

## **Paper #1:** Pedicle Screws Have Fewer Complications than Hooks in Children with Growing Rods

*David L. Skaggs, MD; Karen S. Myung, MD, PhD; Charles E. Johnston, MD; Behrooz A. Akbarnia, MD; Growing Spine Study Group*

**Introduction:** Our purpose was to evaluate the complications of pedicle screws versus hooks in children with early onset scoliosis (EOS) treated with growing rods. As growing rods have a high rate of implant complications compared to spinal fusion, this challenging group of patients is an ideal setting to evaluate the safety of pedicle screws.

**Background:** We examined the rate of complications directly related to pedicle screws versus hooks in children with EOS treated with growing rods.

**Methods:** A retrospective multicenter study of 247 patients with growing rods treated at 18 institutions was performed. Inclusion criteria were children  $\leq 10$  years old who had growing rod surgery between 1998 and 2008 with a complete surgical history. Charts and radiographs were evaluated for complications directly related to a pedicle screw or hook from the index surgery. 896 pedicle screws and 867 hooks were evaluated.

**Results:** The average age at index surgery was 5.2 years. The average length of follow-up was 40 months. Of the 896 pedicle screws, there were 22 (2.4%) complications directly related to the screw: acute loss of fixation (4), migration (14), breakage (1), skin breakdown (2), and unspecified loss of fixation (1). Of the 867 hooks, there were 60 (6.9%) complications: acute loss of fixation (35), migration (22), and unspecified loss of fixation (3). There were no intraoperative pedicle screw-related issues, but two hooks plowed intra-operatively resulting in bone damage. The average time to loss of fixation was 19 months for both implants. There were no complications involving neurologic or vascular injury directly related to a hook or screw.

**Conclusions:** Pedicle screws in growing rods have significantly less complications than hooks ( $p < 0.001$ ). It is encouraging that there were no neurological or vascular injuries associated with either implant in 247 children with over 3 years of mean follow-up. The rate of complications directly associated with the use of pedicle screws in this series is comparable to that reported in the adult spine fusion literature (0.4% to 3%). As pedicle screws were found to have about one third the complications of hooks in this challenging group of patients perhaps FDA approval of pedicle screws in children should be considered.

## **Paper #2:** Use of the S-Hook as Pelvic Foundation as Part of Rib Based Distraction Construct

*Norman Ramirez; John M. Flynn, MD; John T. Smith, MD; Michael Vitale, MD; Ron El-Hawary, MD*

Multiple options exist for distal anchoring of rib based distraction growing rod construct to control early onset spinal deformity including s-hooks or iliac screws. Rib to pelvis fixation with s- hooks was initially recommended for spina bifida patients or in severe thoracolumbar curves allowing rapid and easy attachment to the pelvis. Since the initial report, the indications of the pelvic fixation with s-hooks have been extended and modified. To date, no study has analyzed the clinical and radiographic effects of S-Hooks on patients with VEPTR instrumentation .The purpose of this research is to retrospectively review the effect of S-Hooks used for pelvic fixation in patients with VEPTR instrumentation

### **Material and Methods:**

A multicenter - retrospective IRB approved study was conducted in all patients treated with VEPTR rib to pelvis with s- hooks for pelvic fixation with a minimum of two years follow-up. Preoperative and Post-operative clinical variables, radiological measurements and complications incidence and managements were evaluated.

### **Results:**

Forty- four patients fulfilled the inclusion criteria for the study. Twenty - six patients were female and 18 were male. The average age at surgery was 71 months and the average follow-up was 45 months. The most common surgical indication was progressive neuromuscular scoliosis. The average preoperative Cobb angle was 64 degrees and the most recent was 53 degrees. The most common construct was Dual Rods with side to side domino connectors, resting over the iliac crest without suture to the iliac crest from T3/T4 to pelvis. Forty - three percent of the patients had complications. The most common complication was s-hook medial/lateral sliding after the initial procedures, followed by distal migration, pain, bursitis and infection. No correlation was found between the complications rate and the clinical, radiographic and surgical technique variable evaluated.

**Conclusion:** Control of spinal deformity without fusion presents numerous challenges. As with other foundations used as part of growing rod systems S- hook can migrate off the iliac crest requiring repositioning of implants during the course of lengthening. This highlights the need to explore different fixation technique with a stronger attachment to the iliac crest.

**Paper #3:** Treatment Of Kyphoscoliosis And Thoracic Insufficiency Syndrome (TIS) Associated With Myelodysplasia Using VEPTR in an Eiffel Tower Construct

*Ajeya Joshi, MD; Robert Campbell, MD; Vishwas Patil, MD; Davin Cordell, MD; William Koeck, MD*

**Introduction:** Vertical Expandable Prosthetic Titanium Rib (VEPTR) has been a successful treatment for thoracic insufficiency syndrome (TIS) associated with various spinal deformities. We analyzed the effects of VEPTR treatment on spinal, thoracic and pelvic deformities in patients with myelomeningocele.

**Background:** The surgical treatment of spinal deformities in patients with myelomeningocele is challenging due to high complication rates. Myelomeningocele is associated with both primary and secondary TIS.

**Methods:** We retrospectively reviewed 10 consecutive cases (6 male, 4 female) of myelomeningocele treated with VEPTR with a minimum two year follow-up. Charts were reviewed for motor level, operative course, pulmonary performance, and complications. Sitting AP and lateral radiographs were measured for Cobb angle, kyphosis, pelvic obliquity, and space available for lungs (SAL).

**Results:** The mean age at initial implant was 4.7 years, and the mean follow-up period was 6.2 years. The motor level ranged from T2 to T12. Seven patients were treated with unilateral hybrid rib-to-pelvis VEPTR (half 'Eiffel Tower' construct); the other three with bilateral hybrid rib-to-pelvis VEPTR in a full Eiffel Tower construct. A mean of 2.5 device replacement and 7.8 device expansion surgeries were performed per patient. The mean Cobb angle was 70.8° pre-operatively and 46.9° at last follow-up ( $p=0.004$ ). Lumbar kyphosis (present in 6 patients) was 42.5° pre-operatively and 22.3° at last follow-up ( $p=0.07$ ) (one patient developed a lordosis of 23°). The mean pelvic obliquity was 24.7° pre-operatively and 8.6° at last follow-up ( $p=0.009$ ). The SAL on the concave side improved from a mean of 0.659 pre-operatively to 0.880 at last follow-up ( $p=0.002$ ). Mean respiratory rate decreased from 29 to 24. Assisted ventilation rate (AVR) was constant at 0 in 8 patients, decreased from 4 to 3 in one, and increased from 0 to 1 in the last ( $p>0.05$ ). Prior to treatment, six patients had a marionette sign; none did at last follow-up. Four wound infections (3 superficial, one deep) occurred and were successfully treated.

**Conclusions:** VEPTR treatment is a useful technique for addressing primary and secondary TIS in myelomeningocele patients. Spinal, thoracic and pelvic deformity correction is observed. The 'Eiffel Tower' construct using bilateral rib-to-pelvis hybrid devices with wide base and narrow apex might be most effective for correcting lumbar kyphosis and pelvic obliquity. Infections were surgically treatable with implant salvage and acceptable morbidity.

**Pre- and Post-Treatment Spinal, Thoracic, & Pelvic Measurements**

Age (initial surgery)		4.7yrs (1.2-14.1)					
Time (follow-up)		6.2yrs (2.3-12.1)					
		Pre-operative		Last Follow-up		p value	
		N	Mean	Range	Mean		Range
Cobb angle		10	70.8	23-118	46.9	6-90	0.004
Lumbar kyphosis		6	42.5	22-70	22.3	-23-40	0.07
Pelvic obliquity		10	24.7	0-48	8.6	0-32	0.009
SAL		10	0.659	0.43-0.93	0.880	0.63-1.42	0.002
RR		10	29	20-44	24	20-28	n/a
CBG	pO2	10	81.5	63-126	68.4	57-84	0.15
	pCO2	10	34.4		38.8		0.014
Marionette sign		10	6 positive		0 positive		n/a
AVR		10	changes: 0 to 0 (8); 0 to 1 (1); 1 to 0 (1)				>0.05*

\*using Mann-Whitney U test

## **Paper #4: Definitive Fusion In 12 Early Onset Scoliosis With Dual Growing Rods**

*Teppei Suzuki; Koki Uno*

### **Study Design.**

Retrospective analysis of patients who have progressive early onset scoliosis treated with dual growing rods at one institution.

### **Objective.**

Dual growing rod treatment is used for patients with early onset scoliosis, but there is little data of reporting definitive fusion. We evaluated 12 early onset scoliosis patients who had definitive fusion. Summary of Background Data and Methods.

Between 2004 and 2010, 12 patients treated with dual growing rods underwent definitive fusion. There were 7 females and 5 males. Diagnoses included 3 idiopathic scoliosis, 3 congenital, 6 syndromic. Average age at initial surgery was  $9.6 \pm 3.2$  years. Average follow-up during lengthening was  $4.2 \pm 2.5$  years, and the number of lengthenings was  $5.8 \pm 3.9$ . Average age at definitive fusion was  $13.5 \pm 2.9$  years. Analysis included number and frequency of lengthenings, and complications. Radiographic evaluation included changes in Cobb angle, T1-S1 length during lengthening.

### **Results.**

In 12 patients, average Cobb angle was  $98 \pm 20$  degrees at preinitial,  $55 \pm 8$  degrees postinitial,  $65 \pm 21$  degrees before definitive fusion and  $52 \pm 17$  degree after definitive fusion. Average curve correction rate of initial surgery was  $42 \pm 14$  %, and that of definitive fusion was  $18 \pm 14$  %. Complication rate during lengthenings which divided by the number of surgery was  $25 \pm 20$  %. There were 3 patients who had nothing complications during lengthening. We had to remove all implants before the definitive fusion in 3 patients of 4 patients who had infections during lengthening. On the other hand, there was not any complication after definitive fusion, except one patient who died 2 years after fusion due to unknown reason. T1-S1 length was increased  $39 \pm 31$  mm at postinitial and  $39 \pm 17$  mm after final lengthening.

**Conclusion.** The treatment of early onset scoliosis remains one of the more challenging aspects of spine surgery. Dual growing rods technique maintains the initial correction and allows for reasonable spinal growth, and may improve respiratory function. There is still the potential disadvantage of more surgeries and increased risk of complications.

**Paper #5:** Can Infection Associated With Rib Based Distraction Be Managed Without Implant Removal?  
A Multicenter Study

*John T. Smith; John Emans, MD; Amer Sandami, MD; Randal Betz, MD*

**Introduction:** VEPTR has gained wide acceptance for the management of thoracic insufficiency syndrome and progressive complex spinal deformity in children. Many children in this population have significant co-morbidities and low BMI making them high risk for infection and other complications. Typically, the protocol for treating all but early infection of spinal instrumentation recommends that the implants be removed to resolve the infection. Smith et. al. (SRS 2009) reported a single institution experience with VEPTR infections and managed all without implant removal. The purpose of this study is to determine if this experience can be duplicated throughout multiple institutions.

**Methods:** This is an IRB approved retrospective multicenter chart review of patients who had VEPTR procedures and developed infections at three large tertiary care spine centers.

**Results:** Thirty-one infections developed in 28 patients following VEPTR procedures. (Initial implant: 12; Expansion: 11; Exchange: 1; Revision: 7).. The average age at the time of infection was 6 years. The mean BMI (16.6) and ANC (8.8) were predictably low for this population. The diagnosis was varied. Infection was associated with initial implantation (38.7%), Expansion (35.4%), Exchange (3.2%), and Revision (23 %). 22 of thirty one infections followed a wound dehiscence. Infections were classified as superficial (11) and deep (20). All patients were treated with initial irrigation and debridement and IV antibiotics. The average duration of IV therapy was 88.4 days and followed by oral suppressive therapy for 27.6 days (7-180). Six patients required more than one debridement to control the infection (range 1-6 I&D's). Four patients were initially managed with oral antibiotics alone. Two of the 4 patients failed oral antibiotics. Two patients required VEPTR removal to resolve the infection.

**Conclusion:** These data from three separate centers suggest that infections involving VEPTR instrumentation without fusion procedures can be effectively managed without implant removal in most instances. Nutrition and improved soft tissue management may be significant in reducing the incidence of infection in this patient population. This information may be useful when working with infectious disease consultants who continue to recommend implant removal when infection involves spinal instrumentation.

**Paper #6:** Introduction of VEPTR Surgery into Japan: A Report on the First 33 Patients.

*Noriaki Kawakami, MD; Taichi Tsuji, MD; Ayato Nohara, MD*

**Introduction:**

Although VEPTR has been introduced in more than 25 countries for the last 10 years, it is still a challenging operation. The purpose of this study was to report our learning curves and the experience of the first 33 patients.

**Methods:**

VEPTR operations were started in 2004 with the direct support of Dr. Campbell. Because it took 5 years to get approval as a humanitarian device with restricted conditions from the Government, the first 8 patients were very prudently and cautiously selected and operated in many aspects. Clinical charts and images of 33 patients (male; 10, female; 23) who underwent VEPTR operations for the last six years were retrospectively analyzed. The age at op. was 6 years (3-8). Diagnoses were congenital in 27 (including myelomeningocele in 9 and Spondylothoracic dysplasia in 3), Sotos syndrome in 2, Cerebral palsy, Ehlers-Danlos syndrome, myopathy, and trisomy. Untethering procedures were performed in 8 of 9 myelomeningocele before VEPTR operations. Three patients were treated with home-oxygen therapy at the time of operation.

**Results:**

34 primary implantation procedures (unilateral in 26, one-staged bilateral in 6, two-staged bilateral in 1), 6 reimplantation, and 49 expansion were performed. Total 65 VEPTR implants were implanted and the types of VEPTR were rib-to-rib only in 3 patients, rib-to lumbar in 24 and rib-to-iliac in 6. Expansion thoracoplasty was performed in 28 patients. Five patients underwent simple distraction procedures using VEPTR without thoracoscopy because of co-morbidities. An average of primary implantation operation time was 167mins (70-260) and that of EBL was 60.4ml (3-194). Scoliosis in 26 were corrected from 75.3° to 52.4° with an average of correction rate 28.9%. Intraoperative complications occurred in 5 patients (abnormal MEP in 3, rib fracture in 2, atelectasis in 1). Postoperative complications were seen in 21 patients, showing decrease of occurrence such as 7 of the first 8 patients, 7 of 11 for the next six months, and 7 of 14 for the last six months. 16 of these 21 patients showed respiratory-related complications. Implant-related complications which necessitated unplanned operations were cradle dislodgement in one, hook prominence in 2. Final fusion was performed in two patients at the age of 10 years following decision of parents because of psychological stress on the patients for repeated operations.

**Conclusions:**

During the learning curve, it was possible to decrease the occurrence of perioperative complications as well as the operative time and intraoperative blood loss.

## **Paper #7: Serial Casting As A Delay Tactic In The Treatment Of Moderate To Severe Early Onset Scoliosis**

*Nicholas Fletcher, MD; Charles E. Johnston, MD*

**Introduction:** Serial casting is an established method of curing mild early onset scoliosis (EOS) in children < 19 mo. of age. The use of spine and chest-wall expansion techniques as a delay tactic prior to definitive spinal fusion has increased due to a perceived lack of efficacy of casting in older children with larger curves.

**Background:** To define the role of serial casting as a delay tactic for the management of older children with moderate/severe EOS.

**Methods:** A clinical and radiographic review of a single center's experience with serial casting for EOS was performed. Patients with idiopathic, syndromic or congenital scoliosis > 2.5 years of age and with curves > 50° were included.

**Results:** 58 patients were treated with serial casting for progressive scoliosis between 1998-2010 with 36 (13 idiopathic, 23 syndromic/congenital) meeting all inclusion criteria. 9 of 36 patients (25%) had MRI abnormalities prior to casting. Mean age at 1<sup>st</sup> casting was 4.8±2 yrs, with 3.7 yrs (0.75-9.1 yrs) followup. Patients underwent 4±2 cast changes over 1.05±0.9 yrs. Body mass index decreased 0.22±0.27 kg/m<sup>2</sup> during treatment. Main thoracic Cobb prior to casting was 65.7°±12.9° which was corrected to 37.9°±15.2° (44.2±12.1%) in a cast. Cobb angle after cast removal was 59.4°±18.3° and increased to 75.4°±22.2° at followup. T1-T12 height increased 0.3±1.4cm and pelvic width increased by 0.8±0.7 cm from initial cast to followup. All patients were braced after cast removal. There were 5 minor and one major complication related to casting. 15 patients (39%) underwent surgery after a delay of 3.1±2 years from 1<sup>st</sup> cast. 8 patients had growing rods, 7 had definitive anterior/posterior fusion. Preop Cobb angle was 89.9°±9.3° which corrected to 44.6°±15.7° postop (50.3±17.3% correction). The surgical group had larger pre-cast thoracic Cobb angles (71.8° vs 61.7°, p=0.018), required more time in cast (1.44 vs 0.75 years, p=0.037), and had greater loss of correction out of cast (23.5° vs 9.7°, p=0.017) than the nonsurgical group. Neither age at presentation nor time from initial visit to the 1<sup>st</sup> cast correlated with eventual surgery.

**Conclusions:** Serial casting is a viable nonoperative alternative to surgical treatment for moderate to severe EOS. While a "cure" cannot be expected in most patients, a mean 3 years delay of surgery was achieved in 39% of this patient cohort, and the remainder are still being managed nonoperatively.

## **Paper #8:** Early Onset Scoliosis: The Value of Serial Risser Casts

*George Thompson, MD; Connie Poe-Kochert, RN, CNP; Jochen P. Son-Hing, MD*

**Introduction:** Serial Risser casts are an effective, intermediate method of management of early onset scoliosis (EOS) in very young children. They can control the deformity and allow for spinal growth and lung development until a child reaches a more appropriate age for return to bracing or growing rod surgery. Compliance is assured as the cast cannot be removed.

**Background:** The treatment of progressive EOS is challenging. In many cases, bracing will not be effective and growing rod surgery may not be appropriate. Serial Risser cast placement under general anesthesia may be a safe and effective intermediate method of treatment. We conducted a retrospective review of our results of serial Risser casting in the treatment of progressive EOS.

**Methods:** Nineteen consecutive patients with EOS were treated with serial Risser casting. We analyzed their age, gender, diagnosis, previous treatment, the degree of curvature at the initiation of Risser casting, the number of casts, their response to casting and the transition to subsequent treatment.

**Results:** There were 9 patients with idiopathic scoliosis, 5 patients with syndromic scoliosis, and 5 patients with neuromuscular scoliosis. The mean age at first cast application was  $3.7 \pm 2.3$  years (range, 1 to 8 years). The mean curvature at the initiation of casting was  $74 \pm 18$  degrees (range, 40 to 118 degrees), and at the time of placement of the last cast was  $49 \pm 27$  degrees (range, 12 to 95 degrees). The current mean follow-up is  $15.8 \pm 8.9$  months (range, 4 to 35 months). The mean number of casts/patient were 6 (range, 1 to 11 casts). At the time of this analysis, 4 patients are still undergoing casting, 5 patients have returned to bracing, 6 patients have undergone growing rod surgery, 2 patients have undergone final fusion, and 2 patients have been lost to follow-up. There were 3 complications - skin irritation in 2 patients and cast intolerance in one patient.

**Conclusion:** Our results support serial Risser casting as a safe and effective intermediate method of treatment for EOS. It can stabilize relatively large curves until the child reaches a more suitable age to change their method of treatment. Patients who failed bracing at an earlier age may now find it more effective.

**Paper #9: Non-invasive Positive Pressure Ventilation (NPPV) for Sleep-related Breathing Difficulties in Children with Early Onset Scoliosis (EOS)**

*Gregory J. Redding, MD; Christopher Makris, MD; Kit Song, MD*

Children with EOS often have abnormal breathing and increased arousal rates during sleep. We reviewed the sleep study results of 20 children with EOS who underwent polysomnography to determine the criteria used to begin treatment with NPPV devices long-term at home and the impact of NPPV on breathing during sleep in this group. Eleven patients received no night time therapy based on their sleep study results (column 1); 9 of 20 (45%) of the children received nighttime NPPV therapy (7 on Bilevel Positive Airway Pressure (BIPAP) and 2 on Continuous Positive Airway Pressure (CPAP.)). Of those treated with BIPAP, 6 of 9 were first studied after initial spine or chest wall surgery with a growing construct had occurred. Mean (+/- Standard deviation) Apnea-Hypopnea Index (AHI), Arousal Index (AI), lowest SaO<sub>2</sub> during sleep (SaO<sub>2</sub>), and highest end-tidal CO<sub>2</sub> value (PCO<sub>2</sub>) for those not treated with NPPV (column 1) and for those prior to receiving BIPAP/CPAP in column 2 below. The average amount of BIPAP used was 14/6 cm H<sub>2</sub>O. The changes in sleep indices after BIPAP or CPAP was instituted are listed in column 3. Children with EOS requiring BIPAP/CPAP at night had worse gas exchange, hypopneic events, and arousals than those not treated. BIPAP effectively improved all indices in all treated patients except CO<sub>2</sub> retention during sleep. NPPV is an increasingly common form of therapy both before and after spine surgery which provides better sleep quality and breathing during sleep. NPPV represents an important adjunct to surgical intervention and provides benefit after initial surgical therapy for children with EOS.

No Nighttime Treatment

Nighttime Treatment Group

Pre-BIPAP

1 year of BIPAP Use

AHI (normal <2 events/hour)

3.2+/-

1.7

14.0+/-

7.3

3.4+/-3.0

AI (normal <10 events/hour)

9.8+/-

6.6

18.0+/-

16

7.0+/-4.8

Nadir SaO<sub>2</sub> in sleep (%)

90+/-

4

84+/-

6.2

92+/-6.4

Maximum CO<sub>2</sub> in sleep (mmHg)

46+/-

6.6

51+/-

12.4

50+/-5.7

**Paper #10:** Growing Rods for Scoliosis in Spinal Muscular Atrophy: Structural Effects and Burden of Care

Mark J. McElroy, MS; Paul D. Sponseller, MD; Adam Shaner, MD; George H. Thompson, MD; Rishi V. Kadakia; Behrooz A. Akbarnia, MD; Growing Spine Study Group

**Introduction:** Growing rods (GR) are a treatment option for early onset scoliosis (EOS) in a wide variety of diagnoses. Spinal muscular atrophy (SMA) patients treated with GRs were studied for structural effectiveness, perioperative burden of care, and rate of complications. Control of EOS in SMA may help reduce restrictive pulmonary disease.

**Background:** Most studies study efficacy of GRs in whole patient population. This study examines results in SMA. Rib “collapse” seen in SMA patients was studied.

**Methods:** 14 SMA patients with EOS treated with GRs were followed for  $54 \pm 35$  mos. Radiographic and surgical data were assessed. Thoracic shape was quantified using ratio of T6 and T10 rib angles and thoracic width at T6 and T12.

**Results:** GR treatment began at  $7.8 \pm 2.0$  years. Study included 8 dual and 6 single rod patients. Instrumentation spanned  $15.8 \pm 1.7$  levels, extending to pelvis in 9 patients. Primary Cobb angle was  $91 \pm 17^\circ$  at pre index,  $45 \pm 10^\circ$  at post index, and  $56 \pm 17^\circ$  at latest. Pelvic obliquity was  $32 \pm 13^\circ$  at pre index,  $9 \pm 6^\circ$  at post index, and  $12 \pm 10^\circ$  at latest. T1-S1 length grew  $3.7 \pm 3.0$  cm from pre index to latest, including  $1.2 \pm 0.6$  cm per year of GR treatment. Space available for lung ratio increased from  $0.85 \pm 0.15$  at pre index to  $0.94 \pm 0.21$  at latest. Lung height at pre index to latest increased from  $11.4 \pm 2.6$  cm to  $15.4 \pm 4.7$  cm on concave side and from  $13.5 \pm 2.6$  cm to  $16.7 \pm 4.4$  cm on convex side. Ratio of mean T6 rib-vertebra angle (RVA) to mean T10 RVA was  $1.29 \pm 0.26$  at pre index,  $1.23 \pm 0.30$  at post index, and  $1.01 \pm 0.25$  at latest. Ratio of T6:T12 thoracic width was  $0.84 \pm 0.08$  at pre index,  $0.74 \pm 0.08$  at post index, and  $0.79 \pm 0.05$  at latest. Rods were lengthened  $3.5 \pm 2.5$  times. 5 patients underwent final fusion at  $13.1 \pm 2.5$  years. Lengths of hospital stays were compared with 80 idiopathic GR patients. Stay durations for SMA and idiopathic patients were  $7.7 \pm 6.7$  days and  $5.3 \pm 3.2$  days for initial insertion ( $P = 0.10$ ),  $1.8 \pm 3.7$  days and  $0.8 \pm 1.0$  days for lengthenings ( $P = 0.03$ ), and  $10.6 \pm 7.7$  and  $5.6 \pm 3.1$  for final fusion ( $P = 0.11$ ). 42% of SMA lengthenings were outpatient procedures versus 47% of idiopathic lengthenings. SMA patients had 0.6 significant complications per patient, including 2 who required tracheostomy and 1 deep wound infection following final fusion versus 1.1 for idiopathic patients.

**Conclusions:** GRs improve trunk and lung height while controlling curve and pelvic obliquity in SMA patients who develop severe scoliosis at a young age. Perioperative burden of care is greater than idiopathic scoliosis. Rate of significant complications is similar. Rib collapse continues over time. GRs merit comparison with other treatment options.

**Paper #11:** Does Rib-Based Distraction Control Curve Progression and Prevent Parasol Deformity of the Chest in Scoliosis Associated with Congenital Myopathy?

*John T. Smith, MD; Charles D'Amato, MD; Robert M. Campbell, Jr., MD; Michael Vitale, MD*

**Background:** The diagnosis of congenital myopathy in children encompasses a broad spectrum of diseases that are associated with progressive weakness and a high incidence of Early Onset Scoliosis. There is increasing interest in treating these children with surgical intervention using growing instrumentation. Historically treatment included early surgical fusion which resulted in progressive pulmonary compromise and a 'parasol' deformity of the chest. We hypothesize that rib-based distraction instrumentation is effective in managing scoliosis associated with congenital myopathy and prevents the development of a parasol deformity during growth.

**Methods:** We conducted a multi-center retrospective study of 14 children with growing instrumentation; either growing rods or Vertical Expandable Prosthetic Titanium Rib (VEPTR), who have been diagnosed with Early Onset Scoliosis and congenital myopathy. All patients received a minimum follow-up of two years from implantation of growing instrumentation. To determine parasol deformity changes overtime, rib vertebral angle difference (RVAD) measurements were documented from pre-operative x-rays as well as the most recent follow-up x-rays. The RVAD was measured at T4, T8, and T10. In addition to RVAD measurements, respiratory status, adverse events, and Cobb angles were recorded.

**Results:** The average pre-operative Coronal Cobb angle was 62° and improved to 43° at most recent follow-up. The Sagittal Cobb angle improved from 52° to 42°. Twelve of the 14 patients demonstrated improved RVAD angles. Of the 12 patients with RVAD improvement the main level of improvement was seen at T10 (n=10). Mean change (pre-operative to recent follow-up) in RVAD angles at T10 were -1.56° on the left and -2.33° on the right side. The negative change demonstrated an overall improvement in parasol deformity. Five patients demonstrated improvement at T8 and T4. There were 7 adverse events after initial instrumentation implantation. The adverse events included hardware failure, wound dehiscence, pain, and infection.

**Conclusion:** Scoliosis associated with congenital myopathy can be effectively managed in the growing child with growth-sparing instrumentation, avoiding early fusion. These data suggest that rib-based distraction techniques prevent or reduce the parasol deformity of the chest during growth, and control curve progression. The incidence of adverse events was acceptable for this population of children. Longer term follow-up will determine if this has a beneficial effect on pulmonary function at skeletal maturity when compared to early fusion.

**Paper #12:** To Operate or Not to Operate? Determining the Optimal Timing of Surgical Intervention for Patients with Early Onset Neuromuscular Scoliosis

*Daniel J. Miller, BS; Jacqueline Corona, MD; Jennepher Downs, PhD, MSc; Behrooz A. Akbarnia, MD; Laurel C. Blakemore, MD; Randal R. Betz, MD; Robert M. Campbell Jr., MD; Charles E. Johnston, MD; Richard E. McCarthy, MD; David P. Roye Jr., MD; David L. Skaggs, MD; John T. Smith, MD; Brian D. Snyder, MD, PhD; Paul D. Sponseller, MD, MBA; Peter F. Sturm, MD; George H. Thompson, MD; Muharrem Yazici, MD; Michael G. Vitale, MD, MPH; John M. Flynn, MD*

**Background:** Uncertainty exists among experienced clinicians as to specific indications and timing of surgical intervention in early onset neuromuscular scoliosis.

**Aims:** This study assessed the consensus of experienced orthopaedic surgeons in choosing a conservative or surgical treatment option for case scenarios with spastic or flaccid neuromuscular scoliosis.

**Methods:** Eleven orthopaedic surgeons recorded their treatment choice for 114 case scenarios with increased tone and 102 case scenarios with low tone, that varied by age (3, 6 and 9 years), Cobb angle (30, 60 and 90 degrees), rate of curve progression (0, 15 and 30 degrees over previous 6 months) and presence of respiratory or chest wall involvement, osteopenia, low BMI, kyphosis or spinal rigidity. Group consensus (for conservative or surgical treatment) or no consensus (equipoise) was identified with binomial distribution calculations. Associations between the presence of a co-morbidity and group consensus were assessed with chi squared tests and logistic regression.

**Results:** For cases with increased muscle tone, there was consensus for conservative treatment in 30/114 (26.3%) and surgical treatment in 41/114 (41.4%) of cases with equipoise in 28/114 (24.6%) of cases. For cases with low muscle tone, there was consensus for conservative treatment in 41/102 (40.2%) and surgical treatment in 36/102 (35.3%) of cases with equipoise in 25/102 (24.5%) of cases. Cobb angle was the strongest predictor of management for both groups of cases ( $p < 0.001$ ) with conservative management more likely for case scenarios with a 30° curve, surgery for 90° curves, and equipoise for most 60° curves. In the multivariate model of high tone case scenarios, a lack of respiratory involvement ( $p < 0.001$ ) predicted use of conservative management and flexibility ( $p = 0.001$ ) was significantly associated with equipoise. For cases with low tone, a lack of respiratory involvement ( $p = 0.002$ ), 0° progression ( $p = 0.001$ ) and 15° progression ( $p = 0.003$ ) were significantly associated with equipoise. There was no association between the presence of the other co-morbidities and consensus for conservative or surgical management or equipoise.

**Conclusions:** Surgeons were strongly influenced by Cobb angle and respiratory involvement when deciding on conservative or surgical treatment options. Equipoise was present for case scenarios with slowly progressing 60 degree curves or with a flexible spine. Clinical trials to improve the evidence base for these scenarios could be justified and feasible.

**Paper #13:** Preoperative Thoracic Kyphosis Can Predict Complications in Growing Rod Surgery for Early Onset Scoliosis

*Jeff Pawelek, BS; Samuel Schroerlucke, MD; Behrooz A. Akbarnia, MD; Pooria Salari, MD; Gregory M. Mundis, MD; Growing Spine Study Group*

**Introduction:**

The growing rod technique has become a reproducible and effective technique in the treatment of early onset scoliosis. Although the coronal deformity has been studied extensively, the sagittal profile has not been investigated as a major factor in complications in this complex group of patients.

**Background:**

This study was conducted to identify the complication rate of growing rod surgery in patients with normal versus abnormal thoracic kyphosis. We hypothesized that hyper-kyphotic ( $>40^\circ$ ) thoracic spines lead to more implant complications in distraction-based growing rod surgery.

**Materials and Methods:**

A retrospective review of a multi-center early onset scoliosis database was performed. Out of 387 growing rod patients, 90 patients had complete data with two-year follow-up after initial surgery. The patients were categorized into three groups based on the magnitude of pre-operative thoracic kyphosis (T5-T12): 40 degrees (K+ group). Diagnosis, demographics, radiographic parameters and complications were analyzed.

**Results:**

90 patients were included with 26 in the K- group, 35 in the N group, and 29 in the K+ group. Age (5+8 years), length of follow-up, diagnosis (18 neuromuscular, 19 congenital, 25 syndromic, 28 idiopathic) and complications were tabulated for each group (Table 1). Patients in the K+ group (55 total complications) were 3.1 times more likely to experience a complication than patients in the N group (20 total complications), which was statistically significant ( $p < 0.05$ ). Implant-related problems were the most common type of complication, specifically rod breakage. The number of patients who experienced multiple complications was higher in the K- and K+ groups than in the N group. Although patient diagnosis was not a confounding variable with respect to complications, syndromic patients had 2.9 times the risk of having an overall complication when compared to the entire patient series, which was statistically significant ( $p < 0.05$ ).

**Conclusions:**

Growing rod surgery in patients with kyphosis  $>40^\circ$  have significantly more complications than patients with normal thoracic kyphosis. The most common implant complication was rod breakage. Patients with hyper-kyphotic thoracic spines, particularly syndromic patients, must be monitored closely and parents should be counseled regarding the likelihood of complications after growing rod surgery.

**Table 1**

	<b>&lt; 10° kyphosis</b>	<b>10-40° kyphosis</b>	<b>&gt;40° kyphosis</b>
Age (yrs)	6+10 (range 2 to 10)	5+1 (range 2 to 8)	5+9 (range 1 to 11)
Length of follow up (mos)	82 (25-124)	61 (26-106)	69 (23-135)
<b>Diagnosis</b>			
Syndromic	11	6	8
Congenital	3	10	6
Neuromuscular	7	3	8
Idiopathic	5	16	7
<b>Total Complications</b>	<b>27</b>	<b>20</b>	<b>55</b>
<b>Implant Failures</b>	<b>11</b>	<b>16</b>	<b>34</b>
Rod breakages	7	13	25
Screw or hook loosening/pullout	4	3	9
<b>General Medical Complications</b>	<b>15</b>	<b>4</b>	<b>22</b>
Superficial wound infection	0	0	1
Deep wound infection	3	1	8
Pulmonary	2	2	2
Excessive intra-op bleeding	1	0	1
Unexpected pain	0	1	0
Wound Closure	0	0	1
Death	1	0	0
Neurologic	0	0	3
Other	8	0	6

**Paper #14:** Increased Rates of Anchor Failure can be Predicted by an Early Onset Scoliosis Severity Score

*Sumeet Garg, MD; Charles E. Johnston, MD*

**Introduction:** Surgical treatment with fusion-less spine and rib-based implants for patients with early onset scoliosis (EOS) is almost universally beset by implant complications. A comprehensive assessment score of overall severity may identify those at risk for complications.

**Methods:** An EOS severity score including nutritional status, medical health, radiographic deformity/flexibility and functional status was developed, with a maximum score of 14. Records and radiographs of all patients treated surgically at a single institution were reviewed and scored. Complications were divided into implant (spine or rib-based), neurologic, surgical site infection, and skin erosion. 37 EOS patients have been treated surgically since 2003 with an average age of 5 years (range 1.3-9.3). Diagnoses included syndromic (20), muscular dystrophy (6), congenital (7), idiopathic (3), and thoracogenic (1). Two patients with recent implant placement have not yet had lengthening and are excluded from complications analysis.

**Results:** Severity scores ranged from 2-11 (mean 6). 23 had spine-based growing implants (mean severity 5.4) while 14 had rib-based (mean severity 7.9,  $p=.002$ ). Implant complications were common, averaging 0.54 episodes of rib anchor failure and 0.26 episodes of spine anchor failure per surgical procedure. Overall anchor failures/procedure was 0.64. Patients with  $> 0.4$  failures/procedure had higher severity score (7.8 vs 5.6,  $p<.02$ ) than those with  $<0.4$ . Eight patients had infections requiring operative debridement, three patients had implant erosion through skin, four had intraoperative neuromonitoring changes and two had late motor deficits (1 brachial plexus injury after VEPTR, 1 spinal cord injury from pedicle screw plow into the spinal canal). These complications all occurred without correlation to severity score.

**Conclusions:** Many EOS patients have severe co-morbidities that directly affects success of surgical intervention. A higher (more severe) score correlates with an increased frequency of anchor complications. Patients with more severe disease are more likely to be treated with rib-based devices. The incidence of neurologic injury, infection, and skin erosion was too small to be related to the severity score. The EOS severity score identifies patients prone to frequent implant complications.

**Paper #15: Hemivertebra Resection Via Posterior Approach In Young Children With Congenital Deformities**

*Cağatay Öztürk; Azmi Hamzaoglu*

**Introduction:** In this retrospective study, we evaluated the radiological and clinical outcomes of patients having posterior resection of hemivertebra and pedicle screw to correct and stabilize the deformity.

**Materials and Methods:** Thirty-eight patients between age 2 and 10 having posterior hemivertebrectomy and transpedicular fixation for congenital deformities were reviewed. Radiological and clinical charts were evaluated in terms of correction in coronal and sagittal plane deformity, balance and complications.

**Results:** Average age of patients (17 male and 21 female) was 4.5 years (2-10). Twenty patients had scoliosis with 32.1 degrees (range: 18 - 48), 3 had kyphosis with 53.3 degrees (range: 43 - 68) and 15 had kyphoscoliosis [mean scoliosis 36.9 degrees (range: 20 - 55)], [kyphosis 34.9 degrees (11 - 85)]. Eight (21%) patients had spinal dysraphism (5 with type I and 3 with type II). Twenty hemivertebrae were located in thoracic spine (T3-T11), 11 in thoracolumbar spine (T12-L1) and 13 in lumbar spine (L2-L5). In 6 patients, two-level hemivertebra were present. The mean level of instrumentation was 3.8, operation time was 5.8 hours and blood loss was 383 ml. Five patients with spinal dysraphism underwent same stage neurosurgical intervention. Mean follow-up was 46 (range; 24 to 108) months. The coronal plane deformity improved to 5 degrees (84%) and was 5.9 degrees at final follow-up. The sagittal plane deformity improved to 3 degrees (94%) and it was 5 degrees at final follow-up. Coronal plane imbalance in 18 patients and sagittal plane imbalance in 14 patients could be restored. Two patients (ages 3 and 4) with long sweeping deformity and fused shortly after resection developed C shaped curves in the early follow-up with coronal imbalance and the increase in deformity could be controlled by brace treatment. None of the patients exhibited neurological problems associated with surgery. One patient had experienced dural tear and 3 patients with superficial infection had responded well to debridement surgery and intravenous antibiotic treatment. Pseudoarthrosis or implant failure was not detected.

**Conclusion:** Hemivertebra resection via posterior approach and short segment transpedicular instrumentation is safe and effective in young children. Long sweeping structural curves initiated by a hemivertebrae at its apex may deteriorate after resection and short fusion despite a perfect correction.

**Paper #16:** Vertebral Growth Modulation in the Porcine Scoliosis Model assessed by Computed Tomography: 3-D Effect of a Corrective Tether

*Virginie Lafage, PhD; Frank Schwab, MD; Jean-Pierre Farcy, MD*

**Introduction:**

Using an established Porcine Scoliosis Model, this study aims to investigate the impact of a non-fusion corrective anterior convex spinal tether on an induced deformity, examining detailed vertebral morphology and axial rotation. This study demonstrated that using an anterior tether, favorable growth modulation was possible without affecting the overall vertebral volume and led to a 3 plane correction of the scoliosis: correction of coronal Cobb, reduction of axial rotation, restoration of sagittal kyphosis.

**Background:**

Non-fusion techniques for surgical correction of scoliosis in an immature spine have recently received substantial interest. In theory, vertebral growth modulation through a convexly placed tethering implant in the setting of scoliosis would lead to progressive vertebral correction in the coronal plane (Hueter-Volkman Principle).

**Methods:**

This IACUC approved Study included 10 immature Yorkshire Pigs divided into 2 groups; tether release group (TR, n=5) and corrective tether group (CR, n=5). All animals underwent induction of scoliosis. Once  $>50^\circ$  was noted on radiographic follow up a second surgical intervention was pursued: TR had release of the inducing tether; AC had tether release and placement of a corrective tether over the 5 apical vertebrae. Both groups were observed for 20 weeks then euthanized. Fine cut CT scans were used to create a volumetric 3D reconstruction of the apex (3vertebrae, 2discs). Student T-test was used to evaluate differences between groups.

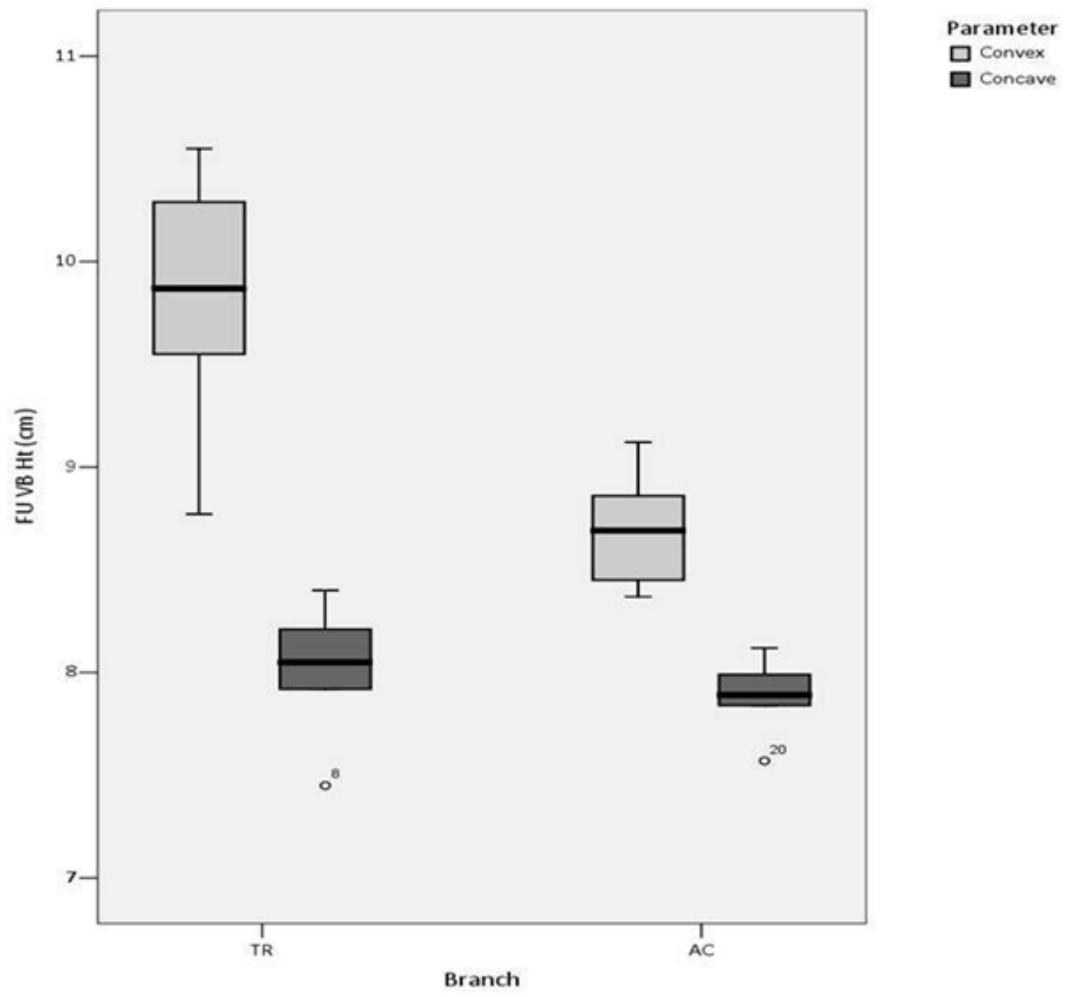
**Results:**

Regarding absolute vertebral heights, no significant differences were observed between TR and AC in posterior and concave dimensions. However, significant reduction was found in anterior and convex AC vertebral heights; TR 8.9cm vs. AC 7.9cm ( $p<0.01$ ) and TR 9.8cm vs. AC 8.7cm ( $p<0.01$ ) respectively. No significant difference was found in apical vertebral body volumes between TR 18.3cm<sup>3</sup> and AC 17.7cm<sup>3</sup> while the AC group presented bigger vertebral enplates: TR=5cm<sup>2</sup>, AC=5.5cm<sup>2</sup> ( $p=0.01$ ) A significant reduction in coronal wedging angle of  $18^\circ$  was found between TR=36.1° and AC=18.1° ( $p<0.01$ ). A significant increase in sagittal kyphosis was observed over the apex: TR= +6° AC= -9.6° ( $p=0.04$ ). A 25% correction in apical rotation was demonstrated in the transverse plane.

**Conclusions:**

This study demonstrated that using an anterior tether, favorable growth modulation was possible without affecting the overall vertebral volume and lead to a 3 plane correction of the scoliosis: correction of coronal Cobb, reduction of axial rotation, restoration of sagittal kyphosis.

Vertebral Body Height Differences: TR vs AC



**Paper #17:** Coronal Plane Displacement Gradient Precedes Vertebral Growth Modification Using Titanium Spinal Hemiepiphyseal Staples

*Donita I. Bylski-Austrow; David L. Glos; Laura A. Boehm; Viral V. Jain, MD*

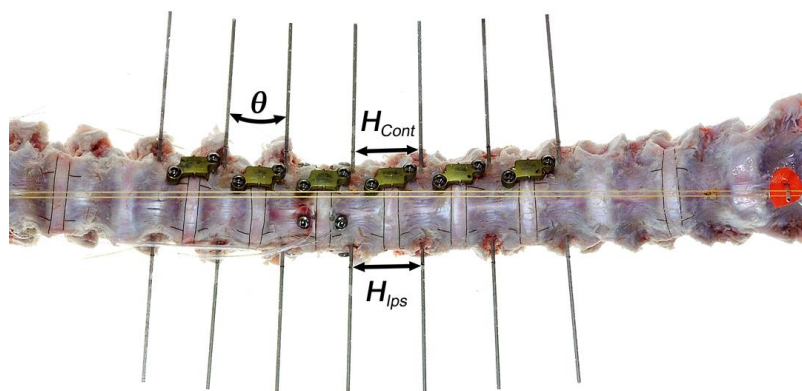
**Introduction:** Efficacy of growth modification methods is presumed to depend on how treatment alters initial biomechanical conditions. This study determined whether implanting hemiepiphyseal staples caused initial coronal plane displacement and stress gradients.

**Background:** Previous studies have shown that spine implants can cause asymmetric spine growth. In a porcine model system, growth plate structural gradients have been reported after 8 weeks. The extent and timing of these changes are likely determined by the initial post-operative biomechanical conditions.

**Methods:** Thoracic spines from normal, skeletally immature pigs were harvested and then tested before and after implant insertion. Images of intact spines ( $n=4$ ) under no-load conditions were taken to isolate effects of the implants on spine realignment. Treatment consisted of six titanium staple-screw constructs. In separate tests ( $n=5$ ) on single motion segments, compressive stresses in the annulus were determined bilaterally during implantation and during cyclic compression. Comparisons between pre- and post-treatment were by paired t-tests.

**Results:** Spine curvature increased  $11.3$  deg ( $\pm 2.1$ ) ( $p < 0.005$ ) after stapling. Displacements ranged from compressive to tensile across the coronal plane. Motion segment heights ( $H$ ), decreased  $0.79$  mm ( $\pm 0.08$ ) on the ipsilateral side, and increased  $0.81$  mm ( $\pm 0.19$ ) on the contralateral side (Fig. 1). Vertebral rotations ( $\theta$ ) increased  $2.0$  deg ( $\pm 0.46$ ) per stapled segment. Compressive stiffness increased by means of a decrease in the neutral zone (NZ) (24%,  $p < 0.02$ ) after staple insertion, while tangent stiffness decreased by 6% ( $p < 0.02$ ) after stapling. Compressive stresses increased during the insertion of the staple, but then relaxed to zero at equilibrium, so that the baseline static stress was not changed. Mean peak cyclic stresses decreased by 20% after stapling.

**Conclusion:** Staple-like implants previously shown to modify growth over time in an *in vivo* porcine model caused a displacement gradient across the intervertebral joint *in vitro*. Implant insertion alone caused the neutral axis to lie between the mid-coronal plane and the ipsilateral side. This simple test may aid comparisons among different methods. Implant design and insertion factors will affect this gradient. The intervertebral joint was not immobilized. Initial compressive stresses induced in the disc annulus during stapling did not persist, but relaxed back to zero within a short time.



**Paper #18: The Effect Of A New Bi-planar Hinge Construct On A Normal Animal Spine: Scoliosis Creation With Retention Of Mobility**

*John G. Burke, MCh FRCS(orth); Timothy Drew, PhD CEng; J. Alastair Gibson, MD FRCS(orth)*

**Introduction**

In the immature child current interventions use growth rods to control but not reverse progressive idiopathic scoliosis. An optimal implant would not only produce a partial correction of deformity at the time of application, but subsequently counteract deforming forces. The aim of this work was to test a novel mobile device designed for this purpose, by seeing whether it would deform a normal spine as growth occurred.

**Methods**

Six 10 week old Scottish blackface sheep underwent a double right thoracotomy for insertion of a linked cobalt-chrome hinged device anteriorly between T4 and T12. During the next 10 months AP and lateral radiographs were taken at 8 week intervals to determine spinal alignment. Spinal motion was calculated from flexion/extension and lateral bending films and, four months post-implantation, rotational deformity was measured by spiral CT. Growth and development in the experimental animals was compared to that of five control sheep who did not undergo any intervention.

**Results**

Over 10 months a scoliosis of  $10\pm 6^\circ$  was created on the opposite side to the implant ( $p < 0.05$ , Student's paired t-test) with no significant change in alignment in the sagittal plane ( $1\pm 6^\circ$  versus  $1\pm 13^\circ$  lordosis, means $\pm$ sd, n.s.). The animals grew at similar rate to the controls with an approximate 50% gain in weight. Flexibility of the curve was retained with a range of movement of  $28\pm 8^\circ$  in the coronal and  $30\pm 15^\circ$  in the sagittal planes.

**Conclusions**

The implant did not cause any adverse effect on growth or neurological deterioration and remained intact without migration. It created a scoliotic deformity and the instrumented spinal segments retained good mobility. It would be expected that when placed on the convexity of a child's scoliosis it would hold and potentially reverse a developing deformity.

**Significance**

These results illustrate that it is possible to progressively deform a growing spine by use of a mobile implant. The methodology should be transferrable to children with idiopathic spinal curves potentially reducing the need for spinal bracing and fusion.

UK animal project licence PPL 60/3832

Funding received from MRC, UK

**Paper #19:** Effects Of T1-T12 Dorsal Arthrodesis On Thoracic Cage And Chest Organs. Anatomical, Histological And Radiological Study On Pre-pubertal New Zealand White Rabbits

*Federico Canavese; Alain Dimeglio, MD; Marco Stebel, BD*

**Introduction:** The purpose of this study is to evaluate clinical, anatomical, histological, and radiological changes induced in New Zealand White (NZW) rabbits subjected to dorsal arthrodesis.

**Background:** Previous studies have shown but not completely elucidated the influences brought by spinal surgery on chest development.

**Methods:** Fifty-four pre-pubertal NZW female rabbits, aged 6 weeks, were used. Rabbits were randomly divided in two groups: 32 operated and 22 sham controls. Surgery consisted in an extracanal dorsal arthrodesis from T1 to T12. Rabbits were sequentially sacrificed at age 2½, 5, 9 and 13 months and had thoracic CT scan done 1, 4, 8 and 12 months after surgery. Blood gas analysis (PO<sub>2</sub>, PCO<sub>2</sub>, TCO<sub>2</sub>, sO<sub>2</sub>, HCO<sub>3</sub><sup>-</sup> and pH) as well as estrogens, cortisol and FGF determinations were performed at 6 to 8 weeks intervals for the whole length of the experiment. The day of suppression, specimens from lungs, heart, diaphragm, intercostals muscles, spine, spinal cord, ovaries and surrenal glands were collected and prepared for histology. 8-10 µm paraffin sections from operated rabbits were compared to specimens from the controls.

**Results:** Histological analysis of ovaries revealed that both operated and controls rabbits were pre-pubertal at the time of surgery. Somatic development as well as heart, lungs and respiratory muscles growth of operated rabbits were reduced compared to controls. Blood gas exchanges were reduced in operated rabbits compared to controls. Chest growth and spine alignment were affected in operated rabbits. Endocrine system of operated rabbits showed an abnormal hormonal profile compared to controls. Histological changes were evident in multiple chest organs of operated rabbits.

**Conclusions:** The development of the spine, thoracic cage, lungs and heart is a complex process which requires synergy among the different anatomical components. Our preliminary observations indicate that alterations in spinal growth induced by dorsal arthrodesis can affect the development of the thoracic cage and can have repercussion on multiples organs, not only intrathoracic. Thoracic cage shape and function are compromised. Our data should be considered as expression of moderate to severe Thoracic Insufficiency Syndrome (TSI) caused by surgery alone. TSI is a more complex phenomenon than previously reported.

**Paper #20:** Scalar Measurements of Pediatric Spine and Ribs from the Hamann-Todd (H-T) Collection

*Richard M. Schwend, MD; Behrooz A. Akbarnia, MD; Laurel C. Blakemore, MD; John Schmidt, PhD; Kevin R. Strauss, ME*

**Summary:** Scalar measurements of pediatric spine and ribs from the Hamann-Todd (H-T) Collection were collected using direct measurements, digital photography and 3D scanning. Statistical analysis was performed and may provide insight into normal human growth. Some data demonstrated a linear growth of the spine and rib cage from ages 1-18 years.

**Introduction:** The Hamann-Todd (HT) Collection at the Cleveland Museum of Natural History (Cleveland, OH) includes 63 pediatric skeletal specimens in varying condition and completeness. The initial data collection included representative skeletons aged 1-18 years. The purpose was to better understand the growth patterns of the pediatric spine and ribs.

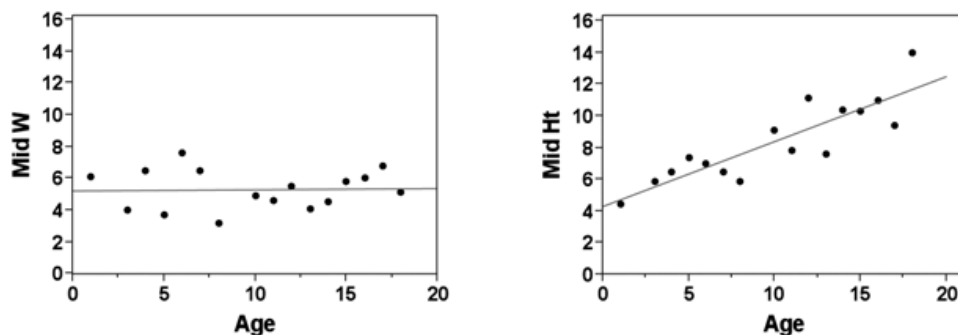
**Methods and Materials:** Data from vertebrae and corresponding ribs were collected. Data included 46 measurements from the vertebral body and ribs at T1, T4, T7, T10, and L3. Measurements were obtained using Vernier calipers, tape measures and photographs of each bone. Several specimens were digitized using a Next Engine 3D laser scanner. The initial analysis used caliper-derived data with some measurements obtained from photographs. The data were analyzed by age, specific bone and morphological features. More than 2000 cross correlations were studied. Linear regressions were performed on scalar measurements using SAS version 9.1.3 and JMP 8.0. While the general demographics for each child was known, specifics such as height and weight, or prior trauma were not.

**Results:** Data analysis showed linear relationships and in the ribs and growing spine. For example, fig. 1 shows the data and linear regression for the right rib at T7 for each age. Rib width showed no significant increase with age ( $r^2 = 0.001$ ), while rib height had a linear increase ( $r^2=0.754$ ). Other measurements, such as costal length, were highly correlated with age.

**Conclusions:** Direct measurements of pediatric cadaveric bones can be statistically analyzed to provide insight into normal human growth. The data demonstrate a linear growth of the spine and rib cage from ages 1-18 years.

**Significance:** There is relatively little known about the normal growth of human ribs and spine. This is the first known osteological data collection on the growing ribs and spine in non-scoliotic children. Understanding chest growth will help improve treatment of spine and chest wall deformity in growing children.

**Figure 1. Right T7 Rib.** Mid-Rib Width (Mid W mm) data is on the left and Mid-Rib Height (Mid Ht mm) is on the right. The width shows no increase with age ( $r^2 = 0.001$ ) while the height of the ribs increase with age ( $r^2=0.754$ ).



## Paper #21: Sagittal Spinopelvic Parameters of Children with Early Onset Scoliosis

*Ron El-Hawary, MD; Peter F. Sturm, MD; Patrick J. Cahill, MD; Amer F. Samdani, MD; Michael G. Vitale, MD; John Smith, MD*

**Introduction:** Spinopelvic parameters describe the orientation, shape, and morphology of the spine and pelvis. In children without spinal deformity, these parameters have been shown to change during the first ten years of life; however, spinopelvic parameters have yet to be defined in children with significant Early Onset Scoliosis (EOS).

**Background:** The purpose of this study is to examine the effects of EOS on sagittal spinopelvic alignment. We hypothesize that sagittal spinopelvic parameters for patients with EOS will differ from age-matched normals. These values will act as a baseline for future studies and may predict post-operative complications such as proximal junctional kyphosis and implant failure in children being treated with growing systems.

**Methods:** Standing, lateral radiographs of 82 untreated patients with EOS greater than 50 degrees were evaluated. Sagittal spine parameters (sagittal balance, thoracic kyphosis (TK), lumbar lordosis (LL)) and sagittal pelvic parameters (pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), modified pelvic radius angle (PR)) were measured. These results were compared to those reported by Mac-Thiong et al (Spine, 2004) for a group of asymptomatic (i.e. without spinal deformity) children of similar age.

**Results:** These patients had a mean age of 5.17 years and mean scoliosis of  $73.3 \pm 17.3$ . Mean sagittal spine parameters were: sagittal balance ( $+2.4 \pm 4.03$  cm), TK ( $38.2 \pm 20.8^\circ$ ), and LL ( $47.8 \pm 17.7^\circ$ ). These values were similar to those reported for asymptomatic subjects. Mean sagittal pelvic parameters were measured for PI ( $47.1 \pm 15.6^\circ$ ), PT ( $10.3 \pm 10.7^\circ$ ), SS ( $35.5 \pm 12.2^\circ$ ), and PR ( $57.1 \pm 21.2^\circ$ ). Although PI was similar to age-matched normals, PT was significantly higher and SS trended lower in the study population.

**Conclusion:** Sagittal plane spine parameters in children with EOS were similar to those found in children without spinal deformity. Likewise, pelvic parameters (PI, SS, PR) were similar; however, those children with EOS had signs of pelvic retroversion (increased pelvic tilt).

### Table 1: Comparison of sagittal spinopelvic parameters in a population of early onset scoliosis (EOS)

versus an asymptomatic patient population.

Parameters	EOS Patients < 10 years old N=82	Mac-Thiong et al., 2004 Patients < 10 years old (n=35)	P Value
Sagittal balance (cm)	$2.4 \pm 4.03$	-	
Thoracic Kyphosis ( $^\circ$ )	$38.2 \pm 20.8$	$38.3 \pm 9.8$	0.97
Lumbar Lordosis ( $^\circ$ )	$47.8 \pm 17.7$	$45.6 \pm 12.1$	0.51
Pelvic Incidence ( $^\circ$ )	$47.1 \pm 15.6$	$44.6 \pm 10.6$	0.48
Pelvic Tilt ( $^\circ$ )	$10.3 \pm 10.7$	$4.3 \pm 8.1$	0.004
Sacral Slope ( $^\circ$ )	$35.5 \pm 12.2$	$40.3 \pm 8.7$	0.06
Modified Pelvic Radius Angle ( $^\circ$ )	$57.1 \pm 21.2$	-	

## Paper #22: Scoliosis Induced by Radiofrequency Ablation in Growing Pigs

*Mariano A. Noel, MD; Eduardo Galaretto, MD; Martin J. Segura, MD; Luciana Sasbon, MD*

### **Introduction:**

The vertebral body growth may be strategically injured to create vertebral deformities in the immature spine. By thermo ablation with radiofrequency (RF) well-defined areas of necrosis may be induced in the bone and other tissues. This is potentially a good technique to perturb the vertebral growth  
Background: This study was to assess the effectiveness of RF in produce selective lesions of the anterior annular synchondrosis, the secondary morphological, histological effect on the growing spine and tolerance of the procedure.

**Methods:** Six 2-month-old pigs were divided into 2 groups A and B of 3 each. A right mini thoracotomy without rib resection was performed. Adjacent to each annular synchondrosis 2 holes were drilled of 1mm diameter, 6mm deep, 5mm between two holes, 2mm below and above the upper and lower annular physis of each vertebra, and more than 3mm before the neurocentral physis on the right anterolateral face of T6, T7, and T8 (12 holes per animal). Additionally, in group B a pulse of RF at 90°C for 90 seconds was delivered to each hole. MEP was monitored during each RF pulse.

The animals were killed 6 months later.

X-rays were performed before surgery and after killed.

The vertebral-costal block was removed for CT and histopathology.

**Results:** None of the animals in group A developed curves, asymmetries, or vertebral rotation. Group B (RF), all animals developed scoliosis of the right concavity (23,24,30) mean 25.7 and kyphosis (15,20,25) mean 20 and axial rotation with rib depression on the right side (6,10,7 mean 7.6). All vertebral bodies treated developed right anterolateral hypoplasia before the neurocentral physis. Pathologic evaluation showed a normal left side and loss of physis, denser bone, and loss of red marrow on the right side. MEP could be successfully monitored during each RF. Only one pulse showed prolonged asymmetric decrease, without neurological sequelae in any cases

**Conclusions:** RF is an effective procedure for selective lesions in the vertebral annular synchondrosis and potential in others.

The asymmetric injury induced scoliosis of the concavity and inward rotation to the side of the lesion, kyphosis, and asymmetric anterior hypoplasia. MEP can be monitored during the RF pulse



## **Paper #23:** Neurocentral Synchronosis Behavior in Cadaveric Vertebra in Skeletally Immature Spines

*Glen M. Ginsburg, MD; Richard M. Schwend, MD; John Schmidt, PhD*

**Introduction:** Scalar measurements of cadaveric vertebrae from the Hamann-Todd skeleton collection were examined for neurocentral synchronosis (NCS) during their developmental stages. Photographs of individual vertebra were measured for the amount of NCS closure at sequential chronological ages. These findings were compared to recent data on NCS maturation in modern children with normal spines.

**Methods:** Vertebrae from thirteen skeletons were obtained for study. The ages of the children at time of death ranged one to eighteen years. Five vertebrae (T1, T3, T7, T10 and L3) from each skeleton were chosen for study. The cephalad and caudal endplates of each vertebra were inspected for NCS closure. The percentages of NCS closures were measured. These measurements were recorded and staged on a six point scale by percent of NCS closure: No closure was stage 0; less than 25% closure was stage 1; 25-49% closure was stage 2; 50-74% closure was stage 3; 75-99% closure was stage 4; 100% closure of the NCS was stage 5.

**Results:** In the vertebrae with a chronological age three or less, there was no evidence of NCS closure (stage 0) at any vertebral level. In the vertebrae with chronological age 4-8, the lumbar vertebrae showed 50-100% NCS closure. The remainder of the vertebrae in this age range showed an average of 23% closure. In vertebrae with chronological age of 8-12, the upper thoracic vertebra (T1) showed 75-100% NCS closure. In the lumbar vertebra (L3), the NCS were closed (stage 5). In the middle thoracic vertebrae (T4, 7, 10), the NCS were all 50-74% closed (stage 3). In vertebrae with chronological age of greater than 12, the NCS in upper thoracic and lumbar vertebrae were completely closed (stage 5). The NCS in the middle thoracic vertebrae were 50-100% closed (stage 3-5). The NCS were symmetrical from left to right in all vertebra examined.

**Conclusions:** The results of this study are in general agreement with recent MRI investigations into the characteristics of the NCS. There was no closure of the NCS in any vertebra age less than 4 chronological years in any study. The lumbar vertebrae were starting to close the NCS in the 4-8 years age group, closely followed by the upper thoracic vertebrae. In the 8-12 years age group, the middle thoracic vertebrae (T4, 7, 10), the NCS were still only 50-74% absent. This supports the theory that vertebral growth rate can be disturbed in the middle thoracic spine at the age of maximal growth rate, which is where most adolescent idiopathic scoliosis is seen.

**Paper #24:** Effects of Posterior Distraction Forces on Anterior Column Intradiscal Pressure in Dual Growing Rod Technique

*Andrew Mahar, MS; Behrooz Akbarnia, MD; Michael Flippin, MD; Richard Oka, MS; Pat Kostial, RN, BSN; Ramin Bagheri, MD*

**Introduction:** Little information exists toward understanding how posterior distraction forces produced by pediatric growing rod constructs affect anterior column biomechanics and if these distraction forces are transmitted to anterior column in a distractive or compressive (kyphogenic) mode.

**Background:** The purpose of this study was to determine this mode and to understand how distraction forces produced by different foundation constructs affect intradiscal pressures when using dual growing rods for correction of early onset scoliosis (EOS).

**Methods:** Six skeletally immature porcine spines were harvested leaving soft tissues and rib heads intact. L3-L4 motion segments were instrumented with pedicle screws while T3-T4 motion segments were randomly instrumented with pedicle screws or laminar hooks. Proximal constructs (hook vs. screw) were switched after initial distraction testing. The dual rod distractor was instrumented with strain gages and calibrated using a custom force transducer. During distraction, intradiscal pressures immediately inferior to the superior foundation construct and the level equidistant between foundations were measured using needle pressure transducers.

**Results:** Maximum distraction force and maximum anterior disc pressure change were compared between hook and pedicle screw constructs using a one-way ANOVA ( $p < 0.05$ ). Upper level pedicle screws had significantly greater distraction forces ( $416 \pm 101\text{N}$ ) than upper level hooks ( $349 \pm 100\text{N}$ ). There were no significant differences in disc pressures between levels or between upper foundation constructs. Disc pressures adjacent to the upper foundation consistently demonstrated greater reduction (disc expansion) than the level equidistant within the construct. Pedicle screw constructs consistently demonstrated greater endplate separation compared to hook constructs.

**Conclusions:** Posterior distraction forces generate endplate separation at multiple levels within the spine. Upper foundation pedicle screws resulted in greater distraction forces compared to hooks, possibly due to hook motion during distraction. Anterior disc pressures indicate that posterior loads are distributed across multiple levels rather than delivered to the disc immediately adjacent to a foundation. The distribution of loads at multiple levels may assist with curve control and may also affect vertebral growth.

**Paper #25:** Growing Rod Graduates: Lessons From 58 Patients Who Have Completed Their Lengthenings

*John M. Flynn, MD; Lauren A. Tomlinson, BA; Jeff Pawelek, BS; George H. Thompson, MD; Richard McCarthy, MD; Behrooz A. Akbarnia, MD; Growing Spine Study Group*

**Introduction:** Over the past decade, spine-based growing rod systems (GRs) have become a valuable tool in managing severe cases of EOS. As more patients advance towards skeletal maturity, little is known about the endpoint of treatment: final fusion, observation without further lengthenings of GRs, or observation after GR removal without final fusion.

**Background:** This is the first large, multicenter report offering insight into the final step in GR management of EOS. Definitive “final” fusion is the most common endpoint of growing rod treatment in early onset scoliosis (EOS). Most final fusion patients had more levels fused than were spanned by their growing rods with moderate correction of deformity.

**Methods:** A multicenter EOS database was queried to capture all skeletally mature patients (defined as  $\geq 14$  y/o) treated with GRs, and younger patients who had a final fusion. Clinical, radiographic, and operative data were analyzed, with a focus on details and results of the final fusion.

**Results:** Of the 58 patients who reached skeletal maturity, 53 (91%) had a final fusion, 3 were observed with GRs in place, 1 had implant removal without final fusion, and 1 had a final fusion aborted for neurologic reasons. Most patients (60%) had more levels fused than the number of levels spanned by their GRs (18 patients: +1 level; 11 patients: +2 levels; 2 patients: +3 levels; 1 patients: +5 levels).

Correction at final fusion was minimal (<20%) in 25%, moderate (21%-50%) in 53%, and substantial (> 51%) in 15%; there was no correction information on 7% of fused patients. Minimal correction was most common in those with neuromuscular scoliosis; substantial correction was most common in those with idiopathic scoliosis. At final fusion, 5 patients had osteotomies, 7 had a thoracoplasty, and 4 had a concurrent anterior spinal fusion.

**Conclusions:** At the end of GR management of EOS, most patients had GR removal and final instrumented fusion. For most patients, the final fusion will include more levels than were spanned by the GRs, and will achieve <50% correction of the deformity remaining at the end of GR management.

## **Paper #26:** Hybrid Growth Rods Using Spinal Implants on Ribs

*David Skaggs, MD; Karen Myung, MD; Muharrem Yazici, MD; Mohammad Diab, MD; Hilali Noordeen, MD; Michael Vitale, MD; Charles Johnston, MD*

**Summary:** Hybrid growing rods where proximal anchors are spinal hooks on ribs may avoid fusion of the thoracic spine, while allowing distractive forces to minimize spinal deformity and encourage growth.

**Purpose:** Fusion of the upper thoracic spine in children severely limits pulmonary development. Traditional growing rods typically include a fusion of the upper thoracic spine. Hybrid growing rods in which the proximal anchors are spinal hooks placed on ribs may avoid fusion of the proximal thoracic spine, while allowing distractive forces to minimize spinal deformity and encourage growth. The purpose was to evaluate this novel use of spinal hooks on ribs as proximal anchors.

**Methods:** A retrospective multi-center study of 28 patients with growing spine instrumentation using spinal hooks on ribs treated at 6 institutions was performed. Mean follow-up was 37 months (24-74 mos). Mean age at index surgery was 44 months (5-111 mos). 24 patients have congenital scoliosis.

**Results:** 23 patients had single rod constructs on the concave side only, and 5 patients had dual rods. Mean primary Cobb angle at the time of index surgery was 69°. Mean Cobb angle correction achieved at the time of the index surgery was 19°, which was maintained through latest follow up. Mean increase in T1-S1 length on the AP radiograph at latest followup was 49 mm, with a mean increase of 13 mm per lengthening procedure. On average, space available for the lung (SAL) improved by on 25 mm on both the concave side and convex side at latest follow-up.

Complications occurred in 7 (24%) patients, all with congenital scoliosis. There is a non-significant trend that complications are associated with younger age ( $p=0.12$ ) and larger Cobb angle at index surgery ( $p=0.12$ ). Complications included 2 wound issues, 9 losses of fixation of rib anchors, and 1 rod breakage. There were no neurologic complications. There was no loss of fixation in any construct that had a proximal foundation of at least 4 up-going hooks on ribs, and there were no complications in dual-sided constructs.

**Conclusions:** We describe a novel technique that compares favorably to traditional growing rods in terms of complication rate, T1-S1 growth, and improvement in SAL and Cobb angle correction, with the potential long-term pulmonary benefit of avoiding fusion or instrumentation of the upper thoracic spine.

**Significance:** Use of spinal hooks on ribs may be included in our armamentarium for growing spine constructs.