Strategies for Treating Scoliosis in Children With Spinal Muscular Atrophy

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Abstract

Progressive pulmonary dysfunction is a major complication of spinal muscular atrophy (SMA). Growing constructs are a well-established alternative to spinal arthrodesis to maximize pulmonary growth.

We describe patients who demonstrated sustained pulmonary function and improved quality of life following hybrid growing construct implantation. The purpose of this article is to demonstrate a range of approaches for managing scoliosis in children with SMA by utilizing vertical expandable prosthetic titanium rib implantation or growing rods with lateral rib fixation to improve clinical and patient-reported outcomes.

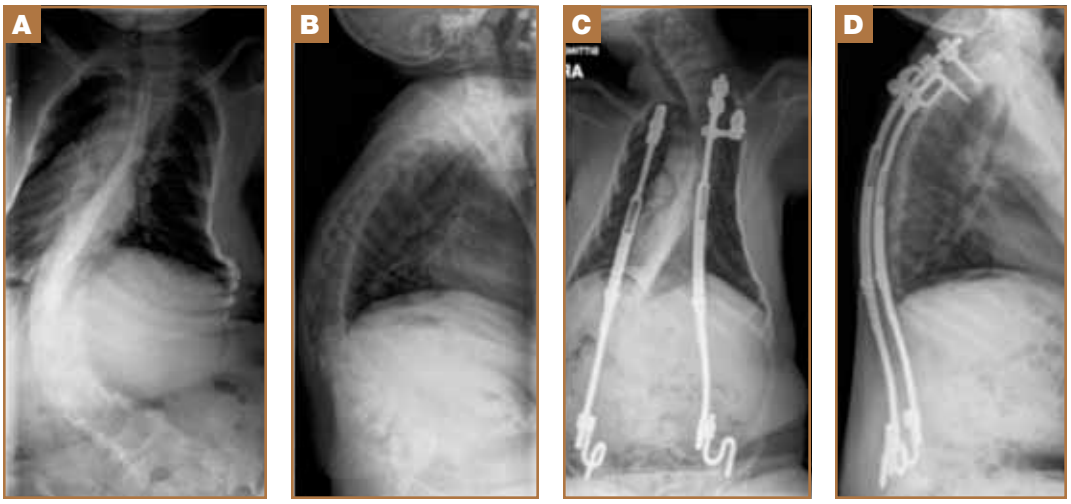
Pulmonary compromise and quality of life decline are leading concerns in the SMA population. This case series highlights important surgical strategies that can be utilized to treat scoliosis in patients with SMA.

The treatment of scoliosis among patients with neuromuscular disease is complex and fraught with conflicting considerations. This is especially true in patients with spinal muscular atrophy (SMA). Virtually 100% of patients with type I or type II SMA develop scoliosis.[1,2] For orthopedic surgeons, the timing of surgery is crucial to allow maximal growth without risking deterioration into deleterious pulmonary function.[3] Progressive reduction of pulmonary function is the natural course of SMA, which is compounded by the concomitant effects of spinal deformity on the thoracic cavity.[4] Indeed, it has been shown that SMA type II and III patients experienced a 7.7% decrease in functional vital capacity (FVC) per year, which can be mitigated by scoliosis surgery to a 3.8% decrease in FVC per year.[5]

The manifestations of SMA include a 3-dimensional deformity of the thorax, or the so-called *collapsing parasol deformity* (**Figure 1**).[6] This deformity can result in thoracic insufficiency syndrome, which was defined by Campbell and Smith[6] as the inability of the thorax to support normal respiration or lung growth. The resulting strain on the cardiopulmonary system induces complications such as cor pulmonale, congestive heart failure, asphyxiation, and eventually death if left untreated.[7]

Previously, patients with early onset scoliosis that needed surgical correction were treated with spinal arthrodesis. However, this has since been shown to worsen the progressive reduction of the thoracic volume.[8] The introduction of the vertical expandable prosthetic titanium rib (VEPTR) implant by Campbell and colleagues[9] in 1989 provided the ability to expand a constricted thorax and provide room

Figure 1. Anteroposterior (AP) radiograph (A) and lateral preoperative radiograph (B) of patient 1. AP radiograph (C) and lateral radiograph (D) of patient 1, 28 months postoperatively. Note the collapsing parasol deformity below the right rib outrigger and lateral propping support at the level of the outrigger (C).



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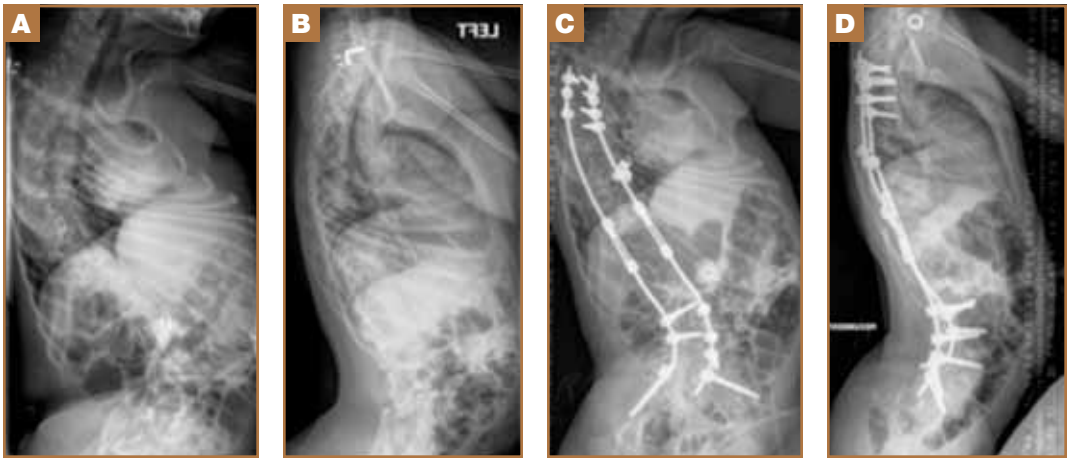

Figure 2. Preoperative AP radiograph (A) and lateral radiograph (B) of patient 2. AP radiograph (C) and lateral (D) of patient 2, 29 months postoperatively. Note the growing rod construct and outrigger on the right side (C).

for growth of the pulmonary tree without fusing the growing spine.

Quality of life (QOL) and caregiver burden are important treatment endpoints, especially in conditions that are currently incurable. Previous studies have evaluated the effect of SMA on patient QOL and caregiver burden using nonspecific instruments. Physical domain scores and caregiver burden are significantly lower compared to healthy children.[10] The Early Onset Scoliosis Questionnaire (EOSQ) was developed and initially validated as a disease specific instrument with domains to measure QOL (ie, general health, pain/discomfort, pulmonary function, transfer, physical function, daily living, fatigue/energy level, and emotion) of EOS patients and caregiver burden (parental impact and financial impact).[11] This instrument is scored by scaling responses for each domain to a score of 1-100, with a higher number indicating a better QOL and less caregiver burden.

Table I. **Pulmonary Function Test Results, Patient 1**

Administration	Time Since Implantation	FVC
Preoperative	-	0.70 L
Prior to 1st Lengthening	6 months	0.60 L
Prior to 2nd Lengthening	17 months	0.65 L
Prior to 3rd Lengthening	23 months	0.79 L
Prior to 4th Lengthening	28 months	0.69 L

Abbreviations: FVC, functional vital capacity; PFT, pulmonary function test.

Table II. **Change in EOSQ Scores, Patient 1**

Domain	Percent Change in Preoperative and Postoperative Scores
General Health	+12.5%
Pain	-12.5%
Pulmonary Function	+25.0%
Transfer	+25.0%
Physical Function	0.0%
Daily Living	0.0%
Fatigue/Energy Level	+12.5%
Emotion	+12.5%
Parental Burden	+10.0%
Financial Impact	+25.0%

Positive change represents improvement in quality of life and decrease in caregiver burden.
Abbreviation: EOSQ, Early Onset Scoliosis Questionnaire.

The purpose of this case series is to highlight the potential benefits of a rib-fixating hybrid growing construct that was used in 3 patients with SMA. These cases illustrate the QOL benefits for patients with SMA type I and II as measured by the EOSQ. In addition, an improvement in the natural history of pulmonary function for a patient with SMA type II is documented.

The patients provided written informed consent for print and electronic publication of this case report.

Case Series

Patient 1

An 8-year-old girl with a history of type II SMA sought evaluation and management of progressive scoliosis. Her birth history was unremarkable; she sat on her own at 6 months of age but was never able to stand on her own. The patient was using a motorized wheelchair for mobility and was able to stand with a thoraco-lumbo-sacral orthosis brace and a bilateral supramalleolar orthosis brace. She had noticeable drooping of her ribs without signs of skin breakdown. Radiographs at the time revealed a Cobb angle of 84° from T6-L4, correcting to 56° in her brace, and significant kyphosis.

Following preoperative clearance from pulmonology consult, the patient underwent implantation of a bilateral VEPTR system with pelvic fixation. Pedicle screws were placed at T2 and T3 on the right side to serve as the proximal anchor points. An extra rib hook was mated laterally with a transverse connector at the T4-T5 rib, which provided rib elevation on the right side where there was significant thoracic droop (**Figure 2**).

At a 6-week postoperative visit, the patient's Cobb angle decreased to 51° from a preoperative value of 84° and did not

significantly change subsequently. Pulmonary function tests (PFTs) performed preoperatively showed a FVC of 0.70 L and prior to the first, second, third, and fourth lengthening were 0.60 L, 0.65 L, 0.79 L, and 0.69 L, respectively. The PFT data is further summarized in **Table I**.

QOL was measured using the EOSQ preoperatively and before the first 2 lengthenings. Overall, this patient demonstrated an improvement in QOL and caregiver burden. The pain domain was the only one that worsened between implantation of the hybrid VEPTR construct and the second lengthening. The specific domain changes are further summarized in **Table II**.

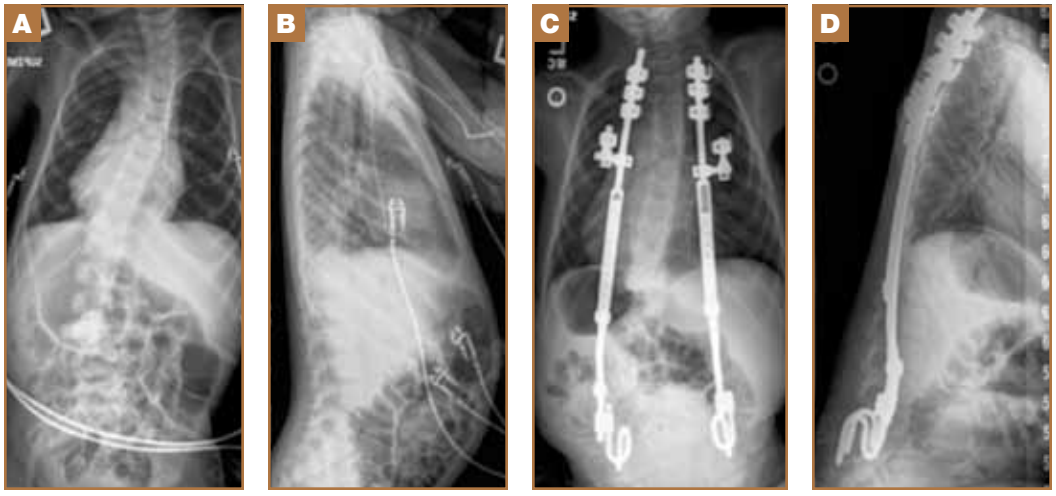

Figure 3. Preoperative AP radiograph (A) and lateral radiograph (B) of patient 3. Postoperative AP radiograph (C) and lateral radiograph (D), 4 months postoperatively. Note the bilateral VEPTR constructs with bilateral outrigger connectors (C).

Patient 2

A 7-year-old boy with type I SMA had been under evaluation for scoliosis surgery since the age of 5. Nutritional concerns including frequent dehydration precluded surgery. On evaluation, the patient was ventilator-dependent; recent radiographs showed progression of the curvature to 90° (**Figure 2**) and physical examination revealed a stiff, inflexible curve. Preoperative clearance was obtained from multiple specialties including cardiology, pulmonology, and intensive care consults.

The patient underwent lumbosacral fusion with growing rod insertion and lateral rib fixation. Pedicle screws were placed intermittently between L3-L5 and T2-T6 bilaterally. Growing rods were contoured and inserted posteriorly. Rib fixation was placed at the level of T9 using a transverse connector. The patient was discharged postoperatively and has since undergone 3 rod-lengthening procedures without complication.

QOL was measured using the EOSQ preoperatively and before the first lengthening. Overall, this patient maintained or improved QOL and caregiver burden across all domains following implantation of the hybrid-growing construct. The specific domain changes are further summarized in **Table III**.

Patient 3

A 3-year-old boy with type II SMA presented for evaluation after concerns from his physical therapist regarding progressing scoliosis. He required a feeding tube and cough assist but was not ventilator-dependent. Radiographs showed a curve of 55° with significant rotation, compared with a 24° curve on studies done 6 months prior (**Figure 3**). Physical examination revealed a moderately flexible curve with a left thoracolumbar prominence.

The patient underwent bilateral hybrid VEPTR placement. The VEPTR device was anchored distally using reversed S-hooks and proximally with pedicle screws at T3-T5. Transverse outrigger devices were fixated at T6 bilaterally, thereby expanding the construct in the coronal plane. Postoperative radiographs show good correction with a curve of 20°. His first lengthening had not occurred at the time of this publication.

Discussion

The VEPTR instrument was first developed in 1989 by Robert Campbell and Melvin Smith.[9] It has been approved by the FDA for use in skeletally immature patients with thoracic insufficiency syndrome (TIS) under a humanitarian device exemption.[12] Since its approval, it has been shown to be a safe and effective technique to address TIS in young children with scoliosis.[9] The primary goals of VEPTR implantation and the

Table III. **Change in EOSQ Scores, Patient 2**

Domain	Percent Change in Preoperative and Postoperative Scores
General Health	+62.5%
Pain	0.0%
Pulmonary Function	Not Available
Transfer	0.0%
Physical Function	0.0%
Daily Living	0.0%
Fatigue/Energy Level	+37.5%
Emotion	+37.5%
Parental Burden	+30.0%
Financial Impact	0.0%

Positive change represents improvement in quality of life and decrease in caregiver burden.
Abbreviation: EOSQ, Early Onset Scoliosis Questionnaire.

necessary subsequent lengthenings are improvement of the spinal curvature without arthrodesis. In addition, improvement in lung function to prevent progressive pulmonary deterioration and improvement in QOL are goals of treatment.

The existing data regarding the effects of VEPTR implantation on pulmonary function are conflicting. Mayer and Redding[13] looked retrospectively at data from the Chest Wall and Spine Deformity Study Group and concluded there was no improvement in lung volume and a decrease in FVC after VEPTR placement for early onset scoliosis.[14] Yet, early studies showed improvement in lung volumes for TIS patients with flail chest as their etiology.[15] In addition, VEPTR implantations in animal models have been shown to improve pulmonary hypoplasia.[16] The difficulty of obtaining pulmonary function tests in patients less than 5 years of age has hindered the ability to collect definitive, comprehensive data on this subject.[13] Some have suggested using surrogate markers of pulmonary function such as hemoglobin levels and weight gain to eliminate PFT reliance on patient effort.[17,18]

"The supply and demand dynamics between industry and our regulatory process are such that the ideal implants simply do not exist for this orphan population. The treating surgeon should consider the whole range of available options."

Patient 1 illustrates stabilization in pulmonary function over 2 years following instrumentation with a hybrid VEPTR construct. The preoperative evaluation was notable for moderate-to-severe restrictive ventilatory defect although the patient did not exhibit the clinical symptoms of thoracic insufficiency syndrome, such as dyspnea and recurrent infections. The trend of this patient's FVC shows an initial decrease after implantation followed by a steady increase and stabilization at subsequent lengthenings, compared with the initial preoperative FVC (**Table I**). This is in contrast to previous studies describing a steady decrement in pulmonary function.[5] We postulate that the mechanical forces of the outrigger device on the thoracic cavity are in part responsible for the stabilization of pulmonary function measured by FVC.

Both patient 1 and 2 showed an overall improvement in QOL and caregiver burden as measured by the EOSQ. This is particularly important in patient 2, who had SMA type I. This form of the disease is the most severe, with the onset of scoliosis earlier and more progressive compared to types II and III. The treatment course of this patient illustrates that a hybrid VEPTR implantation can have a significant positive impact on QOL in a disease that is otherwise known for early, drastic progression, and poor prognosis.

The treatment course of patient 3 represents an attempt to maximally utilize the hybrid growing construct strategy in a patient who entered a surgical range shortly after turning 3 years of age. With many years of growth left, the risk of progression to TIS, and pulmonary compromise is high. Therefore, bilateral rib fixation points were used laterally in an attempt to stave off its development as long as possible.

Children with SMA and significant growth remaining, benefit from growth-sparing approaches to spinal stabilization in many ways. The supply and demand dynamics between industry and our regulatory process are such that the ideal implants simply do not exist for this orphan population. Given this reality, the treating surgeon should consider the whole range of available options including traditional growing rods, VEPTR growth rods, pedicle screws, rib hooks, and rib cradles as well as multiple options for pelvic fixation.

Conclusion

This limited cases series highlights various options for spine stabilization in the young patient with SMA. Perhaps even more important in this population, one must consider the whole range of potential outcomes—pulmonary, thoracic, spinal, and QOL—when assessing the efficacy of surgical intervention.

Stabilization of spinal deformity with limited fusion has taken on an even greater importance given the exciting potential of gene therapy in this population. Animal studies have shown that intrathecal genetic therapies that modulate SMN gene splicing have the promise of halting disease progression.[19] The ISIS-SMNRx trial currently underway in phase 1 is testing dose responses to assess safety and tolerability. Subsequent iterations of this exciting trial may offer even greater hope to this patient population.

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