worry about iatrogenic spinal cord injury.
Aims/objectives: The objective of this study is to review a single institution's experience with flexion/extension cervical MR to determine the safety of this technique.
Methods: We reviewed every flexion/extension cervical spine MR that was performed at our hospital. Our protocol is for a standard neutral cervical MR that is evaluated immediately by a neuroradiologist. If there are sufficient findings of cord compression or myelomalacia, no further imaging is pursued. The patient is then repositioned in extension followed by flexion by the anesthesia team and MR technologist. The provider requesting the imaging is occasionally contacted after the neutral imaging to render an opinion about the safety of proceeding with dynamic imaging but is not present for the study or required to reposition the neck position in the scanner.
Results: Since 2010, we have performed 720 cervical spine MR with dynamic imaging in a total of 531 patients. The most common diagnosis was achondroplasia (193 patients) followed by other skeletal dysplasias (104), mucopolysaccharidoses (85), trauma (59), Down syndrome (30), osteogenesis imperfecta (23), and os odontoideum (10). The median age at imaging was 6 years with 104 scans performed in infants under a year. Roughly 20% of studies did not include both flexion and extension views, either because of sufficient information on the neutral imaging or concern about the airway by the anesthesia team. No patient suffered either transient or permanent neurological changes during or after the study.
Conclusions: Cervical MR imaging with flexion and extension views is safe in children including those under anesthesia. In our practice, the findings often play a key role in determining the need for or type of surgical intervention.

Paper #08

Safety of traditional growing rods in patients with early onset congenital scoliosis associated with type-I split cord malformation

Heng Sun; Jianxiong Shen

Introduction: Literature regarding the application of traditional growing rod (TGR) instrumentation in patients with early onset congenital scoliosis with type-I split cord malformation is scarce.
Aims/objectives: The purpose of the present study was to assess the safety and effectiveness of TGR surgery and repeated lengthening procedures in patients with congenital scoliosis with type-I split cord malformation not treated with prophylactic osseous spur excision.
Methods: Thirteen patients with early onset congenital scoliosis associated with type-I split cord malformation and a stable neurologic status between March 2009 and July 2020 were recruited. All patients underwent primary TGR surgery and subsequent repeated lengthening procedures without osseous spur excision by the same surgical team. Clinical information and radiographic data from the preoperative, postoperative, and latest follow-up periods were collected.
Results: The mean preoperative Cobb angle of the major coronal curve was 74.62° ± 25.59°, the mean early postoperative angle was 40.23° ± 17.89°, and the mean latest follow-up angle was 40.62° ± 16.60°. The scoliotic deformity correction percentage was 46.81% ± 12.26% after the initial operation and 45.08% ± 15.53% at the latest follow-up. Compared with the preoperative values, significant improvements were observed in the coronal and sagittal balance early postoperatively and at the latest follow-up ($p < 0.05$ for all). The average annual amounts of spinal height gained were 15.73 ± 5.95 mm at T1-S1, 8.94 ± 3.94 mm at T1–T12, and 12.02 ± 6.70 mm between the instrumented segments. The total height gained at T1-S1 and T1–T12 was 72.18 ± 28.74 mm and 37.62 ± 12.53 mm, respectively. No intraoperative neurophysiological monitoring events were observed, and no case of neurological deficit was observed postoperatively or during follow-up.
Conclusions: Patients without neurologic deficit and having a stable neurologic exam who have early onset congenital scoliosis associated with type-I split cord malformation can safely and effectively undergo TGR surgery, followed by repeated lengthening procedures, without prophylactic osseous spur excision.

Paper #09

Tethered cord release either prevents or slows scoliosis progression

Sydney Lee, BA; Shanika De Silva, PhD; Lawrence Karlin

Introduction: It is well established that scoliosis is one of the various clinical symptoms associated with tethered spinal cord syndrome (TSCS), but the role of the surgical release of the tethered cord (TCR) for the treatment of scoliosis is as yet undetermined.
Aims/objectives: To determine the effectiveness of surgical TCR in stabilizing or slowing scoliosis curve progression in skeletally immature children.

Methods: This retrospective cohort included patients with scoliosis associated with TSCS who underwent TCR between January 2005 and December 2017. Females under 13 years and males under 15 years of age prior to TCR were included. Patients with congenital scoliosis or concomitant diagnosis associated with scoliosis other than TSCS were excluded. Changes in Cobb angles were classified as improved (> 10° decrease), stabilized (− 10° to 10° change), and progressed (> 10° increase). Demographic, clinical, and radiographic characteristics were summarized using descriptive statistics. Categorical variables were presented as frequencies and percentages, and continuous variables as means and standard deviations or medians and interquartile ranges.

Results: The study included 30 patients (73% female) with a mean age 8 ± 3 years at TCR. Most patients had a thoracic curve pattern (57%) and thickened filum tethered cord anatomy (60%). The median preoperative major Cobb angle was 25°. Following TCR, 19 patients showed curve improvement or stabilization, while 11 patients (mean age 12 ± 2 years, 73% female) showed progression. Patients aged 5–10 years at TCR with preoperative Cobb angles between 30°–39° had the highest progression rate (27%) (Table 1). The greatest rate of progression, 3°/year, occurred in those with curvatures of 30°–40°. 9 patients did not progress until 3–7 years postoperatively. 11 patients (median age 13 years, range 11–21 years) had spinal instrumentation and fusion for a median curvature of 50° (range 46°–81°) (Table 2), with an average delay of 4.1 years between the TCR and the spinal fusion.

Conclusions: TCR is effective in stabilizing or slowing the progression of scoliosis in children with TSCS-related deformity. The best results occur in those with curvatures less than 30°. Ongoing monitoring is essential as curve progression can begin years after TCR.

Table 1: Distribution of curve progression by pre-operative Cobb angle and age at surgery

Age at surgery	Pre-operative Cobb angle group[1]					N in age group	Frequency (%) of age group that progressed
	< 20°	20° - 29°	30° - 39°	40° - 49°	≥ 50°		
≤ 5 years	1 (9%)	0	1 (9%)	0	1 (9%)	7	3 (27%)
5 < years < 10	0	2 (18%)	3 (27%)	1 (9%)	0	12	6 (55%)
≥ 10 years	0	1 (9%)	1 (9%)	0	0	11	2 (18%)
N in Cobb angle group	7	12	7	2	2		
Frequency (%) of Cobb angle group that progressed	1(14%)	3 (25%)	5 (71%)	1 (50%)	1 (50%)		

[1]Presented as frequency (percentage) of patients who progressed. Percentages were calculated based on the total number of patients who showed progression (n=11).

Table 2: Median and range of major Cobb angle at time of tethered cord release, most recent follow-up, and spinal fusion

	Tethered Cord Release[1]			Most Recent Follow-Up[1]			Spinal Fusion[1]		
	N	Age (years)	Major Cobb (°)	N	Age (years)	Major Cobb (°)	N	Age (years)	Major Cobb (°)
Improved	9	7 (4, 12)	20 (15, 70)	9	13 (9, 22)	8 (3, 55)			
Spinal Fusion	1	4	70	1	10	55	1	10	55
Stabilized	10	10 (3, 11)	23 (17, 36)	10	15 (11, 18)	22 (12, 44)			
Spinal Fusion	1	11	35	1	14	44	1	14	44
Progressed	11	8 (4, 12)	33 (17, 54)	11	14 (11, 21)	50 (35, 81)			
Spinal Fusion	9	9 (5, 12)	33 (23, 54)	9	13 (11, 21)	50 (46, 81)	9	13 (11, 21)	50 (46, 81)

[1]Presented as median (minimum, maximum)

Paper #10

Clinical outcomes of one-stage posterior hemivertebra resection and mono-segment fusion for growing children at the end of spinal growth: a mean 10-year follow-up study

Yiwei Zhao; Shengru Wang; Terry Jianguo Zhang

Introduction: Congenital early onset scoliosis (CEOS) due to hemivertebra requires early intervention if severe deformity is indicated. For a single hemivertebra, posterior hemivertebra resection and mono-segment fusion can correct the deformity with minimal involvement of the spinal segment. Previous studies have shown that this technique is safe and effective, albeit most of these patients have not yet reached skeletal maturity. Since CEOS are still in the developmental stage, the final clinical outcomes could only be determined at the end of spinal growth.

Aims/objectives: We therefore performed a long-term study in which all patients reached skeletal maturity to evaluate the outcomes of hemivertebra resection and mono-segment fusion.

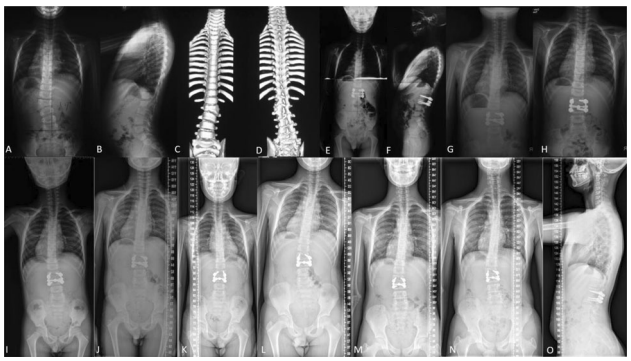
Methods: A retrospective study of CEOS patients who were treated with posterior hemivertebra resection and mono-segment fusion was conducted from 2007–2017. All patients reached skeletal maturity at the latest follow-up (Risser sign ≥ 4 and age ≥ 14 years old), with a mean follow-up of 10.5 ± 2.5 years. Demographic characteristics, coronal and sagittal deformity correction parameters, spinal and vertebral growth parameters, 22-item Scoliosis Research Society (SRS-22) scores and complications were analyzed.

Results: A total of 23 patients (15 males and 8 females) were enrolled, and the mean age was 4.8 ± 2.0 years. The preoperative main curve was 32.3° ± 14.4° and significantly improved to 7.3 ± 6.5° (77.7%) after surgery, with an exacerbate to 11.7° ± 11.1° (62.3%) at the latest follow-up. Sagittal kyphosis significantly improved and was maintained at the latest follow-up. Three patients had coronal imbalance preoperatively, which decreased to 1 at the latest follow-up. The T1–T12 and T1-S1 heights improved from 15.9 ± 1.6 cm and 27.1 ± 1.7 cm preoperatively to 24.0 ± 2.2 cm and 37.3 ± 3.1 cm, respectively, at the latest follow-up. The increase in vertebral body height and interpedicular length was comparable between instrument vertebrae and noninstrument vertebrae. The SRS-22 total score was 4.3 ± 0.2 at the latest follow-up. A total of ten complications occurred in 7 patients.

Conclusions: For long-term follow-up to skeletal maturity, HV resection and mono-segment fusion was a safe and effective surgical approach for simple hemivertebra. Deformity correction could be well maintained without hazardous effects on spinal growth, and achieved acceptable patient-reported clinical outcomes.

Typical case of scoliosis

A 5-year-old male was diagnosed with CEOS caused by L2/3 semisegmented hemivertebra (A-D). He underwent L2/3 hemivertebra resection and mono-segment fusion, and complete deformity correction was achieved (E, F). At the 3-month, 6-month, 1-year, 3-year, 4-year, 6-year, 8-year and 10-year follow-ups, the deformity was well maintained (G-M).



Paper #11

Clinical and radiological outcomes of posterior-only hemivertebra resection and short-segment fusion with pedicle screw fixation in children under the age of 5, followed until skeletal maturity

Bilge Yilmaz; Baris Peker; Hamisi Mraja; Tunay Sanli; Inas Daadour; Sepehr Asadollhmonfared; Mehmet Zamanoglu; Selhan Karadereler; Meric Enercan; Azmi Hamzaoglu

Introduction: Previous studies have evaluated the outcomes of posterior hemivertebrectomy and short-segment fusion in patients under the age of 5. There is no report on the long-term outcomes of patients who reached skeletal maturity following surgery.
Aims/objectives: We evaluate long-term outcomes of patients who had reached skeletal maturity after having posterior hemivertebrectomy and short-segment fusion before 5 years of age.
Methods: 16 patients (10F, 6 M) who underwent posterior hemivertebrectomy and short-segment fusion, and pedicle screw fixation before the age of 5 and who had reached skeletal maturity were included. Coronal and sagittal parameters were measured on preop, post, and follow-up X-rays. Follow-up X-rays were reviewed for a new curve development. Clinical assessment was done with SRS22r at follow-up.
Results: Mean age was 18.9 years and follow-up was 16.2 (15–22) years. Mean age at the time of surgery was 3.5 (1–5) years. 11 patients had single level hemivertebra and 5 patients had 2 hemivertebra located at different levels both in thoracal (T) and lumbar (L) spine. Among 11 patients with single hemivertebra (5TL and 6L), 10 patients (90%) had a stable residual curve of 8.7° (0–28) until skeletal maturity. In 5 patients a new C-shaped, flexible curve developed during the growing period. 4 of them were observed with TLSO brace until skeletal maturity without any surgery. Surgery was recommended only in 1 patient due to curve progression. In 5 patients with 2 different levels hemivertebra, hemivertebra resection was performed for thoracolumbar and lumbar hemivertebra. Observed thoracal hemivertebra progressed over time to 43.5° curve without causing any imbalances. None of the patients had revision or surgery for adding on. Mean SRS22 score was 4.5 at follow-up.
Conclusions: Our study showed that thoracolumbar and lumbar posterior hemivertebra resection and short-segment fusion with pedicle screw fixation before the age of 5, provided satisfactory and stable correction in both planes in 90% (10/11) of the patients with a residual curve of 8.7° (0–28) until they reached skeletal maturity. In the presence of 2 different levels hemivertebra, we recommend performing lumbar hemivertebra resection and following thoracal hemivertebra's progression and perform surgery if needed.

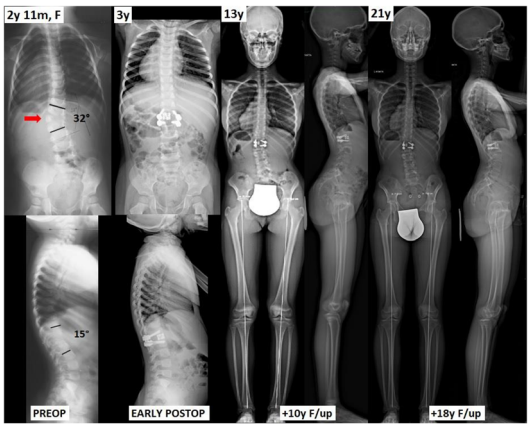


Figure 1 A female patient who underwent posterior hemivertebrectomy and short-segment fusion, and pedicle screw fixation with 18 years follow-up

Paper #12

Lessons learned from posterior hemivertebra resection and short segment fusion for congenital early onset scoliosis: a minimally 10-year follow-up study until skeletal maturity

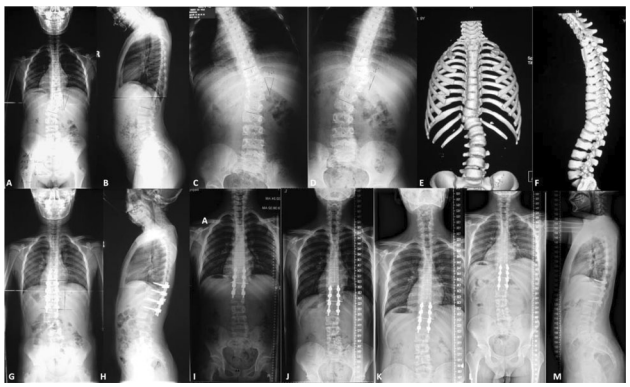
Shengru Wang; Yiwei Zhao; Terry Jianguo Zhang

Introduction: Posterior hemivertebra (HV) resection and short segment fusion are among the mainstream treatments for congenital early onset scoliosis (CEOS). Short- and medium-term studies have indicated that this technique is effective at removing teratogenic structures and correcting deformities and has little impact on spinal growth. However, loss of correction and deformity progression, such as adding-on and crankshaft phenomenon, were observed with spinal growth. Given the substantial growth potential in CEOS patients, the ultimate clinical outcomes can be determined only until skeletal maturity. To date, there is a paucity of studies on clinical outcomes during follow-up until skeletal maturity.
Aims/objectives: We therefore aimed to evaluate the ultimate clinical outcomes of hemiveterbra resection and short segment fusion for CEOS by proposing a definition of successful outcomes and analyzing risk factors for unsuccessful outcomes.
Methods: Data of CEOS patients who underwent hemiveterbra resection and short segment fusion at our hospital between 2006 and 2014 were retrospectively collected. Successful outcomes were defined by a residual curve $< 30°$, coronal and sagittal balance and no need for revision surgery after skeletal maturity. Patients were divided into a success group (group A) and an unsuccess group (group B). Demographic characteristics, deformity correction parameters, vertebral growth parameters, complications and SRS-22 scores were analyzed and compared. Risk factors for unsuccessful treatment were analyzed by binary logistic regression.
Results: Forty-one patients provided complete follow-up data, (-mean: 11.1 $\pm$ 1.3 (10–15) years of follow-up). All patients reached skeletal maturity at the latest follow-up. The main curve decreased from 38.3° $\pm$ 14.9° to 8.9° $\pm$ 6.7° after surgery and exacerbated to 17.3° $\pm$ 16.3° at the latest follow-up. The success rate was 73.2% (30/41). The preoperative main curve, apical vertebra translation, compensatory caudal curve and coronal balance distance (CBD) were large in group B. Binary logistic regression analysis revealed that CBD was an independent risk factor for unsuccessful treatment. No statistical difference in the vertebral growth parameters between instrument vertebrae and non-instrument vertebrae. 14 complications in group A and 19 complications in group B. The total SRS-22 and self-image domain scores were superior in group A than in group B.

Conclusions: CEOS patients treated with posterior HV resection and short segment fusion require close follow-up until skeletal maturity. A total of 73.2% of patients received successful treatment, which - may be associated with better SRS-22 scores. Patients with severe deformity before surgery, especially those with large CBD, were more likely to have unsuccessful outcomes.

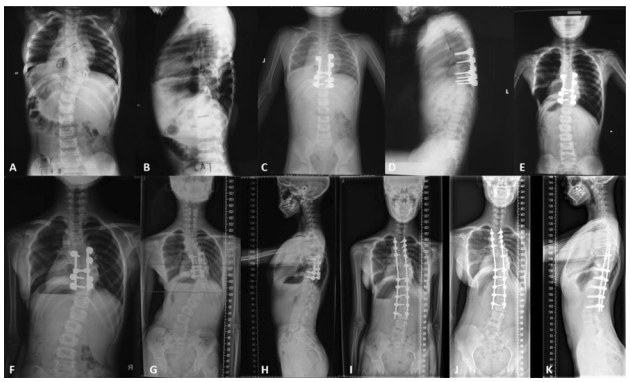
Typical case of successful treatment of CEOS

A 9-year-old male was diagnosed with CEOS caused by a fully segmented T11 hemivertebra (A-F). He underwent T11 hemivertebra resection and T9-L1 segment instrument fusion, and complete deformity correction was achieved (G, H). At 2, 4, 6, 8 and 10 years of follow-up, the deformity correction was well maintained (G-M).



Typical case of unsuccessful treatment of CEOS

A 4-year-old female was diagnosed with CEOS caused by a fully segmented T9 hemivertebra and contralateral segmentation failure combined with rib deformity (A, B). He underwent T9 hemivertebra resection and T5-T11 segment instrument fusion, and the coronal and sagittal deformity was well corrected after surgery (C, D). However, the crankshaft phenomenon was noticed and exacerbated during follow-up (E-3 years; F-6 years; G, H- 9 years). She underwent revision surgery (I) and was followed up for 3 years (J, K).



Paper #13

Severe, focal early onset congenital scoliosis treated with hemivertebra/3-column osteotomy: outcomes of growth guidance vs. distraction-based constructs

Arnaldo Martinez Rivera, MD; Scott Luhmann, MD

Introduction: In severe, focal early onset scoliosis (EOS), optimal surgical treatment should maximally correct deformity three-dimensionally, prevent postoperative progression, allow for maximal spinal growth with minimum clinic/OR visits. Distraction based constructs (DBC) are suboptimal due to foundational fusions which creates iatrogenic spinal shortening, lack apical correction/control, and requires a high number of healthcare episodes. Alternative technique is apical 3-column osteotomy (TCO) and fusion with Growth Guidance Surgery (GGS) to permit maximal spinal growth and stabilize/protect the TCO. Study compares radiographic and clinical outcomes of TCOs for severe, rigid, focal EOS instrumented with GGS and DBC.

Aims/objectives: To investigate effectiveness of GGS and DBC in achieving spinal deformity correction, promoting spine growth, reducing the need for additional surgeries in children with severe, rigid, focal EOS requiring hemivertebra/TCO.

Methods: Database query EOS patients underwent TCO for severe, rigid, focal EOS with GGS or DBC. Prospectively collected clinical and radiographic data. All patients minimum 2-year follow-up. 38 patients: 12 GGS, 20 DBC (5 TGR, 6 MCGR, and 9 VEPTR).

Results: Mean age of patients (pts) at index surgery was 5.25 years (yrs) (range (r), 2–12) in GGS, 4.3 years (r 1–10) in DBC (P = 0.23). Mean yrs follow up (f/u) was 4.11 for GGS, 5.73 for DBC (P = 0.06). All pts had congenital scoliosis. Pts treated with GGS had significantly fewer surgical procedures (mean 2, r 1–3) compared to DBC (mean 4, r 1–11, P = 0.035). In DBC, mean of 6.9 (r, 2–13) lengthening procedures performed. Mean duration of f/u was 4.8 y (2.0–10.0) in GGS and 5.3 y (2.0–14.0) in DBC (P = 0.12). Major coronal deformity of 70.6° (r, 49.6°–97°) in DBC and 62.6° (r, 32°–97°) in GGS (P = 0.26) corrected at initial surgery to 50.38 (DBC; 28%) and 32.3° (GGS; 48%), respectively (P = 0.31). 2-Years Post-Index mean major curve correction held at 50.2 (28%) for DBC, 43 (30%) for GGS (P = 0.14). Last f/u, mean major curve was 58.8° (DBC; 16%) and 42.5° (GGS; 32%) (P = 0.025). Preoperative T1–T12 162.8 mm (r, 120– 212) in GGS and 140.3 mm (range, 84–188) in DBC (P = 0.42). Postoperatively T1–T12 distance increased 8.6 mm/year in GGS and 7.9 mm/year in DBC (P = 0.28). Preoperative T1-S1 distance was 276.2 mm (r, 230– 315) GGS and 222.2 mm (r, 166–268) DBC (P = 0.0421). Postoperatively T1-S1 distance increased 13.3 mm/year growth for GGS,10.8 mm/year growth for DBC (P = 0.04). Seven (58%) pts in GGS, fourteen (70%) in DBS had at least one complication during follow-up (P = 0.23, odds ratio 95% confidence interval 0.3884–19.14).

Conclusions: This is the first study to compare GGS and DBC in the setting of TCOs in severe, rigid, focal congenital EOS. GGS provided better correction of deformity, better T1-S1 growth, reduced number of interventions in pts treated for severe, rigid, focal congenital EOS with TCO when compared with DBS.

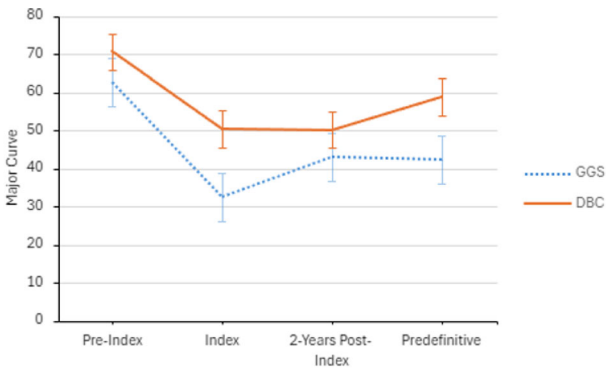


Figure 1. Cobb angles with standard deviations

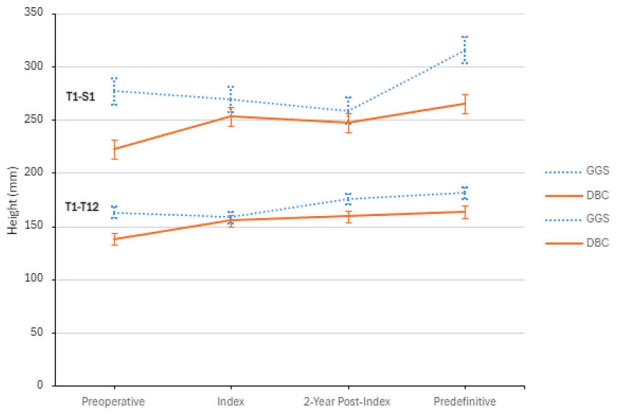


Figure 2. Spinal Height Improvement with standard deviations

Paper #14

Comparative assessment of 3-dimensional true spine length (3D-TSL) between growth-guidance surgery (GGS) and magnetically controlled growing rods (MCGR) for idiopathic early onset scoliosis (i-EOS)

Francisco Narro Garcia; Jennifer Hurry; Richard McCarthy; Ron El-Hawary, MD; Michael Vitale, MD-MPH; Sumeet Garg, MD; Joshua Pahys, MD; Charles Johnston; Pediatric Spine Study Group; Scott Luhmann, MD

Introduction: GGS and MCGR are operations aimed to correct and control severe progressive spine deformity while maintaining growth in i-EOS. Past studies yielded similar results between constructs but used vertical coronal measures (e.g. T1-S1), which don't account for growth outside of plane of measurement due to the spine deformity.
Aims/objectives: Compare outcomes of GGS and MCGR in i-EOS using 3D-TSL, a validated method that measures spine length in 3D.
Methods: A multi-center database was queried for patients undergoing MCGR / GGS surgery for i-EOS with minimum 2-year follow-up. 31 GGS and 130 MCGR patients were included with measurements at preop, postop, and 2 years. Mixed-model statistics allowed for missing data points and included age group, intervention type, and visit as fixed factors with subject as random. Growth was calculated with paired values; thus growth numbers may not equal change in average values.
Results: There were 161 patients (99 female, 61%) whose mean age at surgery was 8.1 yrs. 30% GGS and 8.5% MCGR underwent repeat surgeries within the study period. Age, number of instrumented levels, and preop kyphosis/scoliosis were similar between groups. Total cohort mean scoliosis was 70° preop, 38° postop and 41° at final ($p < 0.001$). GGS reduced the major deformity from 67° to 26° (61% correction), with a 9° loss of correction at 2 years to 35° (46% correction, $p = 0.02$). MCGR reduced the major deformity 71° to 40° (37% correction) but did not significantly lose correction (+ 2°; final 42°, 34% correction) and was not different from GGS at follow-up. GGS maintained kyphosis perioperatively with increase at 2 years (+ 8°, $p = 0.004$), whereas MCGR decreased at postop (− 7°, $p < 0.001$) with increase of 6° at final ($p = 0.002$). Both groups demonstrated T1-S1 height increase from preop (281 mm) to postop (314 mm) and 2-year (336 mm) ($p < 0.001$). 3D-TSL didn't significantly change perioperatively (338 to 342 mm) for either construct. At 2 years GGS 3D-TSL increased 32.6 mm (16.3 /year), while MCGR increased 27.5 mm (13.8/year) ($p = 0.29$).
Conclusions: In i-EOS MCGR and GGS resulted in increase in T1-S1 height preop to postop, but there was no change in 3D-TSL. Post-op to Final 3D-TSL identified growth up to 2 years postop in both constructs. T1-S1 height changes suggest that changes in deformity reduce reliability of planar measurements when assessing spine growth. 3D-TSL constitutes a more reliable indicator of spine growth after i-EOS surgery. Overall, GGS and MCGR offer similar outcomes 2 years postop as assessed by 3D-TSL.

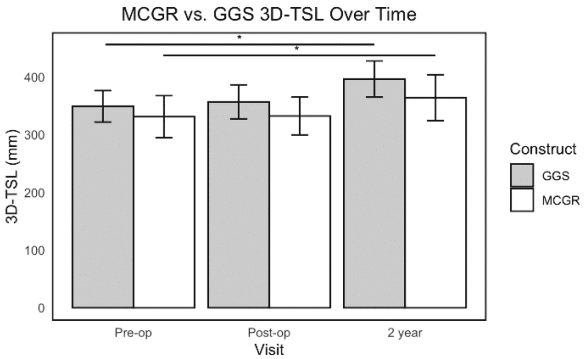


Figure 1 MCGR vs. GGS 3D-TSL Over Time. 3D-TSL increased from preop and postop to 2 year only (p.0010> No difference between constructs at any time. Significance defined as p<.05 and shown as * below

Table 1 Comparison of T1-S1 Coronal height and 3D-TLS over time

	GGS 3D (mm)	GGS Coronal (mm)	MCGR 3D (mm)	MCGR Coronal (mm)
Preop	352.6	302.0	334.4	274.5
Postop	356.1	328.3	338.0	310.3
Final	386.4	350.6	366.6	332.4
Change Preop to Postop	+1.0	+24.4*	+2.4	+31.9*
Change Postop to Final	+32.6*	+24.7*	+27.5*	+21.7*

Paper #15

Growth guidance surgery: what makes it fail?

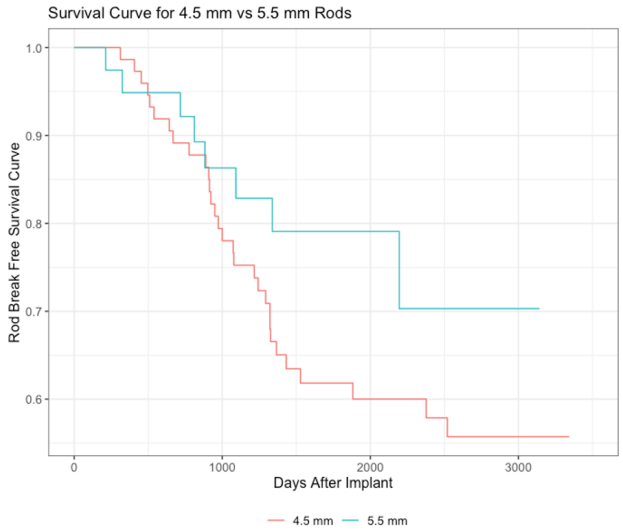
William ElNemer; Zaid Elsabbagh; Myung-Jin Cha; Lindsay Andras, MD; Behrooz Akbarnia; David Bumpass; Scott Luhmann, MD; Richard McCarthy; Pediatric Spine Study Group; Paul Sponseller, MD

Introduction: The Growth Guidance surgery (GGS) reduces reoperation rates compared to other growth-sparing methods yet is still associated with instrumentation complications. Our study used a multicenter early onset scoliosis database to determine the characteristics of these implant failures.
Aims/objectives: We hypothesize that rods break closer to the curve apex. Thicker rods are associated with less breakage. Idiopathic patients will also have more rod breakages.
Methods: The Pediatric Spine Study Group multicenter database was analyzed for patients who underwent GGS. All radiographs were evaluated for instances of rod breakage, screw pull out, rod pull out, and outgrowth of implants. Complication and reoperation notes were evaluated for prominence of instrumentation, rods breaking through the skin, and deep wound infection. Descriptive statistics, chi-square test, and Cox-proportional hazard models were utilized to determine the differences in complications.
Results: 136 patients were included. Rod thicknesses were 4.5 mm (n = 83, 61%), 5.5 mm (n = 45, 33%), or unknown (n = 8, 6%). There were 191 instrumentation complications, comprising 60 (31%)

rod breakages, 6 (3%) rod pull-outs, 47 (25%) screw pull-outs, 34 (18%) instances of prominence, 6 (3%) instances of skin breakage, 28 (15%) instances of outgrowing the rods, and 10 (5%) other complications. Rod breakages more often occurred below the apex vs. above (68% vs. 32%, p = 0.007) and ≤ 4 vertebrae closer to the deformity apex (81% vs. 19%, p < 0.001). Instrumentation prominence more often occurred at the proximal vs. distal instrumentation (77% vs. 24%, p = 0.004). Compared to the population distribution of rod thickness, breakage (86% vs. 14%, p < 0.001) and instances of prominence (85% vs. 15%, p = 0.012) occurred more often in 4.5 mm vs. 5.5 mm rods. Time to first rod breakage was not significantly different between 4.5 mm and 5.5 mm rods (946 days vs. 1078 days, p = 0.587). Idiopathic and syndromic patients accounted for disproportionately greater and fewer, respectively, rod breakages compared to their population distribution (p = 0.001).

Conclusions: When possible, thicker rods should be used to minimize the risk of rod breakage and prominence. Rod reinforcement should be considered near the apex of deformity to reduce rod breakage. Idiopathic patients should be closely monitored for rod breakage, most likely due to their increased activity level.

Rod Breakages Survival Curve for Patients with 4.5 mm vs. 5.5 mm rods



Paper #16 Abstract replaced due to travel issue

Comparison of surgical outcomes for NF-1 dystrophic scoliosis between definitive fusion and growing rods (TGR and MCGR): results from the pediatric spine study group database

Michael Lam; Kenny Yat Hong Kwan; Pediatric Spine Study Group

Introduction: No definitive conclusion has been drawn regarding the efficacy and safety of definitive fusions in NF-1 dystrophic scoliosis due to small patient number, retrospective cohort, mixed aetiology in existing studies, and lack of non-radiographic outcomes.

Aims/objectives: The purpose of this study was to investigate the surgical outcomes of fusion vs. growing rods in NF-1 dystrophic scoliosis.

Methods: This study is a retrospective review of prospectively collected cohort. Patients with NF-1 scoliosis treated with definitive fusion, TGR and MCGR with a minimum of 2-year follow-up were identified from the PSSG database.

Results: 33 patients between age 8–11 were identified. 10 had definitive fusion (DF), and 23 underwent growing rods (GR) (8 TGR and 15 MCGR). Patients in DF group were older than those in GR group at index surgery (10.8 vs. 9.4 yr, p < 0.001). Preoperative data, sex ratio and preoperative major Cobb angles were not significantly different. At minimum of 2 year follow-up, there was no significant difference in Cobb correction rate (23.6 vs. 32.7%, p = 0.31), T1-S1 height gain (52.4 vs. 48.3 mm, p = 0.7), FVC% predicted (81.3 vs. 68.8%, p = 0.52), FEV1% predicted (82 vs. 62.7%, p = 0.33), and mean complication rate per patient (0.1 vs. 0.65, p = 0.07). However, mean number of surgeries was lower in DF vs. GR groups (1.3 vs. 4.0, p < 0.001). Subgroup analyses between TGR and MCGR groups showed no significant differences in Cobb correction rates, T1-S1 height gain, FVC% predicted, FEV1% predicted, and complication rate per patient at minimum of 2 years. However, patients in TGR group had more surgeries (7.4 vs. 2.3, p < 0.001) compared with MCGR group. One-way ANOVA revealed association between elevated complication rate and TGR (p = 0.02) but not DF (p = 0.77) or MCGR (p = 0.71).

Conclusions: Definitive fusion achieved similar surgical outcomes, pulmonary function with fewer complications than growing rods in NF-1 dystrophic scoliosis. MCGR achieved similar outcomes compared with TGR with fewer surgeries and lower complication rates per patient. Definitive fusion can be considered for NF-1 dystrophic scoliosis at an earlier stage despite skeletal immaturity.

Results

Comparison of surgical outcomes between DF and GR (Principal analysis) and between TGR and MCGR (Subgroup analysis).

Principal analysis		
Treatment	DF	GR
Major Cobb (degrees)		
Pre-op	67.9 ± 25.0	73.5 ± 21.9
Corr. post-op	42.1 ± 22.9	41.2 ± 21.9
Corr. at 2y	23.6 ± 24.8	32.7 ± 15.9
T1-S1 (mm)		
Pre-op	324.7 ± 37.0	308.3 ± 45.5
Increase at 2y	52.4 ± 16.6	48.3 ± 26.8
No. of surgeries***	1.3	4
Mean no. of IRC	0.1	0.65
FVC % predicted	81.3	68.8
FEV1 % predicted	82	62.7

Subgroup analysis		
Treatment	TGR	MCGR
Major Cobb (degrees)		
Pre-op	74 ± 15.4	73.3 ± 25.2
Corr. post-op	42.8 ± 14.7	40.3 ± 25.4
Corr. at 2y	32.3 ± 15.6	30.8 ± 18.7
T1-S1 (mm)		
Increase at 2y	44.6 ± 30.0	51.2 ± 25.3
No. of surgeries***	7.4	2.3
Mean no. of IRC*	1.38	0.27
FVC % predicted	45.5	80.5
FEV1 % predicted	45.5	71.2

Paper #17

Rod fracture after MCGR is related to rod diameter but lower than TGR

Ritt Givens, BS; Matthew Weintraub, BSE; Omar Taha, BS; Matan Malka, BA; Kevin Lu, MS; Paul Sponseller, MD; Peter Strum, MD, MBA; John Emans, MD; Francisco Perez Grueso, MD; Michael Vitale, MD-MPH; Benjamin Roye, MD-MPH; Pediatric Spine Study Group

Introduction: Rod fracture is a significant complication of growth friendly surgery for early onset scoliosis (EOS). This study uses a large sample of patients with growth friendly implants to quantify and compare failure rates in magnetically controlled growing rods (MCGR) and traditional growing rods (TGR).

Aims/objectives: To quantify risk of rod fracture after growth friendly EOS surgery, compare risk of fracture between MCGR and TGR, and compare risk of fracture based on rod diameter.

Methods: EOS patients undergoing TGR or MCGR instrumentation were identified from the Pediatric Spine Study Group registry. Patients with unilateral constructs and those with under two years of follow up were excluded. Each bilateral construct represented two unique rods. Patients with rod fracture within two years of surgery were identified. Subgroup analyses were performed between rods with diameters $\leq$ 5 mm and $>$ 5 mm and between MCGR and TGR. A chi-squared test was used to compare incidence of rod fracture amongst subgroups. To account for difference in follow up, a log rank survival analysis was performed between subgroups over a 5-year period. A Mann–Whitney U test was performed to compare patient characteristics between subgroups.
Results: 1,588 patients met inclusion criteria, representing 3,176 rods. 1,251 (39.4%) were TGR and 1,925 (60.6%) were MCGR. 2,225 (70.1%) rods had a diameter $\leq$ 5 mm and 951 (29.9%) had a diameter $>$ 5 mm. There was no clinically important difference in preoperative cobb angle or maximum kyphosis between MCGR and TGR groups. At index surgery, patients with MCGR were slightly older (7.6 Vs. 7.1, p = 0.001), taller (115 cm Vs. 109 cm, p $<$ 0.001), and heavier (20 kg Vs. 18.5 kg, p $<$ 0.001), but BMI was similar. The distribution of etiologies also differed between rod types (p $<$ 0.001) with more TGRs in congenital and syndromic patients, and more MCGRs in idiopathic and neuromuscular patients.77 (4.85%) patients experienced a rod fracture within two years of surgery, representing a total of 97 rod fractures, resulting in an overall risk of rod fracture of 3.05% with a mean and median time to fracture of 1.3 years and 1.4 years respectively. Risk of fracture was higher in TGR vs. MCGR (4.96% Vs. 1.82%, p $<$ 0.001). Amongst MCGR's, rods with diameter $\leq$ 5 mm fractured at a higher rate than those $>$ 5 mm (2.65% Vs. 0.63%, p = 0.001). Table 1 summarizes 2-year fracture results. The 5-year survival analysis, shown in Fig. 1, corroborated our 2-year findings: TGR survival was decreased when compared to MCGR (p $<$ 0.001), and amongst MCGR's there was decreased survival in rods with diameter $\leq$ 5 mm (p = 0.004). Interestingly, TGR survival was not affected by rod diameter.
Conclusions: Although rare, the risk of rod fracture in EOS patients may be higher than previously reported. Overall risk of rod fracture is higher with TGR compared to MCGR, and while smaller rod diameter led to increased risk of fracture in MCGR constructs, rod diameter was not associated with fracture risk in TGR.

Table 1 Incidence of 2 years post-operative rod fracture

	Fracture (n)	Intact (n)	Incidence (%)	p-value
Total rods	97	3079	3.05%	
Total patients	77	1511	4.85%	
Rod Type				
MCGR	35	1890	1.82%	< 0.001
TGR	62	1189	4.96%	
Rod diameter				
MCGR $\leq$ 5mm	30	1104	2.65%	0.001
MCGR > 5mm	5	785	0.63%	
TGR $\leq$ 5mm	53	1038	4.86%	0.663
TGR > 5mm	9	150	5.66%	

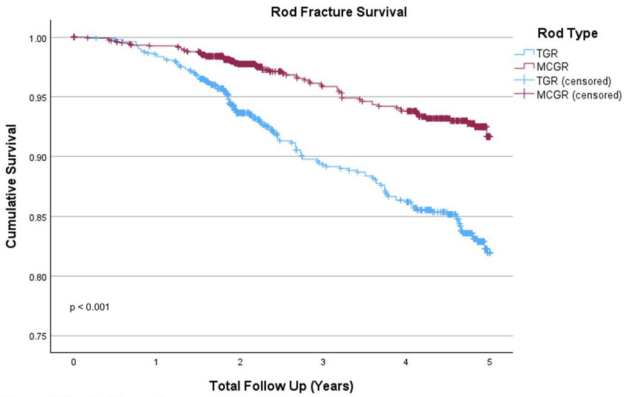


Figure 1 Survival by rod type

Paper #18

Complications of magnetically controlled growth rods (MCGR) using the modified Clavien-Dindo-Sink (mCDS) classification

Vineet Desai; Daniel Yang; Lucas Hauth, BS; Katerina Kourpas; Patrick Cahill, MD; John Flynn, MD; Jason Anari, MD

Introduction: Surgical treatment for early onset scoliosis (EOS) has transitioned away from rods requiring open lengthening to a remote lengthening technology, the magnetically controlled growing rod (MCGR). Complication rates for the surgical management of EOS using MCGRs remain as high as 33% at 2 years follow-up. The validated mCDS classification is a recently popularized system to describe the severity of complications across pediatric spine surgery.
Aims/objectives: The goal of this study is to analyze the complication rate of MCGR in EOS using the mCDS system.
Methods: A retrospective analysis was conducted at a single center from 2013–2022 for all EOS patients treated with MCGR with a minimum of 2 years follow-up from index surgery. Complications were classified using the mCDS classification system by 2 individual evaluators and agreed upon. A classification addition of Grade 0 was defined as an occurrence that did not result in a change of protocol or follow-up but warranted recording.
Results: 63 patients with EOS underwent MCGR, with a mean age of 7.91 years, mean coronal Cobb angle of 79.2°, and mean follow-up of 3.8 years. 40 (63%) patients experienced a total of 60 complications. The most common complication was Grade IIIb, with 27 patients (43%) requiring at least one unplanned surgical intervention. Within this group, 13 patients (21%) required at least one irrigation & debridement (I&D), 16 (25%) required at least one hardware revision, 6 (10%) required unplanned conversion to fusion, and 1 (2%) required unplanned conversion to traditional growing rods for failure to lengthen. The second most frequent complication was Grade II (21%), followed by both Grade I and Grade 0 (16% each). An example of Grade 0 was a patient who developed an asymptomatic bursa over instrumentation, but did not require any treatment. No patients experienced Grade IVa, IVb, or V complications.
Conclusions: Surgeons can counsel families of EOS patients that despite best efforts with the MCGR, complication severity remains approximately 40% for children needing an unplanned procedure or additional surgery.

Grade	Number of Patients with MCGR Complications (Percentage)
0	10 (16%)
I	10 (16%)
II	13 (21%)
IIIa	0 (0%)
IIIb	27 (43%)
IVa	0 (0%)
IVb	0 (0%)
V	0 (0%)

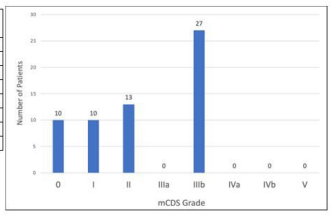


Figure 1 Complications of MCGR assessed using the Modified Clavien-Dindo-Sink (mCDS) classification system

Paper #19

Law of diminishing returns revisited: a 3D analysis of spine growth

Ron El-Hawary, MD; Jennifer Hurry; Scott Luhmann, MD; Joshua Pahys, MD; John Emans, MD; Jack Flynn; Francisco Perez Grueso, MD; George Thompson; Pediatric Spine Study Group

Introduction: In 2011, the "law of diminishing returns" study concluded that with repeated lengthenings of traditional growing rods (TGR), that T1-S1 still increases; however, this gain tended to decrease with each subsequent lengthening and over time. This landmark publication heralded a paradigm shift in the treatment of early onset scoliosis with the popularization of using casting as a "delay tactic" prior to TGR surgery. However, the one-dimensional measurement of spine growth in that study does not fully account for 3D growth of the spine.
Aims/objectives: To determine if using the validated 3D True Spine Length (3D TSL) technique will yield a law of diminishing returns at 5 years post operative TGR.
Methods: From an international pediatric spine registry, patients with idiopathic EOS treated with TGR who had minimum 5-year ± 12 months post-index, minimum 5 lengthening surgeries, and with measurable PA and lateral radiographs were identified. Radiographs were independently evaluated using the 3D TSL technique.
Results: 37 patients (23 Female) were included. At pre-op TGR, mean age was 6.3 years (1.6–11.3), scoliosis 77° (32°–138°), kyphosis 54° (7°–110°). Post-op had 13 instrumented levels (10–16), and a 3D TSL of 320 mm. The final measured radiographs were 4.9 (4.0–5.8) years post-index, mean age of 11.2 years, scoliosis 48°, kyphosis 52°, and with a mean total growth of 61 ± 24 mm. 3D TSL was averaged for lengthenings (L) 1–3 (328 ± 38 mm), 4–6 (357 ± 44 mm), and 7–9 (380 ± 51 mm) (Fig. 1). For those with paired data, 3D growth between L1-3 and L4-6 was not different than 3D growth between L4-6 and L7-9 (22 ± 11 mm vs. 23 ± 13 mm, p = 0.62), neither was the growth per year for those timeframes (15 ± 7 mm and 15 ± 12 mm, p = 0.99). Similarly, 3D growth from 1–2 years post-op to 3–4 years post-op (27 ± 10 mm) was not different than the change from 3–4 years to 5–6 years (27 ± 17 mm, p = 0.97) (Fig. 2).
Conclusions: 3D spine growth did not diminish over 9 lengthenings or over 5 years post-operative TGR for this population of children with idiopathic EOS.

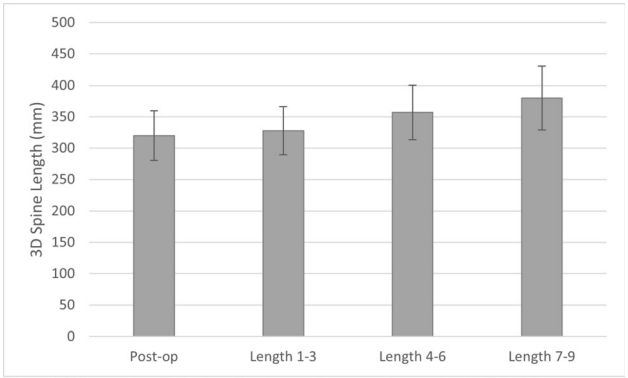


Figure 1 3D spine lengths by lengthening number, error bars = standard deviation

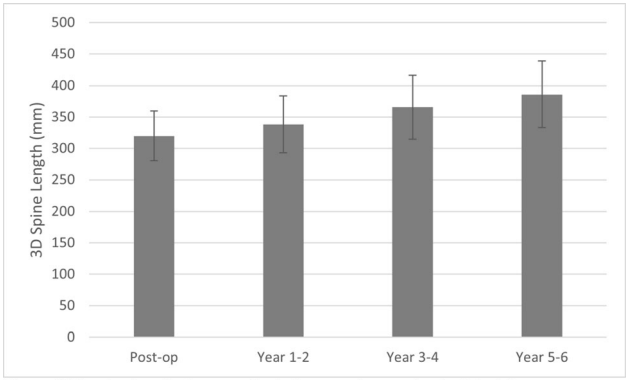


Figure 2 3D spine lengths by year after index, error bars = standard deviation

Paper #20 Abstract replaced due to travel issue

Beyond radiographic success: patient-reported outcomes in adults with early onset scoliosis following surgical intervention

Kenney Ki Lee Lau; Kenny Yat Hong Kwan; Jason Pui Yin Cheung; Janus Siu Him Wong; Graham Ka Hon Shea; Karlen Ka Pui Law; Kenneth Man Chee Cheung

Introduction: The prognosis of surgically treated subjects with EOS into adulthood has been lacking.
Aims/objectives: We aimed to investigate the patients' perspectives on satisfaction with surgical treatment.
Methods: We included all surgical candidates with EOS who had undergone index spinal surgery for scoliosis correction between 2009 and 2013. The minimum duration of post-operative follow-up was ten years at the time of survey completion. Three questionnaires were used in this study, comprising the revised Scoliosis Research Society questionnaire (SRS-22r), the Patient-Reported Outcomes Measurement Information System (PROMIS-29), and the World Health Organization Quality of Life (WHOQOL-BREF). Regarding the treatment satisfaction from SRS-22r, we isolated the two questions for further analysis.
Results: There were 29 participants who completed the survey, and thereby included in the study (i.e., a response rate of 43% and a dropout rate of 6%). Amongst them, 48%, 38%, and 14% received posterior spinal fusion, magnetically controlled growing rods, and traditional growing rods, respectively. The average duration after the index spinal surgery was 12.6 ± 2.2 years. According to the multivariable linear regression model (R-square = 0.690, $p < 0.001$), an increase in SRS-22r mental health (p = 0.008) and PROMIS-29 social participation scores (p = 0.004) corresponded to 0.511 and 0.055

points increases in satisfaction. Every unit increase in PROMIS-29 fatigue (p = 0.043) and WHOQOL-BREF physical domain scores (p = 0.007) was in conjunction with 0.019 and 0.040 points decreases in satisfaction. SRS-22r self-image (p = 0.056) and WHOQOL-BREF environmental domain scores (p = 0.076) were included in the model but did not reach statistical significance.
Conclusions: To improve the long-term quality of life in surgical candidates with EOS, we evidenced that mental health, social participation, fatigue, and physical health were significant factors associated with treatment satisfaction. Interestingly, demographic and radiographic parameters were not correlated to it in our cohort.

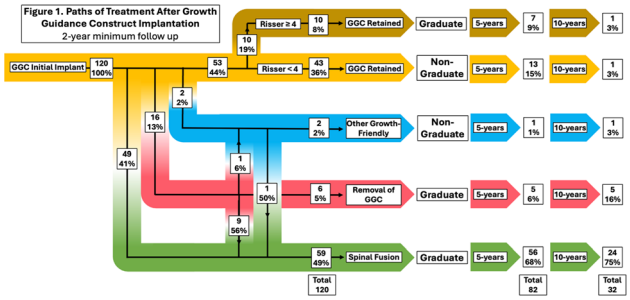
Paper #21

Spinal fusion should be the definitive end point of growth guidance surgery

William ElNemer; Zaid Elsabbagh; Myung-Jin Cha; Lindsay Andras, MD; Behrooz Akbarnia; David Bumpass; Scott Luhmann, MD; Richard McCarthy; Pediatric Spine Study Group; Paul Sponseller

Introduction: Growth guidance construct (GGC) treatment typically concludes with "graduating", marking the end of GGC treatment. Graduates were patients who (1) underwent posterior spinal fusion (PSF), (2) have GGC removed or (3) reached skeletal maturity with GGC retained. Non-graduates were (1) converted to another growth friendly construct (GFC) or (2) did not reach skeletal maturity with GGC retained.
Aims/objectives: We aimed to qualify the treatment course of patients after concluding GGC treatment. We hypothesize: GGC removal will eventually lead to PSF to control growing curves. Undergoing PSF after GGC treatment will risk post-operative infections while retaining GGC will risk further instrumentation complications.
Methods: The Pediatric Spine Study Group multicenter database was analyzed for patients who underwent GGC implantation with a minimum 2-year follow-up. Radiographs were evaluated for major cobb angle and skeletal maturity (Risser Score $\geq$ 4). Reasons for transitioning off GGC treatment were qualified by the authors. Subsequent surgical treatments and complications were also tracked.
Results: General: 120 patients were included. At latest follow up, 10 (8%) patients reached skeletal maturity with retained GGC, while 43 (36%) did not reach skeletal maturity (Fig. 1). Additionally, 49 (41%) underwent PSF, 2 (2%) were converted to another GFC and 16 (13%) had GGC removed. Common reasons for transitioning from GGC were deformity progression (n = 21, 18%), rod breakage (n = 14, 12%), outgrowing the rods (n = 13, 11%), screw pull out (n = 6, 5%), deep wound infection (n = 6, 5%) and other (n = 7, 6%) Hypothesis 1: Of these 16 patients who had GGC removed, 9 (56%) later required PSF, 1 (6%) was converted to another GFC, while the remaining 6 (31%) kept the GGC removed at latest available follow-up. One (6%) of the two patients who was converted to another GFC eventually underwent PSF. Patients underwent PSF at an average cobb of 54° $\pm$ 16° whereas patients who had their GGC removed did so at an average cobb of 43° $\pm$ 13° (P = 0.001) which then progressed to an average of 68° $\pm$ 13° over 1.8 $\pm$ 1.5 years (27° $\pm$ 31°/year). Finally, when limiting to 10-year follow-up (n = 32), 24 (75%) patients required PSF, while only 5 (16%) still had GGC removed. Hypothesis 2: Of the 10 patients who retained GGCs, 2 (20%) experienced instrumentation complications. No patients who underwent PSF experienced any instrumentation complications after PSF. Importantly, no patients experienced a deep wound infection after PSF or retaining GGC.
Conclusions: Many patients who elect for GGC removal eventually undergo PSF due to rapid deformity progression despite a smaller average cobb angle at removal than people who are immediately fused. At later follow-up periods most patients required PSF. We did not detect an increased risk of infection with spinal fusion after removal, while patients retaining GGC had a 20% complication after reaching skeletal maturity rate, thus further encouraging PSF end point.

Paths of treatment after growth guidance construct implantation
A visual representation of this cohort's treatment course for treatment of their Early Onset Scoliosis with Growth Guidance Construct (GGC). Yellow: Retained GGC at latest follow-up Blue: Other Growth Friendly Treatment Red: Removal of GGC Green: Posterior Spinal Fusion.



Paper #22

Surgical indications and outcomes for upper cervical instability in Down syndrome patients

Joshua Pahys, MD; Richard Anderson; Burt Yaszay; Matthew Oetgen; Amer Samdani, MD; Steven Hwang, MD; Pediatric Spine Study Group; Douglas Brockmeyer, MD

Introduction: Upper cervical instability has been reported in 2–15% of patients with Down Syndrome (DS). This is the largest study to date to describe the indications and surgical outcomes of spinal fusion for upper cervical instability in DS patients.
Aims/objectives: To evaluate the surgical indications utilized and outcomes for treatment of upper cervical instability in Down Syndrome patients.
Methods: Retrospective review of a multicenter international database of all DS patients who underwent C0-C2 posterior spinal fusion (PSF) or C1/2 PSF with a minimum one year follow-up (avg: 30 months; range: 12–120 months). Modern instrumentation of occipital plate, plate/rods, and/or screws/rods were used in all cases. Minimum acceptable follow up was determined by successful fusion confirmed with CT scan or dynamic radiographs.
Results: 40 DS patients met inclusion criteria, with a mean age at surgery of 9.7 years (range 1.8–18). Congenital anomalies included flattened atlanto-occipital facet (n = 23, 58%) and os odontoideum (n = 12, 30%). 18/40 patients had an available preop MRI, of which 11/18 (61%) demonstrated cord signal change. The mean condyle-axial interval (CAI) translation on preop dynamic X-rays was 12 mm for C0-C2 PSF patients (n = 23). The mean atlanto-dens interval (ADI) was 8.9 mm (range: 5–13 mm) for C1/2 PSF patients (n = 17). Autograft (rib or iliac crest) was used in 87% of C0-C2 and 65% of C1/2 PSF cases, with the remainder using allograft. 11/40 patients were placed in a halo vest postop (C0-C2: n = 5; C1/2: n = 6). Revision surgery for nonunion was required in 3/23 (13%) C0-C2 patients, all of whom utilized autograft. No C1/2 patients (0/17) required revision surgery. There was no significant difference in nonunion rates for graft selection or halo vest immobilization. Graft selection and halo vest immobilization did not have a statistically significant effect on nonunion rates.

Conclusions: All patients demonstrated at least one of the following surgical indications for C0-C2 or C1/2 PSF: ADI ≥ 8 mm, CAI > 10 mm on static X-rays, CAI translation > 10 mm on dynamic X-rays, and/or cord signal change on MRI. Revision surgery for nonunion was required in 13% of C0–C2 and 0% of C1/2 PSF patients. Autograft was used in the majority of cases (78%), but did not significantly impact nonunion rates. This large international multicenter study demonstrated a relatively low revision rate with PSF for Down syndrome patients with craniocervical instability using modern instrumentation.

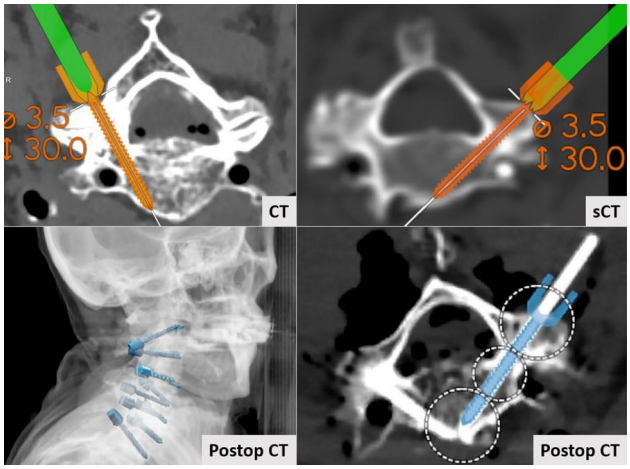
	C0-C2 PSF	C1/2 PSF
Total	23	17
Age at surgery (mean)	10.8 years	8.8 years
Flattened atlanto-occipital facet	70% (n=16)	35% (n=6)
Os-odontoideum	22% (n=5)	41% (n=7)
Autograft used (rib/iliac crest)	87% (n=20)	65% (n=11)
Halo-vest immobilization postop	21% (n=5)	35% (n=6)
Nonunion	13% (n=3)	0% (n=0)

Paper #23

Safety and accuracy of cervical pedicle screw navigation based on AI-generated, MRI-based synthetic-CT versus CT

Peter Lafranca, MD; Yorck Rommelspacher, MD, PhD; Sander Muijs, MD, PhD; Sebastian Walter, MD, PhD; Tijl van der Velden; Rene Castelein, Prof. Dr.; Keita Ito; Peter Seevinck; Tom Schlosser

Introduction: Application of pedicle screw placement in the cervical spine may lead to critical complications due to the surrounding neurovascular structures. Several solutions for navigated cervical pedicle screw placement are available and all these navigation systems require pre- and/or intra-operative 3D CT, C or O-arm imaging. Especially in young patients, it is important to minimize the exposures to ionizing radiation. MRI based synthetic CT (sCT) is a novel method to visualize osseous structures with a CT-like contrast without the use of any ionizing radiation.
Aims/objectives: This investigator-initiated experimental study aims to test the safety and accuracy of MRI-based sCT spinal navigation by assessing whether this is non-inferior to CT for cervical pedicle screw placement.
Methods: 5 cadavers were scanned with CT and BoneMRI. From the BoneMRI sequences, AI-generated sCT scans were made. Four spine surgeons performed surface matching and navigated k-wire placement from levels C2 to C7 bilaterally. Randomization for CT vs. sCT, surgeon, and side was performed with a 1:1 ratio. A postoperative CT was acquired and 3.5 mm virtual screws were simulated on the k-wires. Medial and lateral breaches were verified by an independent researcher. Breach rate was assessed using the Gertzbein-Robbins classification, with grade A and B as a satisfactory screw position. Angulation and distance between intraoperative and postoperative screw positions at pedicle level were evaluated for both CT and sCT.
Results: In total 60 k-wires were placed, 3 wires (1 CT-, 2 sCT-guided) were excluded due to complete wire dislocation during transport. Of the 29 CT-navigated screws, 23 were grade A, 5 grade B and 1 was grade C. Thus, 97% were within the pedicle or < 2 mm exceeding the pedicle cortex. Of the 28 sCT navigation screws, 23 were grade A and 5 grade B, giving in 100% of the cases satisfactory screw positions. Average distance between intraoperative and postoperative screw positions was 2.1 ± 0.5 mm for CT and 2.6 ± 0.9 mm for sCT. Average angulation between intraoperative and postoperative screw positions was 4.7° ± 1.0° for CT and 5.5° ± 1.2° for sCT.
Conclusions: Radiation-free, MRI-based synthetic CT is non-inferior to conventional CT for surface matching and safe and accurate navigated cervical pedicle screw placement.
Screenshot of intraoperative screw planning on CT and sCT
This image shows postoperative virtual screws placed over k-wires.



Paper #24

Spine MRI in patients with arthrogryposis is compulsory due to high rates of tethered cord/low-lying conus medullaris and scoliosis

Arun Hariharan, MD, MS; Hans Nugraha, MD; Aaron Huser, DO; David Feldman, MD; Kaveh Asadi, MD, PhD

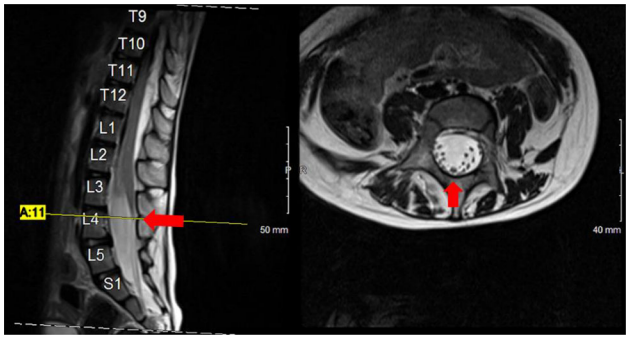
Introduction: Arthrogryposis Multiplex Congenita (AMC) encompasses congenital conditions with joint contractures in 2 or more joints. Patients with AMC may have scoliosis and neural axis malformations. There have been no studies examining the prevalence of tethered cord in this population.
Aims/objectives: The aim of the study was to determine the incidence of tethered cord (TC), characterized by a low-lying conus medullaris (LLCM), and secondarily, scoliosis, in children with AMC.
Methods: Patients less than 18 years old with a diagnosis of AMC and a spine MRI were identified. The presence of a tethered cord was defined as a low-lying conus with termination at or below the lower third of the L2 vertebral body. MRIs were independently reviewed by a pediatric neurosurgeon and a pediatric orthopedic surgeon. The medical records of patients with AMC who underwent detethering were reviewed to evaluate pre- and postoperative clinical findings. Prevalence of tethered cord in pediatric patients was compared to published normative data using chi-square analysis.
Results: Forty-two of 105 patients (40.0%) had tethered cords, while 37 patients (35%) had spinal deformities, mainly scoliosis (92%). Of the 42, 21 (50%) had scoliosis with a mean Cobb angle of 52o (SD 28). There was a greater percentage of patients with AMC and a tethered cord compared to the unaffected population ($p < 0.0001$). Sixteen patients underwent detethering through filum terminale sectioning. Nine patients had preoperative neurologic deficits in addition to their AMC. There were no postoperative complications. All

patients had improvement in their bowel & bladder symptoms within 3 months after their detethering procedure.

Conclusions: Tethered cord is more prevalent in the pediatric population with AMC compared to those without AMC. There is also a high rate of scoliosis among those with TC. MRI is recommended for all patients with AMC due to its high prevalence of TC. Although not a benign procedure, surgical detethering may have potential benefits for children with AMC.

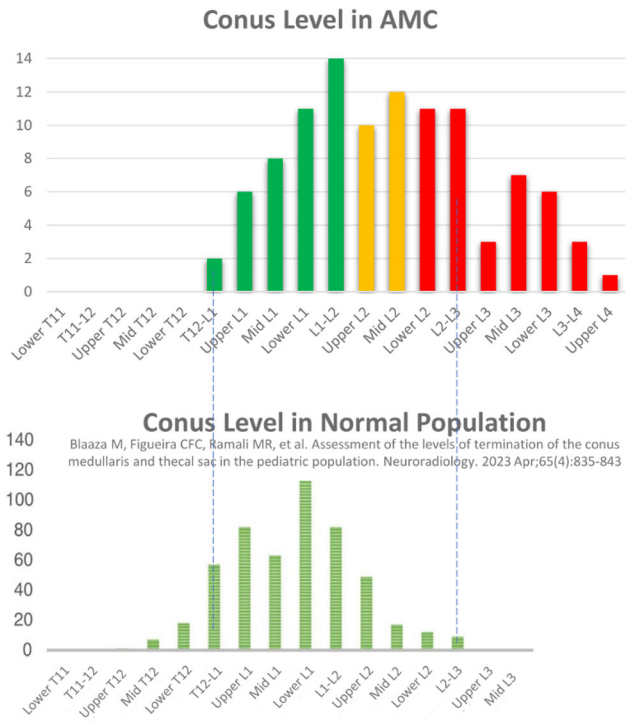
Low lying conus/tethered cord

MRI demonstrating a low-lying conus terminating at L4 in a 4-year-old patient with knee flexion-contractures, urinary incontinence, and constipation.



Conus level in pediatric population with AMC compared to the normal pediatric population

Graphs demonstrating the distribution of conus termination levels in the AMC population compared to the general population.



Paper #25

Rib-on-pelvis deformity: a modifiable driver of pain and poor health-related quality of life in cerebral palsy

Vineet Desai; Margaret Bowen; Jason Anari, MD; John Flynn, MD; Burt Yaszay; Paul Sponseller, MD; Mark Abel; Joshua Pahys, MD; Harms Study Group; Patrick Cahill, MD

Introduction: Cerebral palsy (CP) often presents with a sweeping thoracolumbar scoliosis and pelvic obliquity. With severe pelvic obliquity, the ribs come into contact with the high side of the oblique pelvis, termed rib-on-pelvis deformity (ROP). ROP may result in costo-iliac impingement (pain with ROP), and can adversely affect breathing and sitting balance.

Aims/objectives: The study goal was to evaluate whether CP patients with ROP have worse health-related quality of life (HRQoL) before surgery and a greater improvement in HRQoL after surgery.

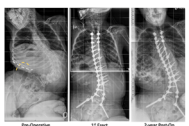
Methods: A retrospective analysis of a prospectively collected, multicenter, international registry was performed for all non-ambulatory patients with CP treated with spinal fusion with at least 2-year follow-up. HRQoL was measured via the Caregiver Priorities & Child Health Index of Life with Disabilities (CP-CHILD) questionnaire domains (0 = most disability, 100 = least disability). ROP was defined as having a rib distal to the superior portion of the iliac crest on preop upright radiographs. The ROP group and control group without ROP were compared regarding all domains of CP-CHILD. Multiple linear regression was used to control for curve apex location, coronal Cobb angle, tone, pelvic obliquity, and percent Cobb angle correction (2-years post-op).

Results: 401 patients met inclusion criteria. The cohort was 52% female with mean age of 14.0 years, mean Cobb angle of 82.7°, and mean pelvic obliquity of 26.4°. 199 patients (49.6%) had ROP while 202 patients (50.4%) did not. ROP was independently associated with worse preoperative Activities of Daily Living (ADLs), Positioning/Transfers/Mobility (PTM), comfort & emotions (C&E), health, and total score via the CP-CHILD questionnaire ($p < 0.05$). Patients with preop ROP experienced a greater improvement in ADLs, PTM, C&E, and total score at 2-years post-spinal fusion than patients without ROP ($p < 0.05$).

Conclusions: CP patients with rib-on-pelvis deformity experience more pain and worse HRQoL than patients without this deformity. These patients experienced a greater improvement in HRQoL after spinal fusion measured via the CP-CHILD questionnaire.

Rib-on-pelvis deformity and mean CP-CHILD scores at preoperative and 2-year post-op timepoints.

CP-CHILD Domain	Rib-on-Pelvis Deformity		No Rib-on-Pelvis Deformity		Did patients with ROP experience greater improvement than those without ROP at 2-years post spinal fusion?	P value
	Preoperative	2 Years Post-Spinal Fusion	Preoperative	2 Years Post-Spinal Fusion		
ADLs/Personal Care	35.3	45.8	42.8	46.2	**Yes**	**< 0.01**
Positioning, Transferring, & Mobility (PTM)	28.8	42.8	40.8	44.9	**Yes**	**< 0.01**
Pain (Comfort & Emotions)	63.6	83.0	83.2	84.4	**Yes**	**< 0.01**
Communication & Social Interaction	51.4	56.9	56.2	58.1	No	0.06
Health	53.1	60.4	58.0	64.6	No	0.96
Overall Quality of Life	58.8	71.4	66.4	73.9	No	0.21
Total CP-CHILD Score	45.9	57.6	56.4	59.5	**Yes**	**< 0.01**



Paper #26

Do cerebral palsy scoliosis patients with postoperative complications have worse CPCHILD scores two years after surgery?

Vineet Desai; Margaret Bowen; Jason Anari, MD; John Flynn, MD; Burt Yaszay; Paul Sponseller, MD; Mark Abel; Harms Study Group; Patrick Cahill, MD

Introduction: The Caregiver Priorities and Child Health Index of Life with Disabilities (CPCHILD) questionnaire is a validated, reliable instrument that is frequently used in studies investigating health-related quality of life (HRQOL) in patients with severe Cerebral Palsy (CP) scoliosis. Research regarding whether complications after surgery for CP scoliosis patients affect long-term HRQOL via the CPCHILD questionnaire remains limited.
Aims/objectives: The goal was to determine whether CP scoliosis patients with postoperative complications have lower CPCHILD scores two years after surgery.
Methods: A retrospective analysis of a prospectively collected, multicenter, international registry was performed for all patients with CP treated with spinal fusion with at least two years of follow-up. HRQOL was measured via the CPCHILD questionnaire domains and total scores (0 = most disability, 100 = least disability). Complications included anything life-threatening, extended hospitalization, spinal cord/nerve injury, or reoperation. Complications were also classified as "existing" or "resolved" based on the 2-year post-op visit. All participating sites were provided a standardized manual for reporting complications. CPCHILD scores were compared between patients with and without postoperative complications.
Results: 298 patients met inclusion criteria (51% female, mean age 14.3 ± 3 yr). 70 patients (24%) experienced a postoperative complication. The most common complication was infection (11%). There was no significant difference in CPCHILD total as well as domain scores at 2 years post-op between patients with and without postoperative complications ($p > 0.05$). Among patients with post-op complications, there was no significant difference in CPCHILD total and domain scores between patients with resolved versus existing complications at 2 years post-op ($p > 0.05$). Patients with complications that resolved by 2 years post-op similarly had no significant difference in total or domain CPCHILD scores in comparison to patients with no post-op complications ($p > 0.05$).
Conclusions: Patients with CP scoliosis who experience post-op complications have no significant difference in HRQOL at 2 years post-op in comparison to those without complications as measured via the CPCHILD questionnaire. Parents and surgeons can be reassured that despite a high complication rate in scoliosis surgery for CP, the initial expectations of improved HRQOL are not diminished when a complication occurs.

Table 1 Distribution of postoperative complications in the overall cohort

Complication Type	N (% of cohort)
Surgical Site Infection	33 (11.1)
Pulmonary	29 (9.7)
Instrumentation	14 (4.7)
Medical	14 (4.7)
Gastroenterologic	11 (3.7)
Neurologic*	1 (0.3)
Pseudarthrosis	1 (0.3)

*Flaccid paralysis of lower extremities observed postoperatively, spontaneously resolved.

Table 2 Mean (Standard Error) CPCHILD domain and total scores for the five complication groups at 2 years post-op

Complication Group	ADLs	PTM	C&E	CSI	Health	Overall QOL	Total CPCHILD Score
No complication	45.3 (1.2)	44.1 (1.2)	83.4 (1.2)	58.1 (1.9)	62.0 (1.2)	72.2 (1.5)	58.3 (1.0)
Complication	45.1 (2.1)	43.3 (2.2)	83.3 (2.1)	56.5 (3.5)	60.9 (2.2)	72.4 (2.7)	57.7 (1.7)
Complication, resolved**	40.6 (5.3)	43.8 (2.1)	83.9 (2.1)	54.5 (3.5)	61.6 (2.2)	72.3 (2.7)	57.8 (1.8)
Complication, existing**	45.8 (2.1)	40.2 (5.5)	80.0 (5.2)	69.5 (9.0)	55.6 (5.6)	72.5 (7.4)	57.4 (4.7)

*ADLs = activities of daily living, PTM = positioning/transfers/mobility, C&E = comfort & emotions, CSI = communication & social interaction, QOL = quality of life

**At 2 years postoperative visit

Paper #27

Outcomes of spinal fusion surgery in cerebral palsy: analysis of complications, reoperations, and clinical and radiographic outcomes with minimum 5-year follow up

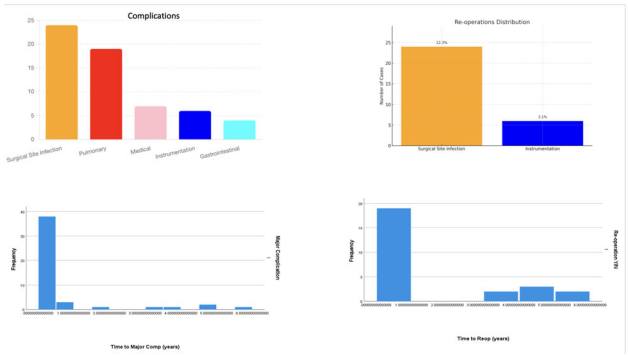
Arun Hariharan, MD, MS; John Vorhies, MD; Craig Louer, MD; Robert Cho, MD, FAAOS, FAOA; Paul Sponseller, MD; Peter Newton, MD; Amer Samdani; Stefan Parent; Firoz Miyanji, MD; Suken Shah; Patrick Cahill, MD; Tracey Bryan; Baron Lonner

Introduction: Understanding the outcomes of spinal fusion (SF) in patients with cerebral palsy (CP) with modern implants and longer-term follow up is important.
Aims/objectives: The aim was to report on the complications, re-operations (UPROR), radiographic, and clinical outcomes in children with CP undergoing SF with minimum 5 y follow up.
Methods: Patients who had GMFCS level-IV/V CP from a prospective, multicenter database with 5 y follow up were analyzed. Major Cobb and pelvic obliquity (PO) were recorded at Pre, First Erect (FE), 2 y, and 5 y. Complications and UPROR were analyzed. Complications were major if prolonged hospitalization or re-admission. The CPCHILD were compared pre to 2 y and 5 y. Statistics included descriptive, Generalized Estimating Equation (GEE), ANOVA, and Kaplan–Meier method.
Results: 195 patients met inclusion criteria, mean age was 13 (SD 2.7). 82% GMFCS V (n = 159), 74% non-verbal (n = 145), 69% seizures (n = 134), 62% G/J-Tube (n = 121), and 4% tracheostomy (n = 7). Mean pre Cobb was 83°(SD 23) and PO was 28°(SD 16). 92% (n = 179) had posterior only SF with screw-based constructs; 8% had anterior surgery also. 91% (n = 178) patients had fusion to the pelvis. On FE the mean Cobb was 27°(SD 14) and PO 8°(SD 7). At 2 y the mean Cobb was 30°(SD 16) and PO 10°(SD 9). At 5 y the mean Cobb was 30°(SD 17) and PO 10°(9.7). There was a significant change from Pre-FE and FE-2y ($p < 0.001$), but not 2 y–5 y for both Cobb and PO. There were 47 (24%) patients with major complications. The causes were surgical site infection (SSI) (n = 19, 10%), pulmonary (n = 19, 10%), medical (n = 7, 4%), instrumentation (n = 6, 3%), and gastrointestinal (GI) (n = 4, 2%). There were 26 patients with UPROR (13%). The causes were SSI (n = 24, 12%) and instrumentation (n = 6, 3%). Complications and UPROR presented even late into the 5 y period, but majority within the first year (Fig. 1). There were no differences in complications or UPROR based on GMFCS or other comorbidities. The survival probability without UPROR and without complications at 5 y is 75% (Fig. 2). All CPCHILD domains improved from Pre-2y ($p < 0.001$), but no difference was seen from 2 y–5 y. RM-ANOVA testing demonstrated no significant differences in change of scores overtime regardless of complications or UPROR.
Conclusions: This study analyzed the outcomes of SF in children with CP utilizing modern instrumentation with minimum 5 y of follow-up. The results demonstrate that surgery leads to sustained improvements in radiographic and HRQoL over 5 y. Despite complications and UPROR within the first year, survival without UPROR/complications is over 75% after 5 y. GMFCS level and medical comorbidities did not impact the rates of complications/UPROR. In all comers, there was an increase in all HRQoL measures at 5 y and complications/UPROR did not result in reduction of scores. These findings underscore the efficacy of SF in enhancing quality of

life and managing scoliosis in this patient population and serve as a useful tool to counsel families.

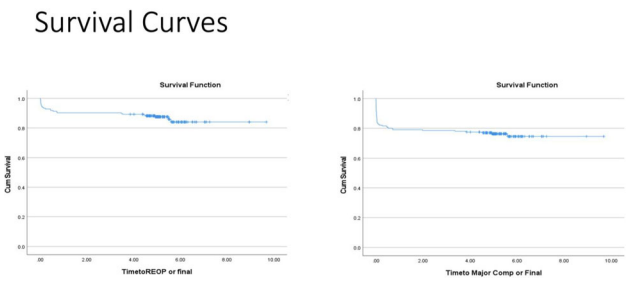
Complications and reoperations

Distribution of major complications and reoperations and time of occurrence of each.



Kaplan Meier survival curves

Kaplan Meier survival curves shows the cumulative survival for time to reoperation and the cumulative survival for time to major complications, both over a 10-year period.



Paper #28

Spinal pathoanatomy of spinal muscular atrophy in the era of disease modifying therapies

Hiroko Matsumoto, PhD; Lennert Plasschaert, MD; Taylor Adams; Brian Snyder, MD, PhD

Introduction: Increased survival and improved motor function have been demonstrated in children with spinal muscular atrophy (SMA) undergoing disease modifying therapies (DMT). However, our preliminary data revealed that DMT had little impact on delaying the inception or progression of early onset spine pathoanatomy, especially the occurrence of severe high thoracic kyphoscoliosis (Fig. 1).

Aims/objectives: The purpose of this study is to characterize the pattern of spine pathoanatomy associated with SMA and investigate the relationship of SMN2 rescue gene copy number and DMT on developing early onset scoliosis (EOS).

Methods: This is a single center retrospective cohort study of SMA patients who underwent surgical correction of EOS from 2004 to 2023. Spinal pathoanatomy (coronal plane scoliosis, sagittal plane kyphosis) was measured on sitting biplanar radiographs: Cobb angle between upper endplate of the cephalad vertebra relative to lower endplate of the caudad vertebra and categorized as thoracic (TK) or thoracolumbar kyphoscoliosis (TLK) based on whether the apex of the deformity was proximal or distal to T10 respectively (Fig. 1).

Results: Of 51 SMA children (age 8.9 ± 3.7) who underwent spinal instrumentation, all had complex deformities (Table 1): 53% TK, 47% TLK. 41 children (80%) received DMT; all children with < 3 SMN2 copies were treated (Table 2). Of patients receiving DMT, 56% had TK and 44% had TLK compared to the untreated cohort where 40% had TK and 60% had TLK. Severe (> 90°) deformities were prevalent (Fig. 2) in 48% with TK vs. 29% with TLK (p = 0.001). While underpowered (0.31), children with < 3 SMN2 copies were more likely to develop TK compared to those with ≥ 3 SMN2 copies (69% vs. 46%, p = 0.154), but 80% of those who could not sit (type 1) developed TK compared to 43% of sitters/standers (type 2/3) (p = 0.038). 75% of children receiving DMT age ≤ 1 yr developed TK compared to 47% treated > 1 yr of age (p = 0.096).

Conclusions: While underpowered, this preliminary study reveals an increase in severe TK among weak SMA patients, not mitigated by DMT. This high thoracic kyphoscoliosis, different from the classic "C-shaped" NM scoliosis may represent a skeletal phenotype previously unobserved prior to the advent of DMT, since most of these patients did not survive or were not mobilized into an upright posture. This preliminary study informed us that we would need N = 648. A multicenter study is underway to obtain adequate statistical power.

Figure 1: Left panel - high thoracic kyphoscoliosis; right panel – thoracolumbar kyphoscoliosis

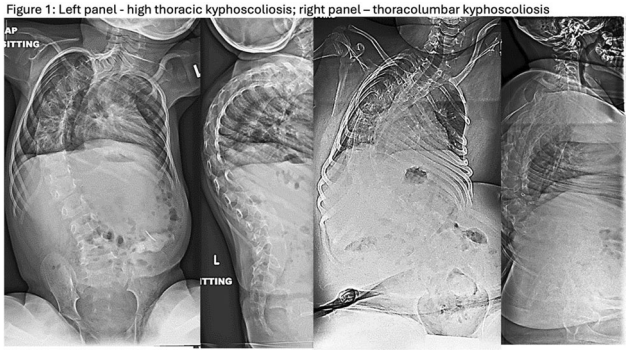


Table 1. Characteristics of Spinal Deformity: All Patients (mean ± SD)

Coronal Plane	
Scoliosis	89° ± 22
Pelvic Obliquity	20° ± 12
Sagittal Plane	
Thoracic Kyphosis	53% Median 54° (Interquartile Range: 29-115)
Thoracolumbar Kyphosis	47% Median 85° (Interquartile Range: 73-109)
Cervical Lordosis	31° ± 24
Lumbar Lordosis	42° ± 24
Pelvic Incidence	56° ± 20
Sagittal Vertical Axis	+3.1cm ± 4
Thoracic Kyphosis	
Thoracolumbar Kyphosis	

Table 2. SMA Type and SMN2 Copy Numbers: Comparison between Disease Modifying Therapy and No Disease Modifying Therapy

	NO DMT (N=10)	DMT (N=41)	p
SMA Type			0.140
1 (can't sit)	0(0%)	14 (34%)	
2 (can't stand)	8 (80%)	22 (54%)	
3 (assisted walking)	1 (10%)	5 (12%)	
Missing	1 (10%)	--	
SMN2 Copy Number			0.116
1	0 (0%)	2 (5%)	
2	0 (0%)	14 (34%)	
3	1 (10%)	20 (49%)	
4	1 (10%)	2 (5%)	
Missing	8 (80%)	3 (7%)	

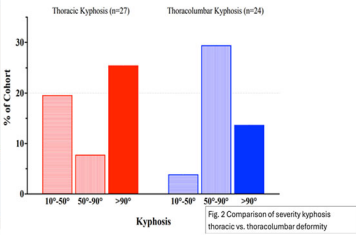


Fig. 2 Comparison of severity kyphosis thoracic vs. thoracolumbar deformity

Paper #29

A changing EOS phenotype in SMA: nusinersen use is associated with increased curve magnitude and kyphosis at the time of index surgery

John Vorhies, MD; Ian Hollyer; Nicole Pham, MPH; Xochitl Bryson; Marleni Albarran; Majella Vaughan; Amy McIntosh, MD; Brandon Ramo, MD; Daniel Bouton; Brian Snyder, MD, PhD; Michael Vitale, MD-MPH; Benjamin Roye, MD-MPH; Patrick Cahill, MD; Jaysson Brooks; Ron El-Hawary, MD; Pediatric Spine Study Group

Introduction: Nusinersen provides functional benefits to SMA patients but does not affect the prevalence or progression of scoliosis. The effect of nusinersen on curve characteristics in SMA has not been described. Here we investigate curve characteristics associated with nusinersen use in a SMA patient population undergoing initial surgical treatment for EOS.

Aims/objectives: We hypothesize nusinersen administration affects preoperative curve characteristics and flexibility among patients with spinal muscular atrophy (SMA) and early onset scoliosis (EOS).
Methods: A multicenter international pediatric spinal deformity database was queried for SMA patients undergoing initial surgical treatment (index growing construct implantation or definitive fusion) for scoliosis. Patients were stratified by exposure to nusinersen preoperatively. Preoperative clinical and radiographic characteristics and first erect postoperative radiographic parameters were compared between the two groups.
Results: 225 patients were identified, 187 of which were controls (nusinersen naïve) and 38 who were treated with nusinersen preoperatively. Patients in the nusinersen group were treated for a median of 1.9 years (range: 0.02–5.9) prior to surgery. Mean age at surgery in the nusinersen group was lower than controls 6.4 vs. 7.7 yrs ($p = 0.002$). The nusinersen group was more likely to be treated with MCGR 87% vs. 45% ($p < 0.001$). 80% of patients were instrumented to the pelvis and this did not differ between the two groups. Mean preoperative major curve and kyphosis were higher among the nusinersen group vs. controls 83° vs. 74° ($p = 0.023$) and 77° vs. 66° ($p = 0.021$) respectively. Mean percent coronal correction was 46% and mean change in kyphosis was 25° and did not differ between the groups. Mean preoperative pelvic obliquity was 20°, was corrected an average of 47% and did not differ between the groups.
Conclusions: Nusinersen use was associated with larger more kyphotic curves and younger age at intervention among SMA patients undergoing initial surgical treatment for EOS. Percent correction of the curves was similar suggesting similar curve flexibility. Further study is needed to understand if nusinersen directly affects curve characteristics or rather improves function in more severely affected patients allowing them to become surgical candidates.

Table 1: Summary Data

	No Nusinersin Use (n = 187)		Nusinersin Use (n = 38)		
	Mean	SD	Mean	SD	p-value
Age (years)	7.7	2.7	6.4	2	**0.002***
BMI	16.7	4.3	16.2	3	0.43
Levels	9.5	2.1	10.5	2.5	**0.025***
Preop Major Curve (degrees)	74	22	83	20	**0.023***
Postop Major Curve (degrees)	39	16	45	19	0.094
Percent correction	-46%	22%	-46%	16%	0.854
Preop T2-T12 Kyphosis (degrees)	66	29	77	24	**0.021***
Postop T2-T12 Kyphosis (degrees)	43	17	49	16	**0.035***
Change in Kyphosis (degrees)	-25	25	-27	27	0.552
Preop Pelvic Obliquity (degrees)	20	13	23	13	0.15
Postop Pelvic Obliquity (degrees)	7	6	9	6	0.272
Percent Correction	-47%	82%	-36%	78%	0.504
	N	**%**	**N**	**%**	p-value
Surgery Type					
MCGR	84	45%	33	87%	
VEPTR/TGR	79	42%	2	5%	**< 0.001***
Other	24	13%	3	8%	
Superior Anchors					
Rib	70	43%	19	54%	
Spine	88	54%	15	43%	0.405
Both	5	3%	1	3%	
Inferior Anchors					
Pelvis	67	41%	15	43%	
Spine	32	20%	6	17%	0.976
Spine and Pelvis	63	39%	14	40%	
Rib and Pelvis	1	1%	0	0%	

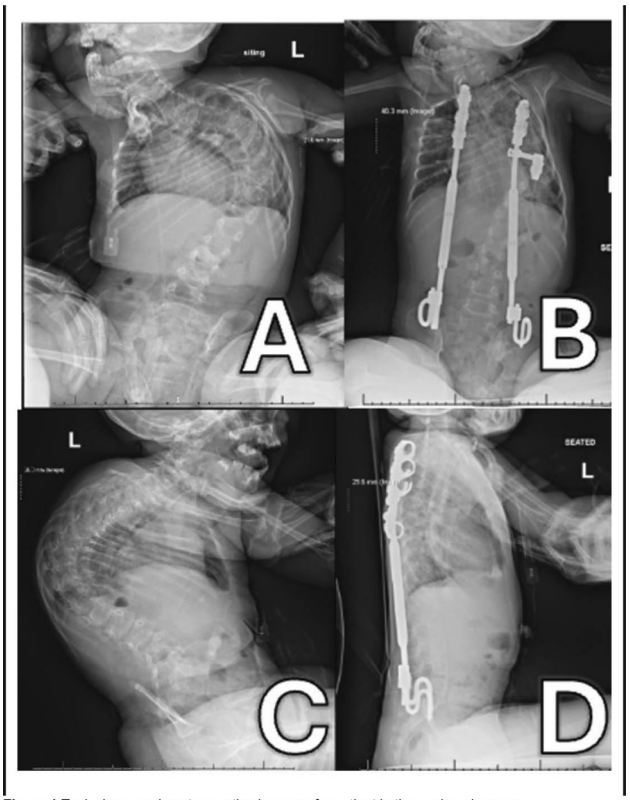


Figure 1 Typical pre- and post-operative images of a patient in the nusinersin group

Paper #30

Risk model prediction for proximal junctional kyphosis (PJK) following spine deformity surgery in spinal muscular atrophy (SMA) patients with early onset scoliosis (EOS)

Hiroko Matsumoto, PhD; Lennert Plasschaert, MD; Taylor Adams; Sydney Lee, BA; David Liu; Brian Snyder, MD, PhD

Introduction: While prior investigations identified associations between risk factors and PJK in EOS, these studies were constrained by an inability to explore interactions among multiple associated risk factors. Additionally, the impact of PJK on health-related quality of life (HRQoL) following spinal deformity surgery has not been explored in SMA patients with EOS.
Aims/objectives: Aim 1: Using retrospective data, develop a prognostic model quantifying the likelihood of PJK in SMA patients undergoing EOS correction using growth-friendly implants based on pre-operative radiographic pathoanatomy and perioperative variables. Aim 2: Assess the impact of PJK on HRQoL.
Methods: This was a single-center retrospective cohort study of SMA patients with EOS treated with growth-friendly implants from 2004 to 2023. PJK ($> 10°$) was evaluated on sitting lateral spine X-ray obtained at most recent follow-up. Candidate predictors determined from pre-op sitting AP/lateral spine X-rays included magnitude of: global kyphosis, major scoliosis, cervical lordosis, proximal junctional angle, lumbar lordosis, pelvic obliquity, sagittal vertical axis, pelvic incidence; perioperative predictors: halo gravity traction and upper instrumented vertebrae (UIV). Several logistic regression models were formulated to evaluate the predictive ability of various combinations of candidate variables, judged using receiver operating characteristic curve (ROC). EOSQ-24 was administered serially during routine follow-up visits or via phone calls.
Results: Of 51 patients, 6 developed PJK (12%) at 2.8 ± 3.1 years postop. The model that best predicted PJK (area under ROC = 0.81)

included: kyphosis ^{3}90°, cervical lordosis > 40°, halo gravity traction, ^{3}50% correction of kyphosis, and UIV below T1 (Fig. 1). No patient with UIV at or above T1 developed PJK. In a subgroup analysis (n = 42), patients with PJK (n = 5) had deterioration in General Health, Pain, Pulmonary Function, Daily Living, Financial Burden, Child Satisfaction and Parent Satisfaction within 4.5 ± 4.4 years after developing PJK (Table).

Conclusions: The risk model achieved 81% prediction of PJK in SMA patients with EOS. This risk model suggests that SMA patients with sagittal deformity of thoracic or thoracolumbar kyphosis ^{3}90° and compensatory cervical lordosis > 40°, who achieve ^{3}50% correction of the kyphosis with preop halo gravity traction should be instrumented at or above T1 to avoid PJK and the subsequent deterioration in HRQoL afterwards.

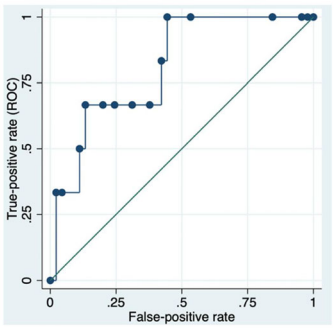


Figure 1a. ROC of PJK predictor model in SMA

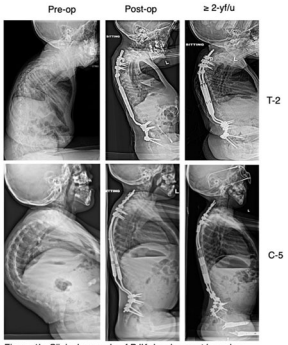


Figure 1b. Clinical example of PJK development based on UIV: T2 vs. C5 at preop, immediate post op, and most recent follow up

Table. EOSQ-24 Mean Scores (higher the better) in Patients With PJK vs Without PJK

Sub-Domains	With PJK	Without PJK	p
General Health	57.5±14.3	76.2±16.7	0.0106
Pain	55.0±14.3	70.5±21.2	0.0594
Pulmonary Function	47.5±32.4	84.2±17.5	0.0001
Transfer	65.0±28.5	64.9±28.7	0.4965
Physical Function	31.7±18.1	48.8±28.6	0.0955
Daily Living	7.5±11.2	33.9±26.9	0.0183
Fatigue	52.5±29.8	62.8±28.6	0.2263
Emotion	55±28.8	62.2±25.8	0.2813
Parental Burden	46±31.9	59.5±25.1	0.1374
Financial Burden	35±41.8	64.9±30.8	0.0270
Child Satisfaction	30±27.4	60.7±22.9	0.0039
Parent Satisfaction	30±32.6	64.3±21.5	0.0013

Paper #31

Growth-friendly surgery improves diaphragm intrusion and thoracic dimensions in patients with neuromuscular scoliosis

Zaid Elsabbagh; William ElNemer; Peter Gabos; Gregory Redding; Paul Sponseller

Introduction: Neuromuscular scoliosis (NMS) can influence abdominal and diaphragmatic positioning, causing diaphragmatic intrusion. We hypothesize that growth-friendly surgeries correct the deformities causing the intrusion, improving overall pulmonary function.

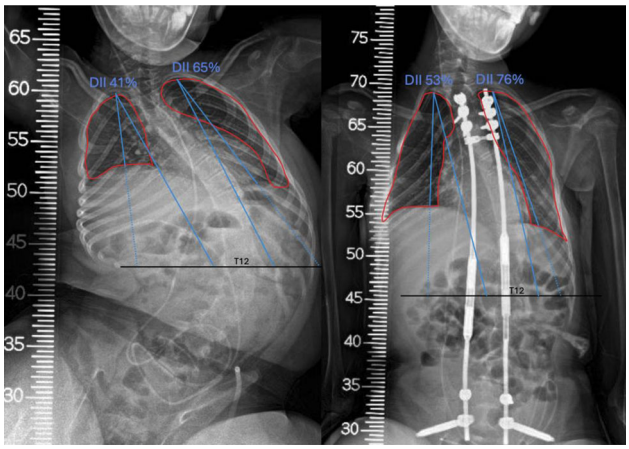
Aims/objectives: Our objective was to investigate changes in diaphragm position and other thoracic radiographic measurements at 2 years post-surgery. Building on prior studies that have provided methods to estimate thoracic volumes using radiographs, we aim to demonstrate the relationship between growth-friendly surgery and improved lung volumes.

Methods: We reviewed data from patients with neuromuscular scoliosis who underwent growth-friendly surgeries between 2015 and 2022. Radiographs taken preoperatively, post-operatively, and 2 years postoperatively were measured for diaphragm intrusion index (DII), diaphragm vertebral level (DVL), space available for the lung ratio (SAL). Lung volume was measured by using the regression equation (volume = 9.6 × S − 1367), validated by previous studies, where S is the sum of the areas of the left, right, and lateral lung fields. We also screened answers from the Early Onset Scoliosis Questionnaire (EOSQ) to assess the improvement of subjective ratings after surgery. Pre-operative and two-year follow up measurements were compared with student's t-tests and chi-squared analysis.

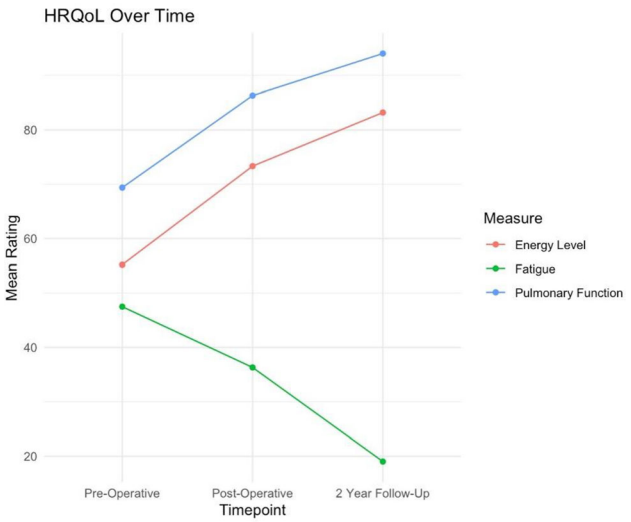
Results: We studied 45 participants with an average age of 8.0 ± 2.4 years. Etiologies of neuromuscular scoliosis were cerebral palsy (56%), spina bifida (11%), and spinal muscular atrophy type 2 (9%). Surgical interventions included traditional growing rods (27%), vertical expandable prosthetic titanium rib (11%), and magnetic expansion control rods (62%). Most participants (76%) were classified as GMFCS V. Lung volume increased from 1992 ± 576 cm^3 preoperatively to 2980 ± 566 cm^3 at the 2-year follow-up ($p < 0.001$). The DII improved from a mean of 0.57 ± 0.08 to 0.7 ± 0.05 on the concave side and from 0.58 ± 0.08 to 0.69 ± 0.05 on the convex side ($p < 0.001$). The DVL increased from 7.5 to 8.7 on the convex side and from 7.5 to 8.8 on the concave side ($p < 0.001$). SAL ratio increased from 0.79 to 0.91 ($p < 0.001$). Per EOSQ ratings, patients' energy levels improved from 55/100 preoperatively to 83/100 at 2-year follow-up ($p < 0.001$). Pulmonary function improved from 69/100 preoperatively to 94/100 at 2-year follow-up ($p < 0.001$). Fatigue levels decreased from 48/100 preoperatively to 19/100 at 2-year follow-up ($p < 0.001$).

Conclusions: In NMS the curve produces significant intrusion of the diaphragm into the thorax. Growth-friendly surgery improves diaphragm position and increases pulmonary volume, and this is maintained over further expansions. Based on EOSQ ratings, increased lung volume and improved diaphragm positioning may lead to enhanced pulmonary volumes, suggesting these procedures effectively manage thoracic dimensions in this population.

Radiographic lung volume and diaphragm intrusion index (DII)
Preoperative and 2-year post-operative radiographs displaying improvements in both lung volume and diaphragm intrusion index after treatment with growth-friendly surgery.



Health-related quality of life over time
EOSQ responses to questions analyzing energy level, fatigue, and pulmonary function over the pre-operative, post-operative, and 2-year post-operative periods.



Paper #32

Does spine fusion limit functional outcomes in spina bifida patients with severe spine deformity?

Ambika Paulson, MD; Austin Montgomery, BA; Ryan Seltzer, MD; Kyle Graham, MPH; Douglass Clayton, MD; Jeffrey Martus, MD; Gregory Mencio, MD; Craig Louer, MD

Introduction: The functional impact of posterior spinal fusion (PSF) in Spina Bifida (SB) patients with severe spinal deformities is under-explored. This study sought to compare how PSF impacts functional capacity in SB patients relative to treatment with observation (OBS).
Aims/objectives: Do SB patients undergoing PSF for severe spinal deformities have significant changes in ambulatory capacity, transfer ability, or independent catheterization ability compared to patients treated with OBS.
Methods: A single-institution SB registry was queried for patients with severe coronal or sagittal deformity $> 50°$, including gibbus deformity. Prospectively collected National Spina Bifida Patient Registry (NSBPR) questionnaire data was used for longitudinal functional assessment. Patients excluded if < 2 years of radiographic or NSPBR data. Primary outcomes were ambulatory level, unassisted wheelchair (WC) transfer, and bladder management. Hoffer criteria was used to define ambulatory status (AS) based on four categories: community, household, therapeutic, and non-ambulatory. PSF and OBS groups were compared at baseline and final follow-up, including pairwise analysis of each patient over time.
Results: 52 patients met inclusion criteria (30 PSF, 22 OBS). 7 PSF patients without pre-operative NSBPR outcomes were excluded from initial visit and within-groups analysis. Length of follow-up was similar between groups (7.1 vs. 5.2 yrs, $p = 0.20$). At study inclusion, PSF was similar to OBS in age (6.8 vs. 7.5 yrs, $p = 0.19$), coronal deformity (57.1° vs. 50.6°, $p = 0.26$), AS (community ambulators: 26% vs. 23%, $p = 0.19$), unassisted WC transfer rate (50% vs. 69%, $p = 0.35$). A greater number of PSF patients used clean intermittent catheterization (CIC) compared to OBS group at study inclusion (87% vs. 55%, $p < 0.01$) Major coronal deformity at last follow-up was decreased in PSF cohort (38.0° vs. 66.7°, $p < 0.001$). Neither treatment resulted in significant change in AS over time ($p = 0.11$ and $p = 0.55$; Fig. 1). Of the 9 patients in each group who performed unassisted WC transfers at initial visit, 6 (66.7%) per group maintained the ability to perform unassisted transfers at last visit. Of the patients that manage with CIC, the number of patients able to self-cath increased from 7 to 14 after PSF ($p = 0.03$).
Conclusions: SB patients with severe spinal deformities undergoing PSF did not show a significant decline in mobility or functional capacity relative to OBS. These findings indicate that while some functional decline may be expected as the natural progression of SB, PSF does not significantly impact this trajectory. Future works may be useful in looking at the apparent improvement in ability to self-catheterize.

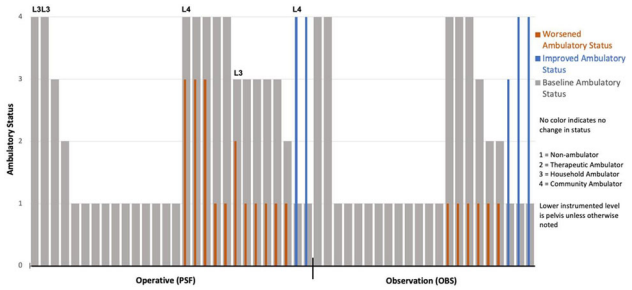


Figure 1 Initial and final ambulatory status

Paper #33

"Cured" patients with early onset idiopathic scoliosis after serial casting are at risk of recurrence at intermediate follow-up

Rayyan Abid; Abigail Manning; Craig Birch, MD; Kim Hammerberg, MD; Peter Sturm, MD; Ying Li, MD; Michal Szczodry, MD; Michael Glotzbecker, MD; Pediatric Spine Study Group

Introduction: Serial casting is an effective non-operative technique for patients with early onset scoliosis. Serial casting limits curve progression, while preserving spinal growth, delaying or even eliminating the need for surgery. Some patients with Early Onset Idiopathic Scoliosis (EOIS), can be "cured" with curve reduction to under 15°. Patients that are cured with casting are typically braced for approximately one year. However, long term studies are not available to define whether "cured" patients maintain a small curve over time or whether they are at risk of needing further treatment because of curve progression. We examined if casting patients remained "cured" over time following their treatment.
Aims/objectives: This study aims to determine the effectiveness of serial casting as a long-term alternative to surgical treatments for patients with early onset scoliosis.
Methods: A retrospective query of a multicenter database identified 43 patients with EOIS who were treated with serial casting and achieved a curve under 15° and for whom we had a minimum of two years of follow up after completing casting. Failure was defined as an increase $> 6°$, resulting in a Cobb angle > 15 at any point during follow up and/or requiring cast/brace treatment after cessation of initial cast/brace, or undergoing surgery. Their average Cobb angle at the time of cure was 11.1°. A Kaplan Meier survival analysis was used to identify failure rates over time.
Results: Of these 43 patients, 13 (30.2%) met our criteria for failure. The overall cohort's mean follow-up time was 4.45 years. 4 patients (9.3%) completed bracing and then were later re-braced. 3 patients (7.0%) required surgery; 2 received VEPTR/TGR while 1 received MCGR. The mean curve magnitude of the patients who failed was 26.3°, with an average Cobb increase of 14.9°. At 5.08 years, the probability of successful treatment is 60.5% with a 95% confidence interval of 41.7–82.7%. Of those who met our criteria for failure, the median time to failure was 2.45 years. 16 patients (37.2%) were braced for > 2 years following casting. Patients with successful treatment were braced for a median of 1.42 years while patients whose treatment failed had a median brace time of 1 year.

Conclusions: While patients with EOIS may be "cured" with serial casting, this may not be sustained over time. At intermediate follow up, 30% of "cured" patients had curve progression and 16% required a second treatment. Many patients continue bracing after casting for an extended period of time even after achieving a small curve. Families should be counseled that reduction of the Cobb angle to under 15° with serial casting in EOIS may require further treatment in the future. The percentage of "failures" likely will increase with longer term follow up through skeletal maturity, and therefore patients need to be closely monitored after completion of casting/bracing.

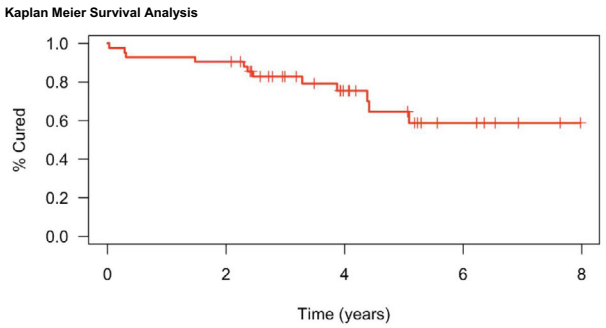


Figure 1 Kaplan-Meier survival curve demonstrating the percentage of patients that had curve progression or required a secondary treatment over time after being successfully treated in a cast for EOIS

Paper #34

Can early brace wear compliance of patients with adolescent idiopathic scoliosis predict future wear?

Michael Hresko, MD; Alexa Bosco; Grant Hogue, MD; Craig Birch, MD; Christine Sieberg; Gabriel Linden, BA; Shanika De Silva; Daniel Hedequist; Lawrence Karlin; John Emans, MD

Introduction: Studies have shown that brace treatment decreases the likelihood of adolescent idiopathic scoliosis (AIS) patients progressing to surgery. As brace effectiveness relates to wear time in the first 6-months, identifying non-adherent patients early allows targeting behavioral interventions for at-risk individuals.
Aims/objectives: This study aims to determine if (1) compliance to the brace weaning protocol at 1-month is associated with 6-month compliance, and if (2) behavioral adaptation to bracing can be assessed by the Transtheoretical Model of Stages of Change.
Methods: This study included a prospective cohort of pediatric patients undergoing bracing treatment for AIS at a single-center, 53 AIS patients received TLSO brace treatment between 2021 and 2023. Brace wear was assessed at 1- and 6-months, categorizing patients as adherent cohort (AC) if they wore the brace $\geq$ 80% of the prescribed 18 h/day and non-adherent (NAC) otherwise. Pre-bracing, patients completed the University of Rhode Island Change Assessment Scale (URICA). At each visit, they also completed SRS-22r, PROMIS Pediatric, and ISYQOL questionnaires. We summarized continuous variables (mean, standard deviation) and categorical variables (frequency, percentage) for each adherence group. To compare between groups, we used Wilcoxon rank sum tests for continuous variables and Fisher's exact or Pearson's chi-squared tests for categorical variables.
Results: The mean age was 13 years, 75% were female, most had Risser 0–2, and mean Cobb angle was 30.7°. Of the 46 patients with 1-month adherence data, 46% were AC and 54% were NAC, with mean daily wear times of 17.6 and 10.6 h, respectively. Among the 35 patients with adherence data at both visits, 78% of AC patients at 1-month remained so at 6-months, while 71% of those NAC at 1-month remained non-adherent at 6-months ($p = 0.004$) (Table 1). We observed no statistically significant differences ($p > 0.05$) in the demographics, radiographic measures, and patient-reported outcomes between the groups. Per the URICA, 44% of patients were pre-contemplative, and 56% were contemplative at baseline. At 6-months, only 1 of 30 patients was in action stage. However, we observed no significant group differences in URICA stages ($p = 0.2$) for AC or NAC groups.
Conclusions: Early brace adherence was associated with 6-month adherence to the prescribed brace wear. However, pre-treatment readiness for change was not associated with brace adherence. Compliance monitoring can identify patients at risk for poor brace adherence to offer opportunity for interventions within the first few months of brace wear.

Table 1 Brace Adherence to 80% of Prescribed Hours/Day

	6-month compliance	
1-month compliance	*Adherent*	*Non-adherent*
Adherent	14 (78%)	5 (29%)
Non-adherent	4 (22%)	12 (71%)

Paper #35

Spine 2.0: the tech revolution in pediatric spine surgery

Sydney Lee, BA; Robert Murphy, MD; Shanika De Silva, PhD; R. Carter Clement, MD, MBA; Allen Kadado, MD; Pediatric Spine Study Group; Grant Hogue, MD

Introduction: Enabling technologies (ET) have emerged as alternatives or adjuncts to freehand pedicle screw placement in pediatric spine surgery, aiming to improve accuracy, safety, and efficiency. However, the significant variability in ET modalities leads to greater variability in usage patterns. Currently, we lack an understanding of ET usage patterns across various spine patients, procedures, and settings.
Aims/objectives: To assess the prevalence, hurdles, and facilitators of ET adoption in pediatric spine surgery, elucidating the current landscape of ET use, and identifying areas where targeted efforts could be implemented.
Methods: An online survey was distributed to pediatric spine surgeons to collect data on their experiences with ET. The survey covered practice characteristics, usage rates of various ET across different procedures and anatomical regions, factors influencing ET use, and interest in ET training.
Results: Among 108 respondents, 57% had over a decade of experience, and 47% had practices dedicated primarily to pediatric spine cases. For anchor placement during surgery, navigation aided by pre/intraoperative axial imaging was the most commonly used ET (70%), followed by intraoperative axial imaging without navigation (33%). 3D printed guides and robotic arms had low utilization rates by adopting surgeons, while navigation with pre/intraoperative axial imaging and axial imaging alone were employed more routinely (Fig. 1). 13% of respondents reported not using any ET, citing safety concerns (50%), lack of availability (29%), increased surgical time (29%), radiation exposure (21%), and cost (21%) as barriers. Increased accuracy of anchor placement (69%) and surgical efficiency (48%) were the primary drivers for ET adoption. Sacropelvic fixation (53%) and congenital scoliosis (50%) had the highest levels of "very high" ET utilization, defined as 76–100% usage rate by surgeons (Fig. 2). "Very high" ET usage was most prevalent in the sacropelvic region (53%), followed by T1–T12 (41%), and L1–L5 (35%). In contrast, the O-C2 (30%) and C3–C7 (25%) regions showed lower rates of "very high" ET usage. Interest in ET training was mixed, with 51% expressing no interest. Among those interested, robotics (26%) and navigated axial imaging (20%) were the most sought-after training areas.

Conclusions: Navigation guided by axial imaging for anchor placement is the most commonly used ET in pediatric spine surgery. ET is used most frequently in sacropelvic fixation and congenital scoliosis cases and least frequently used in the cervical spine. Key motivators for adopting ET include enhanced anchor placement accuracy and surgical efficiency. However, barriers such as safety concerns, cost, and radiation exposure limit usage among some surgeons. High interest in training for robotics and navigated axial imaging indicates a promising area for future efforts.

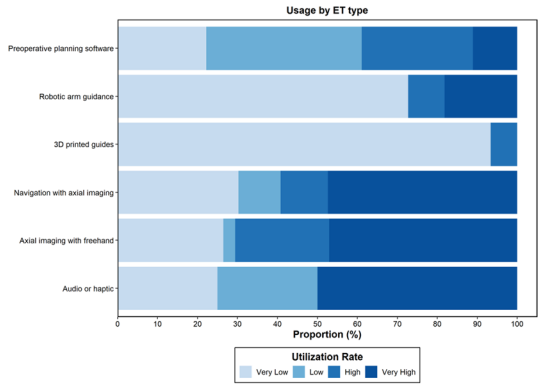


Figure 1 Usage of various technologies among surgeons who have adopted ET into their practice

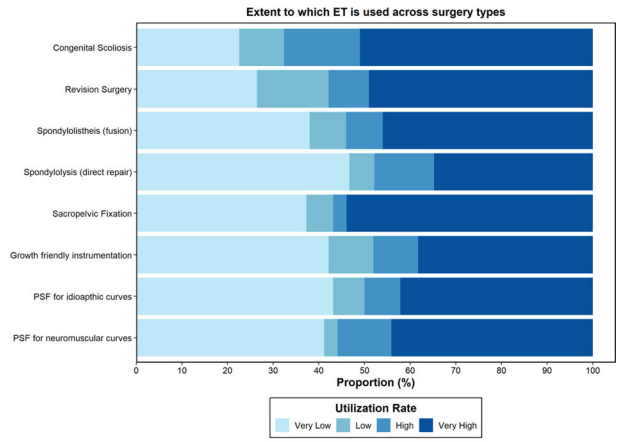


Figure 2 Extent of ET usage across types of surgeries

Paper #36

Development of a machine learning tool to improve intraoperative neurophysiological monitoring: proof of concept

Varun Arvind, MD, PhD; Anil Mendiratta, MD; Omar Taha, BS; Matthew Weintraub, BSE; Michael Vitale, MD-MPH

Introduction: Intraoperative neurophysiological monitoring (IONM) has dramatically improved the neurological safety of spine surgery. The effectiveness of IONM is dependent on the interpretation of data reviewed in real time by highly trained technicians and neurologists/neurophysiologists. Machine learning (ML) provides an attractive approach to standardize IONM interpretation and may allow for earlier alerts by identifying subtle patterns of signal change.
Aims/objectives: To develop a machine learning algorithm to autonomously identify anomalies in motor evoked action potentials (MEPs) in patients undergoing spinal deformity correction surgery.
Methods: In this pilot study, we retrospectively analyzed IONM data from nine pediatric patients (< 18 years) with complex spinal deformities, who experienced significant IONM signal changes that resulted in formal alerts from the neurophysiology team. Stable baseline MEPs recorded prior to instrumentation/correction were used to train a ML classifier to learn a patient-specific MEP signature. The model was trained to detect anomalous patterns of patient-specific MEP waveforms. Based on correlation with subsequent formal alerts of IONM changes, we defined a "red flag warning" if the anomaly varied by more than 20%. (Fig. 1). The time at which the first detectable adverse change in MEPs noted by the IONM team was compared to the time at which the red flag warning by the model was raised.
Results: Red flag warnings were identified in all 9 patients and were raised an average of 13.7 min (95% confidence interval: 1.7–29.1 min) prior to the time at which the first detectable change in MEPs were identified by the IONM team. In 1 case, the red flag warning was identified 12 min after which detectable MEP changes were observed by the IONM team. In 3 cases, red flag warnings were identified at the same time changes were observed by the IONM team. In 5 cases, red flag warnings were raised prior to detection by the neurologist attending. At the time of detectable MEP changes red flag warnings were raised only once per case.
Conclusions: These results provide proof of concept for the utility of ML as a potentially valuable adjunct tool in the interpretation of complex IONM data. Further work is underway to train the model on a larger group of patients and explore the positive predictive value of these automated alerts. It will be equally important to analyze a larger group of patients in order to ensure that the model does not result in an excessive number of false positive alerts. Our hope is that this endeavor will improve safety in spine surgery by providing an additional and autonomous warning system to assist personnel in real time.

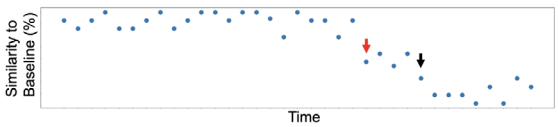


Figure 1 Example model similarity plot evaluated on MEPs over time for one patient. Blue dots correspond to the average similarity of MEPs to baseline MEPs prior to instrumentation/correction based on evaluation by the ML model. A decrease in similarity corresponds to an anomaly. Red arrow marks correspond to red flag warnings, or a drop greater than 20% in similarity from the prior MEP. Black arrow is the earliest change noted by the attending neuromonitoring team

Paper #37

Predicting unplanned return to the operating room in early-onset scoliosis patients using machine learning techniques: a multicenter model

Brett Lullo, MD; Patrick Cahill, MD; John Flynn, MD; Paul Sponseller, MD; Mark Erickson, MD; Amer Samdani, MD; John Smith, MD; Pediatric Spine Study Group; Jason Anari, MD

Introduction: Unplanned return to the operating room (UPROR) is a common complication of surgical treatment of early-onset scoliosis (EOS). The factors that lead to UPROR in EOS patients are complex and often difficult to fully understand using traditional statistical analysis. Novel machine learning algorithms have previously been used to predict UPROR in EOS patients at a single institution, but this technique has not yet been applied to a larger, heterogeneous multicenter population.
Aims/objectives: The aim of this study was to use a multicenter database to create a generalizable machine learning model to predict which EOS patients will require UPROR.
Methods: A retrospective review of a multicenter database was performed of all patients who underwent surgery for EOS with at least 2-year follow-up. Patients were stratified into case and comparison cohorts, based on whether they experienced an UPROR over the follow-up period. Independent t tests and X^2 analysis were used to

evaluate differences between cohorts and identify significant factors from an initial pool of 14 patients, radiographic, and surgical factors. Multiple imputation was used for factors with less than 30% missing data; factors with greater than 30% missing data were excluded. Ten machine learning algorithms (logistic regression, random forest, gaussian naïve bayes, support vector machine, k-nearest neighbor, gradient boosting, stochastic gradient boosting, adaptive gradient boosting, neural network, and elastic-net penalized logistic regression [ENPLR]) were trained using tenfold cross-validation on an independent training set of patients. Model performance was evaluated on a separate testing set via their area under the receiver operating characteristic curve (AUC). Relative feature importance was calculated for the top performing model.

Results: 3427 patients were included with 953 (27%) undergoing at least one UPROR during the follow-up period. Eight factors were identified as significant with sufficient data to be included in model training: age at initial surgery, EOS etiology, initial construct type (TGR, MCGR, VEPTR, or fusion), ambulatory status, weight and height at initial surgery, and initial major curve Cobb angle. The k-nearest neighbor model (Fig. 1) demonstrated the best performance (AUC: 0.74). Significant protective factors against experiencing an UPROR were increased age, height, and weight at initial surgery, initial fusion construct, and congenital etiology.

Conclusions: The k-nearest neighbor machine learning algorithm demonstrated the best performance for predicting UPROR in EOS patients. In our population, older, heavier, taller, congenital patients with primary fusion constructs experienced UPROR less frequently. This model can be broadly used during the shared decision-making process with families prior to initial EOS surgery to predict the risk of UPROR, optimize modifiable patient factors, and choose surgical constructs (Fig. 2).

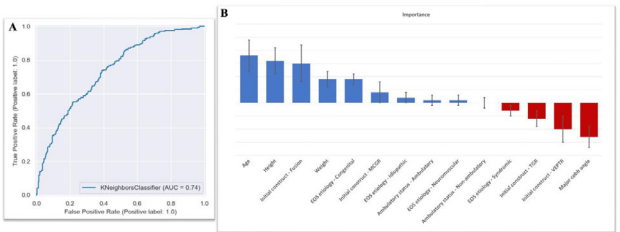


Figure 1 A: Receiver operating curve of k-nearest neighbors machine learning model demonstrating area under the curve (AUC) of 0.74 on the independent testing set. B: Relative feature importance of EOS patient factors included in the model. Size of bars correspond to relative importance of factor. Blue bars indicate protective factors against UPROR. Red bars indicate contributory factors towards UPROR

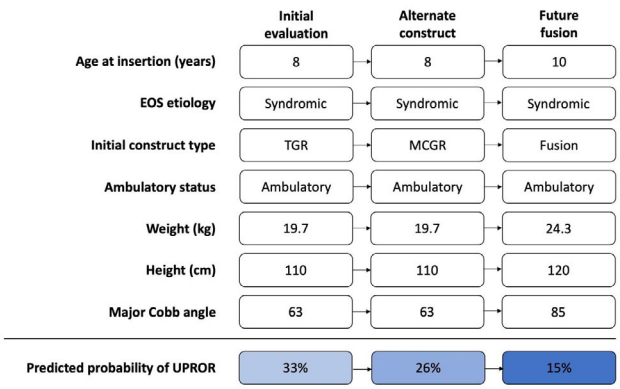


Figure 2 Predicted probability of experiencing an UPROR for an example patient from the database and the effect of considering alternate constructs and optimizing patient factors

Paper #38

MRI-based synthetic CT in pediatric spine patients: a case series

George Michael, BS/BA; David Skaggs, MD, MMM; Meliza Perales, RN/BSN; Cristabelle Alexander, BS; Christopher Watterson, MD; Daniel Hoghoughi, MRSO (MRSC), R.T.(R)(CT)(MR)ARRT; Norman Gellada; Kenneth Illingworth, MD FAAOS

Introduction: Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are common imaging studies used to evaluate pediatric spine patients. Recently, MRI-based synthetic CT (sCT) images have demonstrated near equivalence in accuracy when compared to CT in cadaveric studies. This recent advancement allows potential visualization of both bony and soft tissue anatomy without harmful ionizing radiation. To date, there are no reports of the use of sCT in the evaluation of pediatric spinal pathologies.

Aims/objectives: Evaluate the use of MRI-Based sCT in the clinical management of pediatric and adolescent patients suffering from various spinal conditions.

Methods: Retrospective review of pediatric spine patients from October 2023- July 2024. The inclusion criteria were any patient < 18 years of age seen and referred for spinal MRI with addition of BoneMRI sequence and sCT. An experienced musculoskeletal radiologist read the images, and the findings were discussed and confirmed by the attending pediatric spine surgeon. Case reports were generated for each patient by chart review with IRB approval.

Results: 11 patients underwent spinal MRI with the addition of sCT-generated sequences, two of which were done on the cervical spine and ten on the lumbar spine. Of the 11 patients, two were assessed for congenital muscular torticollis, five for isolated spondylolysis, one had degenerative disc disease with additional neuroforaminal stenosis, and three were evaluated for their pseudo-articulation at the lumbosacral junction. Three patients had received CT scans within 3 months of MRI-Based sCT imaging and had demonstrated equivocal findings as determined by the attending pediatric spine surgeon.

Conclusions: BoneMRI has significant clinical utility in the pediatric and adolescent population, allowing the diagnosis of both bony and soft tissue issues without exposing patients to radiation and utilizing a single imaging study. In this particular study, we were able to save 8 patients from CT radiation exposure, and therefore decreasing their lifetime exposure to radiation. Synthetic CT is a groundbreaking tool for providers dealing with complex pediatric spinal conditions and has the potential to alleviate the need for CT scans in the future.

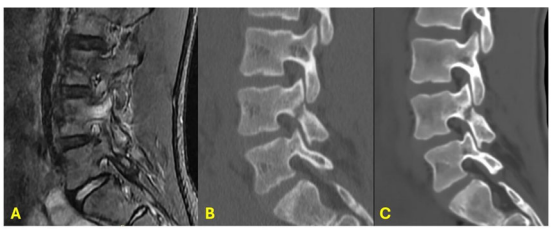


Figure 1 Direct comparison of an MRI (A), CT (B), MRI-based sCT (C) on a right L4 spondylolysis

Table 1 Table demonstrating the demographics of the patients in the study

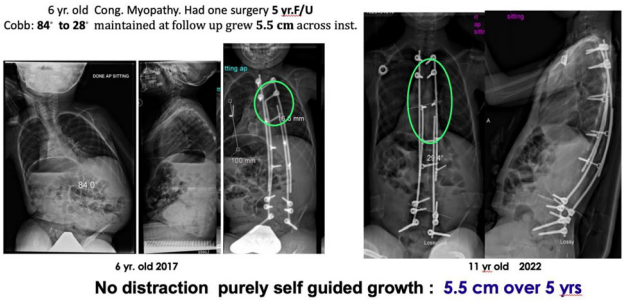
Subject	Sex	Age	Presumed Diagnosis	BoneMRI findings	Previous Imaging/ Studies
1	Female	14	Spondylolysis	Bilateral L4 spondylolysis	X-ray, MRI
2	Female	13	Spondylolysis	Bilateral L3 spondylolysis	X-Ray MRI
3	Male	14	Spondylolysis	Chronic bilateral L4 spondylolysis with minimal healing	X-Ray MRI CT (demonstrating equivalence) Intra-op fluoroscopy
4	Male	8	Congenital Muscular Torticolis	Slight left sided C3-C4 neurofarminal narrowing with left Craniocervical junction curvature	X-Ray MRI EMG Bil UE
5	Male	15	Congenital Muscular Torticolis	No congenital abnormalities in the cervical spine	X-ray scoli series X-ray Cervical
6	Male	15	Spondylolysis	Resolution of previous left L5 spondylolysis	X-ray full spine MRI Lumbar CT lumbar (equivalence with BoneMRI)
7	Female	15	Pseudoarticulation at the Lumbosacral junction	Adolescent Idiopathic scoliosis with Transitional L5 vertebral body with left sided pseudoarticulation at the lumbosacral junction	Multiple X-ray for full spine
8	Male	16	Spondylolysis	Partial disc herniation without spondylolysis	X-ray Cervical MRI cervical X-ray cervical MRI Lumbar
9	Female	12	Spondylolysis	Symptomatic Bertolotti syndrome with pseudoarticulation and associated edema at the Lumbosacral Junction	X-ray Cervical
10	Male	12	Spondylolisthesis	Pseudoarticulation and edema at the Lumbosacral Junction (L5/S1)	X-ray full spine MRI L/S CT L/s x 3 final reading was similar to boneMRI
11	Female	20	Spondylolysis	Degenerative disc disease, prev L5 inferior endplate fracture, prev heaed L5 spondy with L5 disc herniation compressing S1 nerve root	X-Ray CT (Similar to BoneMRI)

Paper #39

Time to first reoperation: modern Luque trolley vs. other fusionless surgery for EOS: a prospective cohort study with matched historical control group

Jean A. Ouellet, MD; Romain Dayer; Michael Grevitt, FRCS (ORTH); Ron El-Hawary, MD; Paul D. Sponseller, MD; Pediatric Spine Study Group

Introduction: Management of early-onset scoliosis (EOS) remains challenging with high rates of revision. The modern Luque trolley (MLT) technique was developed to normalize forces across apical growth plates and harness spinal growth to extend implants while minimizing revisions.
Aims/objectives: To test if EOS patients treated with MLT have fewer reoperations than those treated with other fusionless techniques but with similar spinal growth and Cobb correction.
Methods: A prospective multicenter cohort study with matched historical controls was conducted. The first patient was enrolled in August 2015; the last follow-up data analyzed was September 2023. The study is currently still ongoing. Matched historical controls were selected from the Pediatric Spine Study Group registry. Eighteen EOS patients treated with MLT were enrolled at three European centers and compared to 43 matched controls (16 treated with dual growing rod [DGR], 9 with rib-based growing rod [RBGR], and 18 with magnetically controlled growing rod [MCGR]). Mandatory matching criteria were age, curve magnitude, and etiology. The primary outcome was reoperation of spine within 3 years; secondary outcomes were Cobb angle and spinal growth. Time to first reoperation was calculated using all available data (follow-up mean years: MLT, 4.8; control, 4.6).
Results: Patients treated with MLT, and control techniques had similar baseline age, gender, body measurements, etiology, Cobb angle, and spine length. Within 3 years of surgery, 1 of 18 patients treated with MLT required a revision (unplanned surgery for loose implants). In contrast, 30 of 43 controls (15/16 DGR; 9/9 RBGR; 6/18 MCGR) underwent 122 reoperations (65 DGR; 49 RBGR; 8 MCGR); of these, 90 were planned (48 DGR, 42 RBGR, 0 MCGR), 17 were unplanned (10 DGR, 3 RBGR, 4 MCGR), 5 were definitive treatment (2 DGR, 2 RBGR, 1 MCGR), and 10 couldn't be classified (5 DGR, 2 RBGR, 3 MCGR). The median time (years) to first reoperation was 5.4 for MLT, 0.5 for DGR and RBGR, and 4.1 for MCGR. The hazard ratios comparing MLT to the control techniques were respectively 18.4, 63.3, and 2.9, log-rank $P < 0.0001$, illustrating a significantly longer time to first reoperation than the controls. The MLT group had significantly better initial median curve correction than the controls ($-40°$ vs. $-27°$, $p = 0.023$) but similar reduced correction at 3 years ($-21°$ vs. $-22°$, $p = 0.613$). Median spinal (T1-S1) growth from baseline to 3 years was similar (4.5 cm vs. 4.8 cm, $p = 0.156$).
Conclusions: MLT reduced the number of reoperations compared to other fusionless techniques, with significantly longer time to first reoperation. MLT treated patients had slightly less but similar growth and deformity correction at 3 years compared to the control patients.
Modern Luque trolley construct
Transmuscular Apical Gliding screw to translate Apex of deformity to midline.



Paper #40

Effect of the spring distraction system on different etiologies in early onset scoliosis

Casper Tabeling; Justin Lemans; Isabelle Blaauw; Hilde Stempels; Tom Schlosser; Rene Castelein; Moyo Kruyt

Introduction: Early onset scoliosis (EOS) is a challenging condition that requires 'growth-friendly' implants for severe cases. Four etiologies are relevant for EOS patients, each with typical curve characteristics and different natural histories, likely requiring distinct treatment strategies. Treatment aims to control the spinal deformity while allowing for growth. However, even though current surgical options are effective, they have many disadvantages such as repeated (surgical) lengthenings. To counter this, the Spring Distraction System (SDS) was developed, which is able to support spinal growth while providing continuous distraction. The efficacy of this dynamic implant was shown in prospective studies that included a heterogeneous patient population.
Aims/objectives: The aim of the current study is to determine long-term performance of the SDS specifically for the different etiologies of EOS.
Methods: Retrospective analysis of a prospective study cohort involving skeletally immature EOS patients treated with the SDS (Fig. 1) with at least two years of follow-up. Radiographic outcomes included coronal and sagittal Cobb angles and spinal growth. Disease-, surgery- and implant related serious adverse events (SAEs), unplanned returns to the operating room (UPRORs) and implant-related adverse events (AEs) were recorded.

Results: In total, 61 patients were included (14 congenital, 37 neuromuscular and 10 idiopathic). Four syndromic patients were too heterogenous for relevant analysis. The average age at surgery was 8.4 ± 1.7 years and mean follow-up was 3.8 ± 1.4 years. The primary curve was corrected from 72.6° ± 17.6° to 39.2° ± 16.2° (46%) and maintained in the congenital and neuromuscular group, while curve correction in idiopathic patients was partially lost. The mean annual T1–T12 and T1-S1 growth (Fig. 2) was 5.5 ± 3.8 mm and 8.5 ± 3.8 mm for congenital patients, 5.7 ± 3.4 mm and 10.0 ± 5.5 mm for neuromuscular patients and 3.2 ± 4.1 mm and 5.3 ± 5.5 mm for idiopathic patients, respectively. In total, there were 63 (S)AEs (6 disease-related, 22 surgery-related, 34 implant-related) in 32 patients. The most common SAE was implant-related, mainly caused by rod fractures (15/25), followed by excessive kyphosing in the system (8/21). In total, there were 51 UPRORs, primarily in the neuromuscular group and mainly due to fully extended springs before the end of growth. Consequently, the most common UPROR was a retensioning surgery.
Conclusions: The SDS allowed adequate correction and growth guidance for EOS of different etiologies. Where curve correction was maintained or even improved for neuromuscular and congenital etiologies, this was partially lost for the idiopathic patients. The (S)AE and UPROR rate was 0.27 and 0.22 per patient per year which compares favorably to other systems.

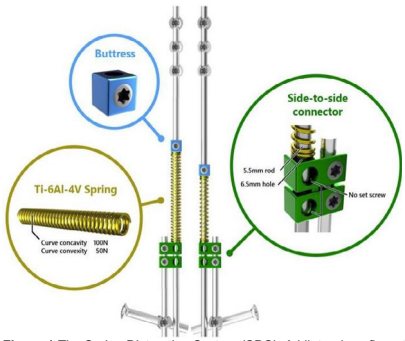


Figure 1 The Spring Distraction System (SDS). A bilateral configuration of the SDS consisting of bilateral springs (gold) placed over a 5.5 mm rod that can slide through bilateral stacked side-to-side connectors (green). The springs are tensioned with a buttress (blue)

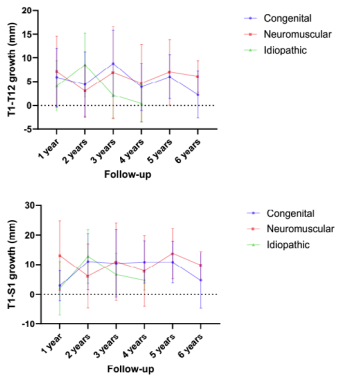


Figure 2 Spinal growth over time. T1-T12 (above) and T1-S1 (below) growth, mean ± SD at each timepoint up to six years for each etiology

Paper #41

Research and development of a novel growth guidance system

You Du; Yanyan Bian; Yiwei Zhao; Terry Jianguo Zhang; Shengru Wang

Introduction: Our study team improved the sliding interface of the traditional Shilla implants and developed a novel growth guidance system.
Aims/objectives: This study aims to detail the design of the novel growth guidance system and further validate its ability to reduce metal debris and decrease sliding friction through both in vitro and in vivo experiments.
Methods: Two major modifications were made to the traditional Shilla system, including the use of ultra-high molecular weight polyethylene (UHMWPE) gaskets to avoid direct contact between the screw and rod, and polishing the surface of the sliding part of the rod. We test the durability of the system by a fatigue test of 10 million cycles of a constant displacement. The sliding capacity was measured by a sliding displacement test. The maximum sliding displacement of the system was measured after 300 cycles of dynamic compressive loads in a sinusoidal waveform. The system was implanted in miniature pigs, and X-rays were taken in the anteroposterior and lateral views to assess the preservation of spinal growth by the system. MRI and CT scans were performed to evaluate the discs and facet joints of the instrumented spine. Blood metal ion concentrations were measured, and histological examination of peri-implant soft tissues was conducted to assess the system's ability to reduce metal debris reaction and histo-compatibility.
Results: After the fatigue test, all the UHMWPE gaskets samples showed some of the fretting on the edge of the inner sides, but it's still isolated and avoided the friction between the screws and rods. There was no sign of metallic fretting around the screws and rods. The average wear mass of the gaskets was 0.002 ± 0.001 g, less than 1.7% of the original mass. In the sliding test, the novel growth guidance system demonstrated the best sliding capacity, with an average maximum sliding distance(AMSD) of 35.75 ± 5.73 mm, significantly better than the traditional Shilla implants. Six miniature pigs underwent in vivo experiments, with an immediate postoperative mean spinal fixation length of 20.1 ± 0.7 cm and a mean spinal fixation length of 23.5 ± 0.7 cm at 12 weeks postoperatively. CT and MRI scans showed no signs of degeneration of the facet joints or intervertebral discs in the instrumented spine. There were no significant changes in titanium ion concentrations. Gross anatomy revealed no metal debris around the sliding screws. Histological reaction scoring indicated that the tissue response to the implantation of the novel sliding screws was either non-irritating or mildly irritating.
Conclusions: The novel growth guidance system demonstrated excellent wear resistance and sliding performance in vitro. In vivo experiments revealed sliding capabilities of the system, preserving spinal growth potential while causing no damage or degeneration to intervertebral discs and facet joints. The system also exhibited no irritation to local soft tissues and displayed favorable biocompatibility.

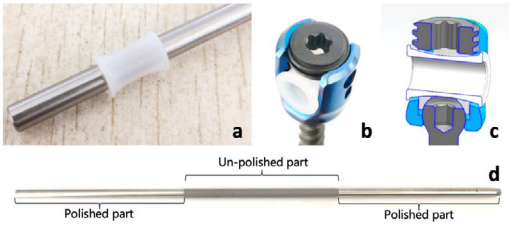


Figure 1 The design of the novel growth guidance system. Fig.1a shows the UHMWPE gasket. Fig.1b shows the UHMWPE gasket can be perfectly fitted into the tulip of the sliding screw and locked by the nuts. Fig.1c shows the longitudinal section of the sliding screw with gasket assembled. Fig.1d shows the rod, the sliding part of the rod was polished, the middle part of the rod was un-polished

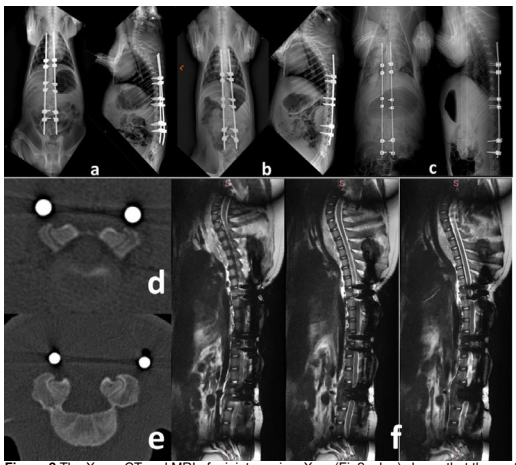


Figure 2 The X ray, CT and MRI of miniature pigs. X ray(Fig2 a,b,c) shows that the system was sliding smoothly. CT(Fig2 d,e) shows that the instrumented facet joints were intact. MRI (Fig2 f) shows that there was no sign of the degeneration of the instrumented discs

Paper #42

Complications of the Nemost growth rod

Kristopher Lundine, MD MSc FRCSCS FRACS; Michael Johnson, MBBS, FRACS (Ortho), FAOA

Introduction: Early onset scoliosis (EOS) is a challenging clinical scenario with many surgical options to consider. Complications are common regardless of implant choice. We began using a new growth rod at our institution in June 2017. This is a 'ratchet-like' system called Nemost that allows ongoing spinal growth after implantation without the need for further surgery.
Aims/objectives: The purpose of this study was to assess clinical and radiographic outcomes in patients undergoing implantation of a new spinal growing rod to try and optimize indications for this procedure.
Methods: All patients undergoing EOS correction with Nemost growth rod were identified in the surgical database of a single pediatric institution. Patient charts were reviewed for demographic data and clinical outcomes. Pre-operative and most recent post-operative radiographs were reviewed to assess curve measurements and spinal growth. Complications were recorded as part of a prospective database and were classified according to the modified Clavien-Dindo-Sink (CDS) classification system. Major complications were considered CDS 3 or greater.
Results: 55 patients have undergone surgery with the Nemost growth rod between June 2017 and June 2024. Median age at surgery was 10 years (range 6–13) and average pre-operative major cobb angle was 87° (range 45–132). There was a minimum 12-month follow-up on 45 patients. Mean pre-op Cobb angle was 87°, 45° post-op and 50° at most recent follow-up for a mean correction of 43%. The mean increase in thoracic height (T1–12) from pre-operative radiograph to post-op was 24 mm with an additional 10 mm at most recent review. 30 of 45 patients (67%) had at least 1 cm ongoing spinal growth from surgery to most recent review. There have been 25 major complications in 18 patients. 37 patients (67%) experience no major complications. Over half of the major complications were experienced by 6 of the patients. There were 21 cases of unplanned return to theatre in 17 patients. The most common hardware complication was slippage of the Nemost device which occurred in 5 patients. Three patients had broken rods requiring revision surgery. There were two deep infections (3.6%) from the primary surgery and one deep infection subsequent to a revision procedure.
Conclusions: This growth rod demonstrated ongoing spinal growth in 67% of patients. In this series of 55 patients, 33% experienced at least one major complication. Many complications have resulted in modifications of the original technique to improve safety and prevent future similar complications. Slippage of the Nemost device on the fixed rod is an ongoing concern that hopefully can be addressed with design modification. This is the largest clinical series of this implant outside of the original centre where it was designed.

Paper #43

Anterior scoliosis correction for the treatment of patients 5 to 10 years of age with early onset scoliosis

M. Darryl Antonacci; Janet Cerrone; Anthony Yung; Laury Cuddihy; Randal Betz

Introduction: Currently, there exists a paucity of research exploring the clinical outcomes for patients aged 5 to 10 years with Early Onset Scoliosis (EOS) who have been treated using Anterior Scoliosis Correction (ASC). ASC is the authors' multi-year modification of the original vertebral body tethering (VBT) to a double screw-line and incorporating multilevel releases of the contracted annular disc complex.
Aims/objectives: The aim of this paper is to present intermediate term results on a single center cohort of young patients 5 to 10 years of age who underwent non-fusion anterior scoliosis correction.
Methods: The study included patients diagnosed with EOS, aged 5–10 years of age, Sanders stage 2 or less, Risser sign of 0, open triradiate cartilages, and a minimum of 2 years of follow-up. Within a database encompassing 840 patients treated with ASC, 15 patients (17 curves) met the inclusion criteria. The average duration of follow-up for this cohort was 48.3 months, with a range of 25 to 86 months.
Results: The mean age at the time of surgery was 8 years, with a range of 5.7 to 10.1 years. Preoperative scoliotic curves averaged 81° (range 58° to 100°) and demonstrated a mean flexibility of 51%. At the most recent follow-up, the instrumented curves improved to an average of 22° (range − 15° to 68°), culminating in a mean correction of 75%. Preoperative 3-dimensional kyphosis, calculated as an average of − 6° (range − 23° to + 20°), was improved to an average of 28° (range − 1° to 59°) at latest follow-up. Within the cohort, 11 of the 15 patients underwent a secondary surgical procedure at an average of 43 months following the index procedure. Of these 11, lengthening was necessary for overcorrection in 3 patients (20%), anterior revision was done for cord breakage with loss of correction in 6 patients (40%), and spinal fusion was performed in 2 patients (13%).
Conclusions: A cohort of 15 patients aged 5–10 years with EOS treated with ASC (initial average curve of 81°) demonstrated a substantial mean correction of 75% in the instrumented curve. Although 2/15 patients (13%) subsequently underwent posterior spinal fusion, these early outcomes suggest that ASC could potentially be an effective alternative to traditional posterior growing rod systems for these young patients.

Table 1. Data Summary: 15 Patients (17 Curves) with Early Onset Scoliosis

	Patients/%	Average (Range)	
Mean age at surgery (years)		8.0 (5.7 to 10.1)	
Mean follow-up (months)		48.3 (25 to 86)	
Construct of curves (n=17)			
Single row screw/cord	9 (53)		
Double row screw/cords	8 (47)		
Disc (Annulus)Releases			
# patients	14/15 (93)		
Avg # releases per patient	3.3 (1 to 7)		
Coronal Curve		**Maximum**	**Instrumented**
Pre-op (°)		81.1 (58 to 100)	
Average flexibility (%)		50.9 (21 to 71)	
First erect post-op (°)		33.2 (16 to 66)	26.9 (6 to 46)
Average correction (%)		57.5 (23 to 78)	65.9 (47 to 91)
Most recent post-op (°)		30.6 (-38 to 73)	22.5 (-15 to 68)
Average correction (%)		63.5 (25 to 158)	74.7 (30 to 123)
3D Sagittal Curve T5 to T12 (by Formula)			
Pre-op (°)		-5.6 (-23.2 to 19.7)	
Most recent (°)		27.6 (-0.8 to 58.6)	

Paper #44

Addressing the curve: a comparative analysis of vertebral body tethering and posterior spinal fusion outcomes in older early onset scoliosis patients

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Introduction: Skeletally immature patients with scoliosis are at risk of refractory curve progression despite bracing and should be surgically corrected when appropriate. The best documented treatment for early onset scoliosis (EOS) is posterior spinal fusion (PSF) but is known to cause lifelong functional limitations. Vertebral body tether (VBT) shows promise as a non-fusion, growth-modulation alternative but data on EOS patients is limited. This study compares outcomes for EOS patients treated with VBT and PSF.

Aims/objectives: To compare surgical outcomes and radiographic measurements up to 2-years between EOS patients undergoing VBT and PSF.

Methods: Idiopathic EOS patients undergoing index VBT or PSF with a minimum of 2-year radiographic follow-up were included. Older EOS patients were defined as those aged 8–11 years, having a Sanders score ≤ 2, Risser score ≤ 1 or open triradiate cartilage on preoperative XR. The cohort was separated by procedure. Outcomes of interest include demographic variables, surgical characteristics, and radiographic measurements at baseline, post-op and 2-year follow-up. Independent samples t-test and χ^2 test were used to compare outcomes between groups.

Results: 55 patients met inclusion criteria (23 VBT; 32 PSF). Baseline demographic variables and skeletal maturity did not differ significantly between groups. PSF patients experienced more blood loss (642.6 ± 468.5 vs. 306.5 ± 191.5 mL, $p < 0.001$), required more intraoperative blood products ($p < 0.05$) and had greater duration of surgical drain placement postoperatively than VBT patients (3.7 ± 1.2 vs. 2.5 ± 1.0 days, $p < 0.001$). The PSF group had a larger baseline main thoracic cobb angle and greater change from baseline to post-op/2 years ($p < 0.05$). However, no differences were detected in all major cobb values at post-op or 2-year follow-up ($p > 0.05$). PSF achieved greater post-op mean thoracic and total height than VBT but grew significantly less compared to the VBT group by 2 years (change in total height from postop to 2 years: 3.4 ± 2.7 vs. 6.0 ± 3.9 cm, $p = 0.008$; change in thoracic height from postop to 2 years: 0.2 ± 1.1 vs. 1.5 ± 1.6 cm, $p < 0.001$). VBT patients demonstrated a larger correction of the cSVA from pre-op/postop ($p = 0.042$). Tether breakage occurred in 7 (30.4%) VBT patients but none required reoperation by 2 years.

Conclusions: VBT has similar outcomes to PSF in older EOS patients. However, the advantage of thoracic and total height growth and modulation make it a safe treatment option in this age group of patients.

Table 1. Comparison of clinical and surgical characteristics between early onset scoliosis patients treated with vertebral body tether and posterior spinal fusion patients.

	Total (N = 55)	Vertebral Body Tether Patients n = 23	Posterior Spinal Fusion Patients n = 32	p-value
Demographics	Age (years)	12.2 ± 1.9	11.9 ± 1.3	0.538
	Gender (% Female)	21 (91.3%)	29 (90.6%)	0.931
	Height (cm) at baseline	152.4 ± 9.5	154.7 ± 8.7	0.368
	Height (cm) at post-op	**153.3 ± 8.4**	**158.3 ± 7.8**	**0.028**
	Δ from baseline	**0.9 ± 2.9**	**3.6 ± 4.3**	**0.007**
	Height (cm) at 2 year follow-up	159.1 ± 7.7	161.8 ± 7.9	0.923
	Δ from baseline	7.0 ± 5.5	7.1 ± 4.3	0.923
	Δ from post-op	**6.0 ± 3.9**	**3.4 ± 2.7**	**0.008**
	Weight (kg)	46.1 ± 8.2	48.8 ± 13.2	0.353
	BMI (kg/m^2)	20.0 ± 2.9	20.2 ± 4.5	0.800
Surgical Characteristics	Operative Time (mins)	422.4 ± 139.4	368.8 ± 128.7	0.147
	Levels Involved	**8.4 ± 2.1**	**10.1 ± 1.4**	**0.003**
	Estimated Blood Loss (mL)	**306.5 ± 191.5**	**642.6 ± 468.5**	**<0.001**
	Intraop pRBC (mL)	**0.0 ± 0.0**	**71.9 ± 160.6**	**0.017**
	Intraop Salvage Blood returned (mL)	**44.5 ± 122.7**	**164.9 ± 168.1**	**0.005**
	Days with Drain in Place	**2.5 ± 1.0**	**3.7 ± 1.2**	**<0.001**
	Length of Stay (Days)	4.6 ± 0.9	4.4 ± 1.0	0.541
Post-op course	Any complication*	2 (8.7%)	0 (0.0%)	0.089
	Pulmonary complication[1]	2 (8.7%)	0 (0.0%)	0.089
	Urinary Complication[2]	1 (4.3%)	0 (0.0%)	0.234
	Return to OR in 90 days[3]	1 (4.3%)	0 (0.0%)	0.234
Skeletal Maturity and Lenke Type	Risser 0	16 (69.6%)	20 (62.5%)	0.587
	Risser 1	7 (30.4%)	10 (31.3%)	0.949
	Risser 3	0 (0.0%)	2 (6.3%)	0.222
	Sanders (n, mean)	**20 (3.5 ± 1.6)**	**4 (2.3 ± 0.5)**	**0.013**
	Triradiate Cartilage Open	8 (34.8%)	7 (21.9%)	0.289
	Lenke 1	7 (31.8%)	18 (58.1%)	0.059
	Lenke 2	1 (4.5%)	5 (16.1%)	0.190
	Lenke 3	3 (13.6%)	2 (6.5%)	0.378
	Lenke 4	0 (0.0%)	3 (9.7%)	0.133
	Lenke 5	**5 (22.7%)**	**0 (0.0%)**	**0.005**
	Lenke 6	6 (27.3%)	3 (9.7%)	0.093
Tether Characteristics	Total	7 (30.4% of VBT patients)		
	Thoracic	1 (14.3%)		
	Thoracolumbar	1 (14.3%)		
	Lumbar	5 (71.4%)		
	Overcorrection	0 (0.0%)		
	Conversion to PSF	0 (0.0%)		

** One patient experienced a pulmonary annd urinary complication at the same time.*
1 Acute hypoxic respiratory failure in one patiient and loculated pleural effusion in another patient.
2 Hydronephrosis with infected pararenal urinoma/psoas muscle fluid collection requiring ureteral stent placement.
3 Return to OR for migrating T5 screw.
pRBC = packed red blood cells; Δ from baseline = change from baseline measurement to measurement at specified time point

Table 2. Comparison of radiographic characteristics between early onset scoliosis patients treated with vertebral body tether and posterior spinal fusion patients.

	Vertebral Body Tether Patients n = 23	Posterior Spinal Fusion Patients n = 32	p-value
Thoracic Height in cm (T1-T12)			
Pre-op	22.5 ± 2.6	21.7 ± 2.3	0.257
Post-op	**22.9 ± 2.2**	**24.3 ± 1.8**	**0.012**
Δ from baseline	**0.4 ± 1.0**	**2.5 ± 1.8**	**<0.001**
2 years	24.2 ± 2.5	24.5 ± 1.8	0.706
Δ from baseline	1.9 ± 1.9	2.7 ± 1.9	0.112
Δ from post-op	**1.5 ± 1.6**	**0.2 ± 1.1**	**<0.001**
Coronal balance (mm)			
Pre-op	21.7 ± 14.0	17.6 ± 12.2	0.267
Post-op	21.2 ± 13.4	15.4 ± 18.8	0.210
Δ from baseline	-0.4 ± 13.3	-4.6 ± 17.2	0.345
2 years	12.7 ± 8.0	11.3 ± 9.0	0.571
Δ from baseline	-10.8 ± 12.2	-7.2 ± 14.6	0.389
LS Tilt (°)			
Pre-op	**12.8 ± 7.0**	**8.1 ± 7.8**	**0.026**
Post-op	7.5 ± 4.2	6.3 ± 4.9	0.341
Δ from baseline	-5.3 ± 7.7	-1.7 ± 5.4	0.059
2 years	7.5 ± 4.6	5.2 ± 4.3	0.090
Δ from baseline	-5.3 ± 6.6	-2.5 ± 5.1	0.120
Proximal Thoracic Cobb (°)			
Pre-op	40.7 ± 0.0	44.0 ± 13.0	0.818
Post-op	30.1 ± 0.0	24.0 ± 9.9	0.581
Δ from baseline	-10.6 ± 0.0	-20.0 ± 9.4	0.379
2 years	29.8 ± 0.0	33.1 ± 8.8	0.736
Δ from baseline	-10.9 ± 0.0	-11.5 ± 10.1	0.961
Main Thoracic Cobb (°)			
Pre-op	**54.3 ± 11.2**	**62.7 ± 14.5**	**0.040**
Post-op	26.5 ± 11.5	23.3 ± 7.1	0.236
Δ from baseline	**-28.3 ± 15.2**	**-39.4 ± 13.7**	**0.013**
2 years	30.8 ± 10.2	27.6 ± 7.2	0.238
Δ from baseline	**-22.7 ± 12.7**	**-37.7 ± 10.5**	**<0.001**
Thoracolumbar Cobb (°)			
Pre-op	54.0 ± 11.6	59.4 ± 11.9	0.276
Post-op	20.7 ± 14.4	19.6 ± 7.3	0.822
Δ from baseline	-33.2 ± 16.5	-39.4 ± 12.2	0.341
2 years	26.6 ± 13.8	21.3 ± 11.0	0.353
Δ from baseline	-25.9 ± 12.9	-36.7 ± 12.1	0.076
Lumbar lordosis (°)			
Pre-op	57.4 ± 12.2	55.5 ± 13.2	0.594
Post-op	51.3 ± 11.9	52.3 ± 14.3	0.775
Δ from baseline	-6.1 ± 8.3	-4.3 ± 9.2	0.484
2 years	55.1 ± 11.3	57.5 ± 15.6	0.557
Δ from baseline	-2.3 ± 6.9	-0.4 ± 10.3	0.486

	Vertebral Body Tether Patients n = 23	Posterior Spinal Fusion Patients n = 32	p-value
Pelvic Incidence-Lumbar Lordosis			
Pre-op	-6.7 ± 11.3	-10.5 ± 13.3	0.282
Post-op	-1.4 ± 13.6	-6.6 ± 15.4	0.217
Δ from baseline	4.3 ± 9.9	4.2 ± 9.9	0.978
2 years	-6.2 ± 11.5	-9.7 ± 13.4	0.344
Δ from baseline	0.8 ± 7.4	1.1 ± 8.9	0.907
Pelvic Tilt (°)			
Pre-op	6.5 ± 6.8	4.6 ± 8.8	0.387
Post-op	10.0 ± 7.6	7.3 ± 10.0	0.298
Δ from baseline	3.2 ± 6.4	1.9 ± 5.2	0.448
2 years	18.1 ± 43.7	6.1 ± 8.0	0.191
Δ from baseline	11.6 ± 41.0	2.2 ± 5.8	0.304
Sacral Slope (°)			
Pre-op	44.2 ± 11.2	47.4 ± 34.9	0.678
Post-op	39.9 ± 10.2	38.7 ± 9.2	0.655
Δ from baseline	-5.0 ± 7.6	-9.9 ± 38.8	0.562
2 years	39.4 ± 10.7	41.4 ± 12.0	0.563
Δ from baseline	-4.4 ± 7.3	-11.0 ± 44.1	0.495
Sagittal Vertical Axis (mm)			
Pre-op	25.9 ± 24.6	27.3 ± 21.5	0.835
Post-op	27.4 ± 21.5	44.7 ± 92.5	0.393
Δ from baseline	1.6 ± 26.8	15.5 ± 93.7	0.503
2 years	23.4 ± 15.6	23.5 ± 18.1	0.983
Δ from baseline	-2.6 ± 28.9	-3.2 ± 27.7	0.947
Thoracic Kyphosis (°)			
Pre-op	28.4 ± 12.2	28.3 ± 15.0	0.981
Post-op	28.8 ± 13.4	29.1 ± 9.4	0.936
Δ from baseline	1.6 ± 8.2	0.8 ± 14.0	0.777
2 years	31.0 ± 11.9	29.7 ± 10.7	0.696
Δ from baseline	2.5 ± 7.6	0.8 ± 13.9	0.596
T1 Pelvic Angle (°)			
Pre-op	6.9 ± 3.9	6.0 ± 3.5	0.382
Post-op	9.6 ± 7.4	8.2 ± 8.4	0.537
Δ from baseline	2.6 ± 6.0	0.4 ± 5.4	0.183
2 years	6.9 ± 6.4	6.2 ± 5.5	0.690
Δ from baseline	0.0 ± 5.1	-1.0 ± 5.8	0.547
Cervical Sagittal Vertical Axis (mm)			
Pre-op	25.0 ± 13.4	21.6 ± 6.9	0.253
Post-op	21.0 ± 7.8	24.5 ± 8.6	0.149
Δ from baseline	**-3.6 ± 8.7**	**1.9 ± 9.2**	**0.042**
2 years	23.3 ± 12.2	27.9 ± 9.5	0.161
Δ from baseline	-1.5 ± 15.4	6.1 ± 8.3	0.053
Pelvic Incidence (°)			
Pre-op	50.7 ± 13.1	45.0 ± 9.4	0.073
Post-op	49.9 ± 13.6	46.0 ± 12.0	0.280
Δ from baseline	-1.8 ± 7.6	-0.6 ± 4.5	0.482
2 years	48.9 ± 14.6	47.5 ± 13.7	0.726
Δ from baseline	-1.5 ± 7.7	0.7 ± 4.7	0.271

Paper #45

Matched comparison of non-fusion surgeries for adolescent idiopathic scoliosis: posterior dynamic distraction device and vertebral body tethering

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Introduction: Two non-fusion devices for adolescent idiopathic scoliosis (AIS) received HDE approval for clinical use in 2019: posterior dynamic distraction device (PDDD) and vertebral body tether (VBT). Although indications are similar, there is no comparative study of these devices.

Aims/objectives: We aim to compare the perioperative outcomes for these two non-fusion devices for management of AIS. We hypothesize that curve correction will be comparable, but PDDD will have better operative metrics.

Methods: AIS PDDD patients were prospectively enrolled in this matched multicenter study. Inclusion criteria were Lenke 1 or 5 curves, preoperative curves 35°- 60°, correction to ≤ 30° on bending radiographs, and kyphosis < 55°. Patients were matched by age, sex, Risser, curve type and magnitude to a single-center cohort of VBT patients. Results were compared to 2-years.

Results: 20 PDDD patients were matched to 20 VBT patients. Blood loss was higher in the VBT cohort (88 vs. 36 ml, $p < 0.001$). Operative time and postoperative length of stay were longer in the VBT cohort, 177 vs. 115 min ($p < 0.001$) (2.9 vs. 1.2 days, $p < 0.001$). Postoperative curve measurement and correction at 6 months were better in the PDDD cohort (15° vs. 24°, $p < 0.001$; 68% vs. 50%, $p < 0.001$). At 1-year, PDDD patients had improved Cobb angles (14° vs. 21°, $p = 0.001$). At 2-years, correction was improved in the PDDD cohort, with a curve measurement of 17° for PDDD and 22° for VBT ($p = 0.043$). At latest follow-up, 3 PDDD and 1 VBT patients underwent revision surgery.

Conclusions: PDDD demonstrates better index correction, reduced operative time, less blood loss, and shorter length of stay but higher rates of revision compared to a matched cohort of VBT patients at two-year follow-up.

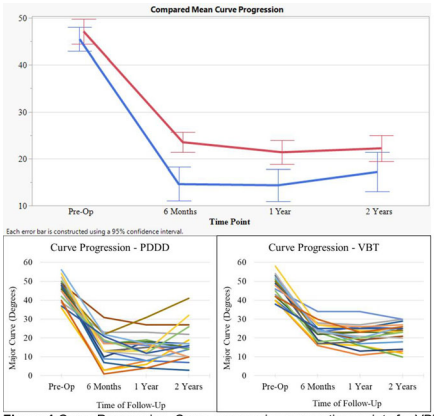

Figure 1 Curve Progression. Curve progression across time points for VBT and PDDD non-fusion scoliosis surgery

Table Matched radiographic outcomes of PDDD and VBT cohorts

Radiographic Outcomes	PDDD (N=20)		VBT (N=20)		P-value
	Average	Std Dev (Range)	Average	Std Dev (Range)	
Preop Coronal Curve	46°	6° (36-56)	47°	6° (38-58)	0.358
6 Month Coronal Curve	15°	8° (1-31)	24°	5° (16-34)	**<0.001**
1 Year Coronal Curve	14°	7° (4-31)	21°	5° (11-34)	**0.0014**
2 Year Coronal Curve	17°	9° (3-41)	22°	6° (10-30)	**0.043**
% Correction at 6 Months	68%	17% (37-97)	50%	11% (26-68)	**<0.001**
% Correction at 1 Years	69%	16% (34-92)	54%	14% (26-74)	**0.003**
% Correction at 2 Years	62%	19% (13-94)	52%	14% (30-80)	0.081
Preop Kyphosis	20°	9° (7-39)	18°	13° (0-43)	0.538
6 Month Kyphosis	33°	9° (17-49)	24°	11° (5-42)	**0.005**
1 Year Kyphosis	34°	11° (19-61)	33°	10° (10-52)	0.701
2 Year Kyphosis	34°	9° (15-53)	34°	9° (12-50)	0.819

Paper #46

Early outcomes in hybrid spine fixation for adolescent/juvenile idiopathic scoliosis: posterior spinal fusion with combined anterior vertebral body tethering

Daniel Cherian; Amer Samdani, MD; Joshua Pahys, MD; Alan Stein; Alexander Schupper; Steven Hwang, MD

Introduction: Anterior vertebral body tethering (VBT) and posterior spinal fusion (PSF) are both options for patients with idiopathic scoliosis with the former having a higher reoperation rate balanced with maintained motion. Combining both procedures in patients with double curves where a PSF is performed for the thoracic curve and VBT for the lumbar curve provides maximal correction of the thoracic curve with a theoretical maintenance of motion for the lumbar spine.

Aims/objectives: To determine the early outcomes off a combined approach of PSF with VBT for young patients with double curves.

Methods: A retrospective chart review of 19 patients at a single pediatric institution with a diagnosis of idiopathic scoliosis who have undergone thoracic PSF combined with lumbar VBT were included. Demographic, clinical, and radiographic variables were collected, and univariate statistics were compared via t-test analysis.

Results: 19 patients were identified with an average age of 12.7 ± 1.6 years (female = 68.4%) with an average follow-up of 8 months (range 1–24). These patients were skeletally immature (Sanders 3.8 ± 1.8) with the following Lenke curve types: 6 (11), 3 (6), and one each of 4C and 1C. All patients underwent staged PSF and VBT procedures, and of the 17 patients who had both procedures in the index admission, procedures were performed with an average 3.4 ± 2.1 days apart. PSF procedures took an average of 273 ± 63 min, and VBT procedures had a duration of 275 ± 55 min. Estimated blood loss (EBL) was 121.8 ± 80.6 mL for VBT procedures, and 426.6 ± 294.0 mL for PSF procedures. Following hybrid correction, thoracic Cobb angles improved from 66.9° to 17.9° ($p < 0.001$), and lumbar Cobb angles improved from 65.0° to 20.4° ($p < 0.001$). In patients with 1-year follow-up, Cobb angles did not progress in either thoracic ($p < 0.001$) or lumbar ($p < 0.001$) regions. No patients required revision surgery, and there were no major perioperative complications.
Conclusions: A combined approach of PSF with VBT is a safe and effective approach for idiopathic scoliosis. This approach applies the gold standard of performing a selective thoracic fusion with the purported benefits of motion preservation of VBT for the lumbar spine. Hopefully, this study will continue to refine indications for VBT to where it is most impactful.

Table. Patients undergoing hybrid tether/fixation correction

Number of patients	19	
Average age (years)	12.7 ± 1.6	
Female, n (%)	13 (68.4)	
Lenke Curve type, n (%): 1C	1 (5.3)	
3C	6 (31.6)	
4C	1 (5.3)	
6C	11 (57.9)	
Sanders score (avg.)	3.8 ± 1.8	
Avg. days between procedures	3.4 ± 2.1	
	PSF	**VBT**
Surgical time (minutes)	263 ± 63	275 ± 55
Estimated blood loss (mL)	426.6 ± 294.0	121.8 ± 80.6
	Thoracic	**Lumbar**
Pre-op coronal curve angle	66.9°	65.0°
Post-op coronal curve angle	17.9°	20.4°
p-value	<0.001	<0.001

PSF = posterior spinal fusion
VBT = vertebral body tethering

Paper #47

Bilateral anterior lumbar vertebral body tethering: a feasibility cohort study

Alan Stein; Amer Samdani, MD; Alexander Schupper; Sabrina Zeller; Zan Naseer; Joshua Pahys, MD; Solomon Praveen Samuel; Alejandro Quinonez; Emily Nice; Kaitlin Kirk; Steven Hwang, MD

Introduction: Anterior vertebral body tethering (aVBT) is a viable option for children with idiopathic scoliosis. The benefits of motion preservation, however, must be balanced with a higher reoperation rate. There is a paucity of literature addressing the efficacy of treating double major with bilateral aVBT.
Aims/objectives: We wished to determine whether bilateral aVBT allows patients with double curves to avoid spinal fusion while improving the coronal Cobb angle.
Methods: A single center retrospective study was conducted to identify all patients who underwent bilateral aVBT (LIV L3 or 4) with minimum 2-year follow-up. Clinical and radiographic parameters were collected including complications and reoperations. Statistical analysis was performed utilizing Students' t-test of qualitative variables.
Results: From a dataset of 551 patients, we identified 73 patients (67 girls [91.8%]) who underwent bilateral aVBT with a mean follow-up of 4.2 ± 1.5 years. Preoperatively, these patients were all skeletally immature (age 12.7 ± 1.2 years with a Sanders score of 3.3 ± 0.8 and Risser grade of 0.6 ± 0.8). The preoperative lumbar Cobb angle measured 51.1° ± 7.9° which corrected to 20.7° ± 11.3° at most recent follow-up ($p < 0.01$), and the preoperative thoracic Cobb angle measured 52.3° ± 9.0° which corrected to 27.0° ± 11.3° ($p < 0.01$) at most recent follow-up. At latest follow-up, 51/73 (69.9%) had a thoracic Cobb angle < 30°, 59/73 patients (80.8%) had a lumbar Cobb angle < 30°, and 47/73 (64.4%) had both thoracic and lumbar Cobb angles < 30°. Fifteen patients (20.5%) underwent 17 reoperations with overcorrection being the most common indication (8/17, 47.1%). Broken tethers led to reoperation in 3/17 instances (17.6%). Five of 73 patients in the cohort (6.8%) eventually required a posterior spinal fusion.
Conclusions: AVBT has emerged as a viable treatment option for skeletally immature patients with idiopathic scoliosis. The high reoperation rate must be balanced with the benefit of motion preservation. Bilateral aVBT as such is a safe and viable option for patients with double curves, with the majority of curves measuring < 30° at most recent follow-up. Surgeons can use these data to help patients and parents make an informed decision regarding treatment options.

Paper #48

Single-row vs. double-row anterior vertebral body tethering: which offers better clinical and radiographic outcomes for AIS patients?

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Introduction: Vertebral body tethering (VBT) is a promising growth-modulating technique in treatment of AIS. While the use of an additional tether has been proposed to reduce the risk of tether breakage and improve correction, there is limited evidence supporting this.
Aims/objectives: Compare clinical and radiographic outcomes in patients undergoing either single or double row vertebral tethering.
Methods: Patients ≤ 16 years of age with AIS who underwent anterior VBT with 2-year minimum follow-up were included in the study. Patients were excluded if they had structural proximal thoracic curves (Lenke 2 and 4). We performed three separate analyses comparing main thoracic only (T), thoracolumbar only (TL) and combined thoracic/thoracolumbar (T/TL) tether constructs between single row (SR) and double row (DR) VBT. Independent sample t-tests and chi-squared analyses were used for comparison of baseline, clinical, and radiographic characteristics between groups.
Results: A total of 228 patients were enrolled in the study (191 SR: 37 DR). Across T, TL, and T/TL cohorts, DR patients were more skeletally mature based on differences in Rissers ($p < 0.05$). Both groups had similar Lenke Type distributions in each analysis. In our T analysis while DR trended towards improved correction at post-op and 2 years, no differences were found in tether breakage (SR 42.6% vs. DR 50.0%, $p = 0.725$) or revision (SR 7.4% vs. DR 0.0%, $p = 1.000$). In our TL cohorts, patients with DR had significantly

greater percent correction at early post op (75.1% vs. 51.1%, p = 0.003). While there was no significant difference in correction at 2-years (DR 49.7% vs. SR 33.0%, p = 0.279) and tether breakage (DR 70.0% vs. SR 50.0%, p = 0.650), SR experienced higher rates of revision (38.5% vs. 7.1%, p = 0.077) and had a higher conversion to fusion rate (23.1% vs. 0.0%, p = 0.098) compared to DR. In patients with T/TL constructs, while patients in the DR group were shown to have greater correction of their TL curve at first postoperative imaging (69.1% vs. 56.7%, p = 0.055), 2-year outcomes for percent correction, tether breakage (DR 84.6% vs. SR 78.6%, p = 1.000), and revision (DR 15.4% vs. SR 0.0%, p = 0.206) were equivalent between the groups.

Conclusions: While outcomes between single row and double row VBT were mostly similar in thoracic only tether and thoracic/thoracolumbar tether constructs, double row was shown to be superior to single row in thoracolumbar tether constructs, providing greater correction and reduced rates of revisions and fusions.

Table 1. Patient and Radiographic Data Between Either Thoracic or Thoracolumbar Single and Double Row Tethers

			p-value
Thoracic Tether	Single Row (N=162)	Double Row (N=10)	
Preoperative Main Thoracic Cobb	50.5±8.5	51.9±9.4	0.948
Main Thoracic Bending Angle	32.0±11.5	30.9±15.2	0.809
Main Thoracic Flexibility	37.7±18.2	36.1±27.8	0.830
Levels Instrumented	**6.6±0.8**	**7.7±0.7**	**<0.001**
First Post-Op Erect	28.7 ± 9.5	25.6 ± 10.3	0.315
Δ from baseline	-21.7 ± 8.9	-26.3 ± 10.0	0.117
% correction	42.9±16.3	50.8±17.3	0.141
2 years	29.1 ± 13.2	23.4 ± 14.5	0.243
Δ from baseline	-21.4 ± 13.3	-26.8 ± 14.0	0.275
Δ from Post-op	0.3 ± 10.4	-0.4 ± 10.5	0.852
% correction	41.9±24.8	56.0±25.5	0.120
2-Year Tether Breakage	55 (42.6%)	4(50%)	0.725
Main Thoracic Breakage	42 (32.6%)	4 (50.0%)	0.442
Distal Thoracic/Thoracolumbar Breakage	24 (18.6%)	1(12.5%)	1.000
2-Year Revision Needed	12 (7.4%)	0 (0.0%)	1.000
Conversion to PSF	3 (1.9%)	0 (0.0%)	1.000
Tether Revision	9 (5.6%)	0 (0.0%)	1.000
Tether Breakage	5 (3.1%)	0 (0.0%)	1.000
Thoracolumbar Tether	Single Row (N=13)	Double Row (N=14)	
Preoperative Thoracolumbar Cobb	48.9±7.8	52.3±8.7	0.306
Thoracolumbar Bending Angle	23.0±14.5	29.8±14.1	0.344
Thoracolumbar Flexibility	54.1±26.7	41.7±28.4	0.369
Levels Instrumented	**4.5±9.3**	**5.9±9.5**	**<0.001**
First Post-Op Erect	**23.9 ± 7.8**	**13.7 ± 10.3**	**0.017**
Δ from baseline	**-25.0 ± 11.6**	**-38.6 ± 7.7**	**0.001**
% correction	**51.1±21.6**	**75.1±16.1**	**0.003**
2 years	31.0 ± 19.0	26.9 ± 13.8	0.604
Δ from baseline	-15.3 ± 18.3	-26.8 ± 14.1	0.149
Δ from Post-op	6.8 ± 14.7	12.1 ± 12.7	0.423
% correction	33.0±39.2	49.7±23.8	0.279
2-Year Tether Breakage	5(50.0%)	7 (70%)	0.650
Distal Thoracic Breakage	1 (10.0%)	0 (0.0%)	1.000
Thoracolumbar Breakage	5 (50.0%)	7 (70.0%)	0.650
2-Year Revision Needed	5 (38.5%)	1 (7.1%)	0.077
Conversion to PSF	3 (23.1%)	0 (0.0%)	0.098
Tether Revision	2 (15.4%)	1 (7.1%)	0.596
Tether Breakage	5 (38.5%)	1 (7.1%)	0.077

Table 2. Patient and Radiographic Data Between Bilateral Thoracic and Thoracolumbar Single and Double Row Tethers

	Single Row (N=15)	Double Row (N=13)	p-value
Preoperative Thoracic Cobb	53.1±9.7	55.5±10.9	0.541
Thoracic Bending Angle	32.5±13.1	33.8±10.1	0.812
Thoracic Flexibility	36.6±13.6	37.8±18.0	0.875
Preoperative Thoracolumbar Cobb	51.6±9.4	52.6±9.8	0.780
Thoracolumbar Bending Angle	27.0±6.5	36.4±10.9	0.060
Thoracolumbar Flexibility	49.1±13.3	35.8±17.8	0.115
Levels Instrumented	**9.9±0.9**	**10.6±0.7**	**<0.001**
Thoracic Cobb Angle (°)			
First Post Op Erect	25.8 ± 10.2	27.7 ± 12.5	0.663
Δ from baseline	-27.3 ± 10.4	-27.8 ± 10.3	0.897
% correction	51.7±15.9	51.2±18.9	0.941
2 years	29.3 ± 11.4	33.0 ± 13.8	0.493
Δ from baseline	-26.4 ± 12.1	-23.5 ± 11.0	0.556
Δ from Post-op	1.7 ± 9.2	4.1 ± 10.2	0.551
% correction	46.3±18.8	40.7±23.4	0.530
Thoracolumbar Cobb Angle (°)			
First Post Op Erect	22.6 ± 10.1	16.9 ± 10.0	0.143
Δ from baseline	-29.0 ± 9.6	-35.8 ± 8.6	0.062
% correction	56.7±16.1	69.1±16.5	0.055
2 years	31.0 ± 12.1	32.0 ± 12.5	0.847
Δ from baseline	-21.9 ± 10.5	-21.7 ± 10.2	0.967
Δ from Post-op	6.7 ± 7.2	13.9 ± 13.1	0.114
% correction	41.9±19.1	41.1±18.7	0.916
2-Year Tether Breakage	11(78.6%)	11 (84.6%)	1.000
Thoracic Breakage	7 (50.0%)	5 (38.5%)	0.704
Thoracolumbar Breakage	10 (71.4%)	10 (76.9%)	1.000
2-Year Revision Needed	0 (0%)	2 (15.4%)	0.206
Conversion to PSF	0 (0%)	1(7.7%)	0.464
Tether Revision	0 (0%)	1(7.7%)	0.464
Tether Breakage	0 (0%)	2 (15.4%)	0.206

Paper #49

Early tether rupture compromises 3D growth modulation by failing to impede convex growth

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Introduction: Vertebral body tethering (VBT) is a novel technique for growth modulation in select patients. Though tether ruptures are common, early ruptures are thought to result in greater clinical importance, as the remodeling process is ongoing at this stage.

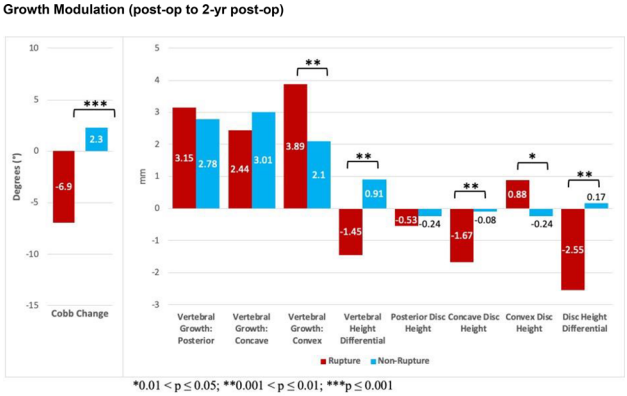
Aims/objectives: (1) Identify suspected segmental ruptures, (2) characterize the effect of rupture on 3D morphologic parameters and (3) identify patient and segment-specific risk factors for rupture.

Methods: A multicenter pediatric spine registry was queried for patients with juvenile or adolescent idiopathic scoliosis treated with VBT. Ruptures were identified using 2 definitions: $> 5°$ in inter-screw angle or $> 13\%$ in screw distance at any level between post-op and 2-year images with the intent to use the most sensitive measurement. Biplanar slot scanning radiographs were used to create 3D reconstructions at multiple timepoints for analysis. Morphologic measurements of individual vertebrae and discs were obtained through a custom MATLAB script. Significance for continuous variables was determined using the non-parametric, Wilcoxon test given the data was not normally distributed. Categorical variables were analyzed using Pearson's chi-square test.

Results: 50 patients with 300 instrumented disc-spaces were identified. Screw distance was more sensitive than inter-screw angle, identifying 6 ruptures missed by the former criterion. Ultimately, 19 (6.3%) segments in 13 (26%) individual patients met rupture criteria. Post-op 2-year radiographs showed significant worsening of

segmental Cobb (− 6.9° vs. 2.3°, $p < 0.001$) in ruptured segments due to increased convex VB growth (3.9 vs. 2.1 mm, $p = 0.007$), larger decrease in concave disc (− 1.7 vs. − 0.1 mm, $p = 0.007$) and increased convex disc (0.9 vs. − 0.2 mm, $p = 0.04$) heights (Fig. 1). Ruptured segments had decreases in disc (− 2.6 vs. 0.2 mm, $p < 0.001$) and vertebral (− 1.5 vs. 0.9 mm, $p = 0.002$) height differentials. Groups did not differ in sex, race, maturity indices, curve flexibility, or segmental tension. Segments with rupture occurred in taller (157.2 vs. 153.2 cm, $p = 0.033$) and heavier patients (46.4 vs. 42.9 kg, $p = 0.05$), and were more likely located towards the caudal end of instrumentation (42% occurring at T10-T11). Ruptured segments had higher pre-index posterior VB (36.2 vs. 33.6 mm, $p = 0.04$), posterior disc (5.2 vs. 4.5 mm, $p = 0.014$), concave disc (5.3 vs. 4.1 mm, $p = 0.01$), and convex disc (6.6 vs. 5.5 mm, $p = 0.006$) heights.

Conclusions: Early tether ruptures occur in 1 of 4 patients, demonstrating not only a loss of segmental coronal correction, but also altered growth modulation represented by increased convex VB growth and decreased concave disc height. Taller and heavier (but not necessarily more mature) patients were more at-risk for early rupture.



Paper #50

Thoracic anterior vertebral body tethering for adolescent idiopathic scoliosis: long-term outcomes with minimum 5-year follow-up

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Introduction: While posterior spinal fusion (PSF) for adolescent idiopathic scoliosis (AIS) provides robust deformity correction, it may sacrifice motion and potentially lead to adjacent segment disease. Anterior vertebral body tethering (VBT) is a growth-modulating treatment alternative that has shown significant promise, but long-term outcomes data are currently absent. We present the largest series of thoracic VBT with a minimum of 5 years of clinical and radiographic follow-up.

Aims/objectives: To assess clinical and radiographic outcomes of thoracic VBT with minimum 5-year follow-up.

Methods: We performed a retrospective review of all thoracic VBT performed at a single institution from 2011–2017 with minimum 5-year follow-up. Clinical and radiographic data were collected at preoperative, 2-year, and final follow-up. Independent t-tests were used to compare clinical and radiographic measurements.

Results: A total of 113 patients met inclusion criteria. Mean age at index surgery was 12.3 ± 1.2 years (range 9.0–16.7); mean follow-up was 76.8 ± 14.2 months. The majority of patients were skeletally immature (Risser 0.4 ± 0.9, Sanders 3.0 ± 0, 40.7% open triradiates). At final follow-up, 112 patients (99.1%) had achieved skeletal maturity (Risser 5 and/or Sanders 7). Average number of levels tethered was 7.8 ± 0.7 (range 6–9). At pre-op, 2-year, and final follow-up, average thoracic Cobb angles were 50.6° ± 10.8°, 18.0° ± 11.4° and 26.3° ± 12.9°, respectively; this represented a significant improvement ($p < 0.0001$). At final follow-up, 79 patients (69.9%) had successful coronal correction (defined as thoracic tethered Cobb < 35°). At pre-op, 2-year, and final follow-up, thoracic kyphosis was 19.6° ± 11.2°, 21.0° ± 11.4° and 23.1° ± 13.6°, respectively. ($p < 0.0001$; Table 1). Overall reoperation rates were 26.5%, and 10 patients (8.9%) required conversion to fusion. Further breakdown of the etiologies for revision showed that 9 patients (8.0%) had overcorrection, 6 (5.3%) had adding-on, and 1 (0.9%) had significant curve progression after tether breakage (Table 2).

Conclusions: Our results demonstrate that 70% of patients who underwent thoracic VBT had a Cobb angle < 35° at > 6 years follow-up. However, the reoperation rate was 27%, with 9% of patients requiring PSF. These results highlight the importance of shared decision making when discussing fusion versus tether for patients with thoracic scoliosis.

TABLE 1. Comparison of radiographic outcomes

Visit	Sanders (Median)	Risser (Median)	Open Tri-Radiates	Proximal Cobb	Main Thoracic Cobb	Lumbar Cobb	Kyphosis	Lordosis
Preop	3B	0	46 (40.71%)	25.94 ± 9.56	50.62 ± 10.75	28.18 ± 8.61	19.58 ± 11.15	55.35 ± 10.78
2-Year	5	3	6 (6.00%)	16.57 ± 10.15	18.02 ± 11.39	14.48 ± 9.75	21.01 ± 11.38	55.34 ± 10.40
Latest F/U	8	5	0 (0.00%)	18.96 ± 11.94	26.31 ± 12.93	19.41 ± 9.43	23.13 ± 13.62	57.24 ± 13.31

Comparison of Outcomes	P Value	P Value	P Value	P Value	P Value
Preop vs 2-Year	<0.0001	<0.0001	<0.0001	0.0766	0.7094
Preop vs Latest F/U	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Variable	No. (%)
Thoracic Tethered Cobb <35°	79 (69.91%)
Thoracic Tethered Cobb <30°	65 (57.52%)

Preop: Preoperative

TABLE 2. Reoperation outcomes

Reason	No. (%)
Total Overall	***30***
Conversion to fusion	10/113 (8.85%)
Tether Breakage	1/113 (0.88%)
Over-correction	9/113 (7.96%)
Adding-On	6/113 (5.31%)
Screw Migration	2/113 (1.77%)
Cosmetic	2/113 (1.77%)

Paper #51

Complications and unplanned return to the operating room (UPROR) at 5-years postoperative vertebral body tethering for idiopathic scoliosis

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Introduction: Our group previously published 2-year post-operative VBT complication rates for a cohort of 120 patients that is now 5 years post-operative. There is a paucity of data in the literature on longer term complications for patients undergoing VBT.

Aims/objectives: Now that our previously published cohort is 5 years post-operative, our goal is to re-examine its post-operative complication rate at 5-year follow-up. Our hypothesis is that there will be a higher rate of postoperative complications at 5-year follow up as compared to 2-years follow up for this group of patients.

Methods: All 120 patients treated with VBT from the initial 2-year cohort had 5-year follow up and were included in this study. Prospectively collected clinical and radiographic data was analyzed retrospectively.

Results: Pre-operatively, the mean patient age was 12.6 year (8.2–15.7 year), Risser 0–3, with mean main thoracic scoliosis 51° (40°–

70°). All patients underwent thoracoscopic VBT with immediate post-operative scoliosis improvement to 27° (6°–53°, $p < 0.01$), which was maintained at 1-year post-operative 23° (− 11°–50°; $p < 0.01$), at 2-year post-operative 26° (− 5°–52°; $p = 0.64$), and at 5-year post-operative 33° (− 31°–59°; $p < 0.01$ compared to post-op). Pre-operative global kyphosis was 29° (2°–64°) which did not change at 1-year post-operative 29° (6°–65°) or at 2-year post-operative 29° (6°–67°); however, kyphosis did increase at 5-years post-operative 41° (− 17°–93°; $p < 0.01$). By 5 years post-operative, using the modified Clavien Dindo Sink classification, there were 39 grade 0 occurrences, of which 38 were failure of the tether cable that was noted radiographically on follow up visits without curve progression or UPROR. There were 9 grade I, 2 grade II, 20 grade 3b, and 2 grade 4a complications. There were no grade 4b or grade 5 complications. There was a 9% minor complication rate (mCDS 1 and 2) and an 18% major complication rate (mCDS 3 and 4) for an overall complication rate of 27.5%. There was an 18% UPROR rate.

Conclusions: For the same cohort of patients, our previously published 2-year rate of complications (16%) increased to 27.5% at 5-year follow up and the 2-year rate of UPROR (7%) increased to 18% at 5-year follow-up.

Paper #52

Does open triradiate cartilage lead to poor outcomes among cerebral palsy patients undergoing spinal fusion?

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Introduction: The optimal timing for SF in patients with CP and scoliosis remains a subject of debate. This study investigates whether SF in skeletally immature patients during or before peak height velocity provides equivalent radiographic and clinical results versus those nearing skeletal maturity.

Aims/objectives: We hypothesize that spinal fusion (SF) yields equivalent radiographic and clinical results in skeletally immature patients with cerebral palsy (CP) compared to patients nearing skeletal maturity.

Methods: We identified patients with GMFCS 4 and 5 CP undergoing SF to the pelvis with minimum 2-year follow-up. Patients were classified based on skeletal maturity at the time of surgery: open or closed triradiate cartilage (TRC). We compared perioperative clinical and radiographic outcomes and Caregiver Priorities and Child Health Index of Life with Disabilities (CPCHILD) scores.

Results: Of 127 patients with 2-year follow-up 86(68%) had TRC-closed at the time of SF and 41(32%) had TRC-open. TRC-open group mean age was 11.9 y (range: 9.6–21) vs. 15.4 y (range: 8.47–17.2) ($p < 0.001$). TRC-open patients were more likely to be G-tube fed, 82.9% vs. 47.7% ($p < 0.001$). Demographics were similar between the groups. Preoperative mean major curve was 77° and mean pelvic obliquity was 26° and did not differ between the two groups. Two years postoperatively there was improvement in major curve magnitude by 65% and pelvic obliquity by 17°, which did not differ between the two groups or among the 46% of patients who had 5-year follow-up. There was no significant difference in blood loss, length of hospital stay, infection, or medical complications. TRC-open group had more instrumentation-related complications vs. TRC-closed group (24% vs. 9% $p < 0.03$), often prominent implants, but this did not result in a higher rate of reoperation. TRC-open group transiently improved in CPCHILD communication subdomain scores, but there were no other score differences at any time points between the groups (Table 1).

Conclusions: CP patients aged 8.5–21 undergoing SF achieved similar perioperative outcomes and radiographic results at 2 and 5 years, regardless of open or closed TRC. Skeletally immature patients may have increased risk of implant related complications. These results suggest that definitive SF is a viable treatment option in CP patients approaching adolescence with open TRC.

Table 1

		Triradiates Open (N=41)	P-value
Baseline Demographics			
Age	15.4 (SD: 2.3), [9.6, 21.0]	11.9 (SD: 1.9), [8.4, 17.2]	<0.001*
Sex (Female)	41 (47.7%)	19 (46.3%)	> 0.999
Weight (kg)	35.2 (SD: 8.6), [22.0, 68.0]	33.7 (SD: 21.2), [18.5, 143]	0.654
GMFCS Level V	73 (84.9%)	34 (82.9%)	0.798
Gastrotomy Tube Feeding	41 (47.7%)	34 (82.9%)	<0.001*
Verbal Communicator	14 (16.3%)	3 (7.3%)	0.078
Tracheostomy	1 (1.6%)	2 (5.7%)	0.285
Seizure Disorder	59 (68.6%)	32 (78.0%)	0.300
Posterior Approach Only	81 (94.2%)	39 (95.1%)	0.340
Major Curve Magnitude			
Preop	77 (SD: 23.0), [27, 138]	76 (SD: 21.1), [48, 131]	0.873
First Erect	25 (SD:16.1), [2, 81]	22 (SD: 12.1), [5, 57]	0.181
% Correction	-66.8 (SD:17.2)	-70.0 (SD:15.7)	0.298
2-year Follow-up	28 (SD: 15.9), [4, 80]	24 (SD: 13.2), [8, 63]	0.204
% Correction	-63.5 (SD:16.2)	-67.1 (SD:16.5)	0.257
5-year Follow-up	29 (SD: 15.3), [6, 64]	27 (SD: 12.9), [10, 67]	0.419
% Correction	-60.3 (SD:16.9)	-64.0 (SD:18.4)	0.418
Pelvic Obliquity (PO)			
Preop	26.5 (SD:15.2), [0, 61]	25.5 (SD:13.6), [3, 56]	0.712
First Erect	8.0 (SD:7.69), [0, 40]	6.6 (SD:7.1), [0, 37]	0.337
Δ from preop	-19.4 (SD:12.3)	-19.2 (SD:12.2)	0.945
2-year Follow-up	9.3 (SD: 8.5), [0, 40]	6.6 (SD:5.6), [0, 20]	0.046
Δ from preop	-17.3 (SD:13.1)	-18.4 (SD:12.6)	0.671
5-year Follow-up	9.5 (SD:8.6), [0, 33]	8.4 (SD:6.0), [0, 23]	0.537
Δ from preop	-16.5 (SD:13.2)	-18.5 (SD:12.9)	0.555
CPCHILD			
Preop	63.4 (SD:25.2)	62.8 (SD:23.0)	0.901
2-year Follow-up	72.8 (SD:22.5)	67.0 (SD:25.9)	0.251
5-year Follow-up	68.2 (SD:23.2)	62.9 (SD:28.5)	0.471
Complications			
Death	4 (4.7%)	5 (12.2%)	0.147
GI	9 (10.5%)	8 (19.5%)	0.174
Instrumentation	8 (9.3%)	10 (24.4%)	0.0303*
Medical	22 (25.6%)	5 (12.2%)	0.106
Neurologic	6 (7.0%)	4 (9.8%)	0.726
Pain	6 (7.0%)	2 (4.9%)	> 0.999
Pulmonary	24 (27.9%)	15 (36.6%)	0.411
Surgical Site/Infection	17 (19.8%)	7 (17.1%)	0.812
Reoperation	12 (14.0%)	3 (7.3%)	0.383