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SYMPOSIUM: EARLY ONSET SCOLIOSIS

Surgical Technique

Modern Luqué Trolley, a Self-growing Rod Technique

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Abstract
Background The challenge when managing early-onset scoliosis (EOS) is to prevent curve progression while maintaining spinal growth. Current surgical treatments (growing rods, VEPTR) require repetitive interventions to lengthen the implants.
Questions/purposes We asked whether a modern Luqué trolley construct could achieve and maintain scoliosis correction in EOS during spinal growth without the need for repetitive surgeries, thus decreasing the morbidity of the surgical treatment.
Methods We retrospectively reviewed five patients who underwent a modern Luqué trolley construct between 2003 and 2008. This construct consists of inserting apical gliding spinal anchors using muscle-sparing techniques to the proximal and distal fixed anchors found in the dual growing rod construct. We documented age at surgery, correction and maintenance of deformity, spinal growth, number of procedures, and complications.
Results The primary curve was corrected from 60° to 21° and was maintained at 21° at a minimum followup of 2 years (mean, 4 years; range, 2–5.5 years). An average of 10 vertebrae was spanned allowing the spine to grow a mean of 3 cm over 4 years, representing a mean of 77% of the expected growth. Two of the five cases outgrew the construct requiring lengthening of rods. One patient had gradual recurrence of deformity without substantial axial growth that required revision surgery after 4 years.
Conclusion Modifications of the Luqué trolley may be useful for managing EOS without the morbidity of repetitive surgery. However, questions such as the effect of wear debris and the risk of spontaneous fusions still remain.
Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Early-onset scoliosis (EOS) can lead to severe spinal deformities that hinder lung development, which is the primary morbidity associated with EOS [4, 10, 17]. Spinal fusions performed before the age of 8 can lead to a decrease in lung volume, a common limiting factor in the life expectancy of children with EOS [5]. To avoid these early fusions, new surgical techniques are emerging to address the core challenge when managing EOS: the ability to prevent curve progression while maintaining longitudinal growth of the spine [6]. Because the etiology of EOS varies, the treatment options also vary. With the exception of definitive spinal fusion, all current treatments (serial casting [7], dual growing rods (DGR) [2], and vertical expandable prosthetic titanium ribs (VEPTR) [9]) require repetitive interventions as the spine grows.

The initial management of EOS is to proceed with serial casting followed by bracing [1]. If such treatment is not feasible or not successful (malignant curve progression reaching a critical curve > 50°), then surgical management is warranted [1]. Conceptually rods are anchors to the spine, the rib, or the pelvis and are lengthened every 6 months.

To offset these recurrent interventions, we explored a new surgical technique that allows for spinal growth without repetitive surgical interventions. Luqué and Cardoso [12] described the first growing rod construct consisting of two L- or U-shaped rods fixed to the spine in a segmental fashion using sublaminar wires [11]. As the spine grew, these rods were able to "guide" the long axis of the spine, allowing for growth while maintaining spinal correction. However, the use of the Luqué trolley has been abandoned as a result of poor spinal growth maintenance (32%–49%) [13, 18], high spontaneous fusion (4%–100%) [13], and high implant failure (32%) [18]. We modified Luqué's original idea of an internal tutor for the scoliotic spine [15, 20] by using minimally invasive approaches and newer implants in the hope of addressing some of its shortfalls.

Our purposes were to determine whether a modern Luqué construct could (1) correct and maintain spinal deformity in EOS; (2) allow for spinal growth; (3) lead to lower complication rates; and (4) whether patients require additional surgeries.

Patients and Methods

We reviewed all radiographs and charts of 17 patients with EOS who had been treated at our institution between 2003 and 2008. Twelve of these 17 patients had conventional treatment consisting of three successful Risser casts; four failed casting requiring DGR; one DGR as an initial treatment; and four VEPTRs as the initial treatment. The diagnoses were: four infantile scoliosis; three congenital scoliosis; one neuromuscular scoliosis; and four syndromic scoliosis. Their average age at the time of initiation of treatment was 4.5 years (range, 11 months to 8.5 years) with a minimum 2.5-year followup (average, 3.6 years; range, 2.5–5 years). Average Cobb angle of the major curve was 61° (range, 38°–94°), which at last followup was 35° (range, 23°–46°). In total, these 12 patients underwent 73 procedures representing on average six procedures over 3.5 years. None of these patients had thoracic insufficiency syndrome.

The remaining five patients had the modern Luqué trolley construct with the first surgery performed in 2003. Surgical indications for this procedure included: (1) large spinal deformity (Cobb greater than 40°–50°); (2) failed nonoperative treatment (curve progression greater than 10° over a 6-month interval); and (3) considerable growth potential (open triradiate, prepeak growth velocity). Associated factors that influenced the choice of this technique over the conventional techniques (DGR, VEPTR) were: unfavorable social environments for repetitive surgery, families' reluctance to impose repetitive surgery on their child, and comorbid factors leading to a higher risk of repetitive surgery (eg, difficult airway). Contraindications for this surgery were patients with chest wall abnormalities contributing to thoracic insufficiency syndrome or patients with rigid kyphoscoliosis. The etiology of the deformities in these five patients were: two idiopathic EOS, one patient with cerebral palsy, and two with syndromes (Prader-Willi syndrome and global hypotonia of unknown etiology). With the exception of the child with cerebral palsy, all were ambulators. The average age at surgery was 6.5 years (range, 3 years 10 months to 8 years 6 months). The minimum followup was 2 years with an average followup of 4 years (range, 2–6 years). No patients were lost to followup and no patients were recalled specifically for this study.

In the prone position, the modern Luqué construct involved a midline incision spanning the segment of the spine to be instrumented (we note that the instrumentation used to develop this growing rod construct was used off-label). Fixed spinal anchors (screws or hooks locked to the rods) and gliding spinal anchors (screws or sublaminar wire free to travel along the rods) were inserted through multiple "keyhole" dissections (Fig. 1A). At the fixed proximal

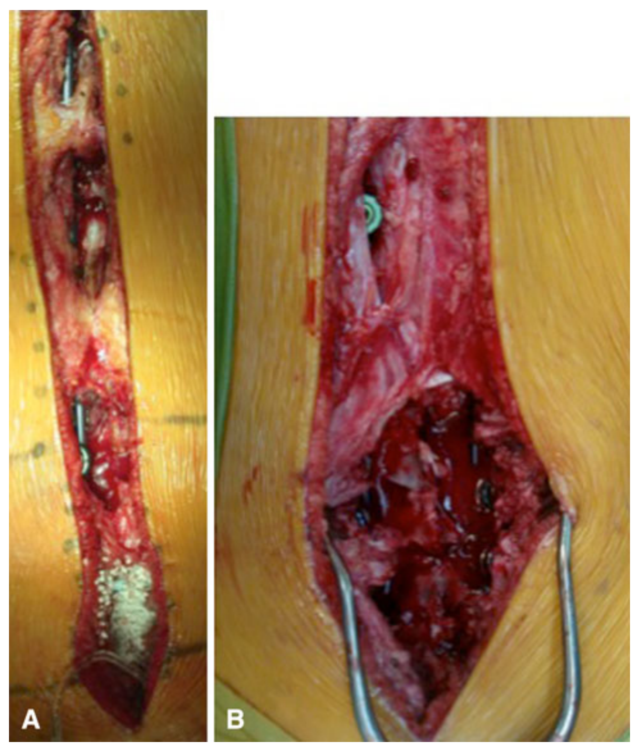

Fig. 1A–B (**A**) A single midline incision is made with multiple keyhole transmuscular dissections for the gliding anchors and a subperiosteal dissection for distal and/or proximal anchor fusions. (**B**) Two types of dissections are demonstrated, a muscle-sparing minimally invasive approach versus a standard subperiosteal approach.

and/or distal anchorage points, a classic subperiosteal dissection (Fig. 1B) was performed because these segments were to be fused. At the apex of the deformity, gliding anchors (either screws or sublaminar cables) were placed for maximal apical translation and deformity correction. The dissection at the gliding anchors was kept to a minimum using extraperiosteal and muscle-sparing techniques to avoid spontaneous fusion. In the lumbar spine, the gliding pedicle screws were inserted through a Wiltse approach sparing the joints and minimizing bony exposure. In the thoracic spine, the gliding pedicle screws were inserted lateral to the midline erector spinae, dissecting directly onto the transverse process and avoiding exposure of the lamina (Fig. 2A–C). Fluoroscopic guidance confirmed the pedicle entry point, and using a freehand technique, the gliding screws were inserted at strategic points allowing maximal apical translation. These gliding screws captured a 5-mm rod with a locking cap and nut designed for 6-mm rods, thus permitting motion. At segments where sublaminar titanium cables were to be passed, the dissection was carried from midline to the medial border of the facet. We were careful to leave the periosteum on the bone even with some muscle still attached. Dissection was performed with bipolar cautery and forceps at hand to control blood loss and minimize disruption of the periosteum off the bone. We carefully removed the spinous processes to avoid stripping the periosteum off the lamina while giving access to the ligamentum flavum and permitting the passage of sublaminar cables (Fig. 3). Two pairs of 5-mm titanium rods were tunneled in a subfascial/intramuscular fashion (below the fascia, above the periosteum) from the opened proximal and distal ends. Each rod had only one end rigidly anchored to the spine. In the intermediate segments, a series of gliding spinal anchors maintain the correction by keeping the rods parallel and engaged. As the spine grows, the rigidly proximal-fixed rods move away from the distally fixed rods (Fig. 4). A classic apical translation reduction maneuver was performed to correct the deformity. The number of gliding anchorage points was kept to a minimum to minimize the risk of spontaneous fusion, yet an adequate number of gliding anchors was necessary to translate the apex of the deformity toward the midline to control and correct the spinal deformity. An average of 10 vertebrae (range, 8–13) was between the fixed anchors.

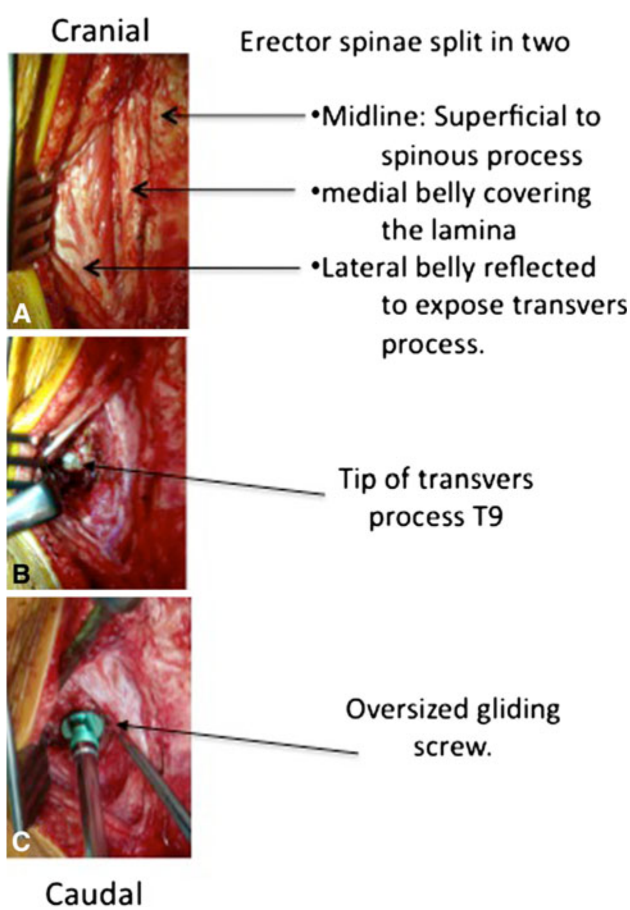

Fig. 2A–C A technique to insert a thoracic gliding anchor is shown. (**A**) To avoid spontaneous fusion, dissection is taken lateral to the midline erector spinae. (**B**) The transverse process is exposed. (**C**) Insertion of pedicle screws is shown. Gliding screws must be a low-profile implant and must be left slightly proud to keep rods of bony elements.

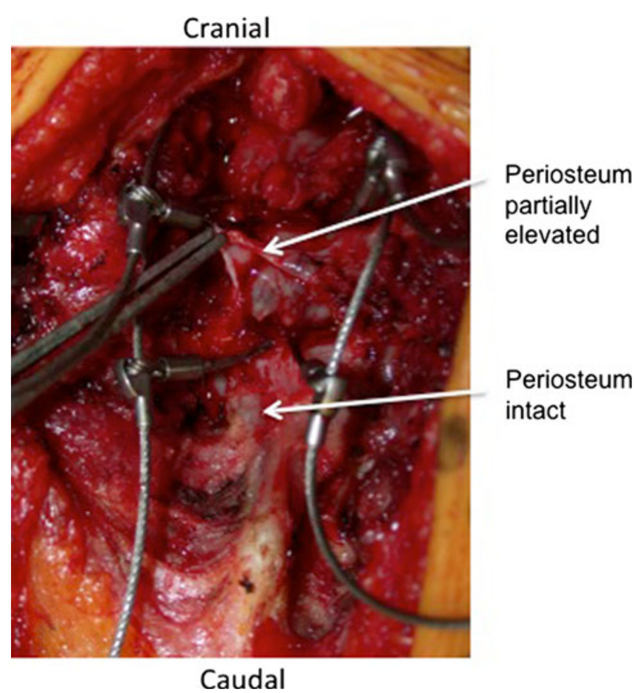

Fig. 3 A technique to insert a sublaminar gliding wire is shown. Sublaminar cables are inserted through an extraperiosteal dissection. The dissection is done leaving some muscle and periosteum on the lamina. When removing the tips of the spinous process, great care must be taken not to strip the periosteum off the lamina as demonstrated with the forceps.

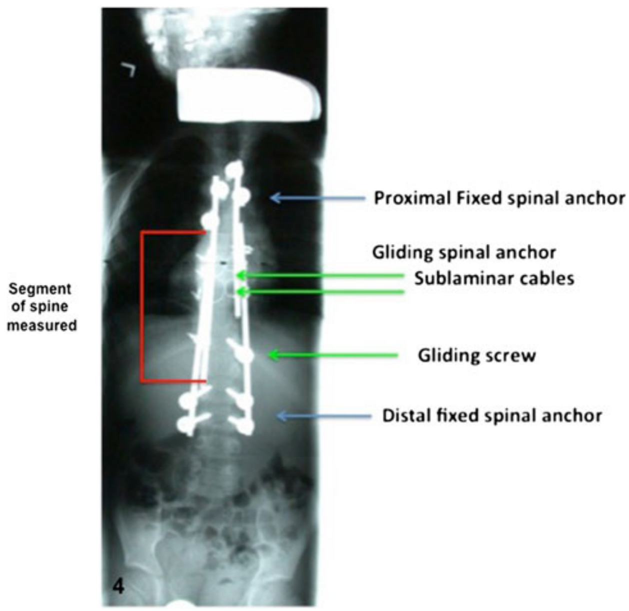

Fig. 4 Classic construct of a modern Luqué trolley consisting of two proximal claws (or four proximal screws) and four distal pedicle screws as fixed anchors are shown. Two intercalated sublaminar cables are placed across the thoracic curve and one gliding screw at the apex of the lumbar curve.

Postoperatively, patients were mobilized on Day 2 to 3 and discharged home with a soft Boston brace to be worn for 12 weeks. No specific physiotherapy was initiated and return to regular activities was recommended by 6 months after surgery.

All patients were seen at a regular postoperative visits, 6 weeks, 12 weeks, and then at 6-month intervals until they reached skeletal maturity. Parents and patients were questioned about pain and limitation of activities. A detailed neurologic examination was performed at each visit. All the data were collected from the medical records and patients' radiographs. Complications and additional procedures were recorded. As part of our standard perioperative scoliosis imaging protocol, posteroanterior and lateral radiographs of the entire spine were done with an embedded radio-opaque ruler allowing us to calibrate actual lengths.

One independent reviewer (FA) measured the Cobb angles and the spinal heights from plain radiographs, posteroanterior, and lateral scoliosis films. The interobserver error on Cobb measurement is 7.2°, whereas the intraobserver is 4.9° [18]. Spinal growth was measured from the inferior end plate of the proximal anchor to the superior end plate of the distal anchor (Fig. 4) and compared with the expected growth. Dimeglio's maximum growth estimate of 0.1 cm per year per vertebra was used as the expected growth reference [8]. The expected growth was calculated by multiplying the number of vertebra between the proximal and distal anchors times the number of years since the initial surgery times. This 0.1 cm per vertebra per year represents the vertebral body growth during the initial peak growth of infancy from 0 to 5 years. Despite knowing that spinal growth has a bimodal peak, we decided empirically to apply it across all ages. We expect that this estimate may be inflated during the growth between 5 and 10 years but should be valid again during the second peak growth.

Results

The mean preoperative Cobb angle of the primary curve was corrected from 60° (range, 45°–70°) to 21° (range, 15°–32°). Over the course of the next 4.5 years, the mean Cobb angle had gradually increased back to 31° (range, 14°–54°) as Patients 1 and 2 outgrew their initial constructs and required revision surgery. Patient 3's Cobb angle regressed close to its initial value and demonstrated little spinal growth (Table 1). All three underwent revision surgery at 5.5, 4, and 4.5 years, respectively, after their initial surgery (Figs. 5, 6). The revision surgery resulted in improvements in the Cobb angle for all cases. Patients 4 and 5 continued to grow with no evidence of curve regression. The average Cobb angle at the last followup was back to the initial correction of 21° (range, 5°–33°) after Patients 1 through 3 underwent revision surgery (Table 2). The mean preoperative Cobb angle of the secondary curve decreased from 33° to 15° and back up to 20° before any revision surgery. At the last followup, the mean Cobb of the secondary curve also returned to the initial correction of 15°.

The average total growth across the average 10 vertebrae before any revision surgery was 2.3 cm (range, 0.7–4.1 cm) over an average of 3.6 years, or 63% of the expected growth (range, 12%–100%). Patient 1 (Fig. 5) and Patient 2 outgrew their constructs, but Patient 3 lost the initial gain in spinal height over a 4-year period as his deformity recurred (Fig. 6). At the last followup, subsequent to the revision surgery, the average total growth was 3 cm (range, 1.7–4.8 cm) over a 4-year period, representing 73% (range, 26%–100%) of the expected growth. Intraoperative findings demonstrated persistent gliding motion across the three gliding screws and at the sublaminar cables. In keeping with motion, particle debris was noted at the rod-screw interface as well as at the cable-rod interface (Fig. 5F). The last two patients continued to grow with their deformity remaining stable.

During the ongoing treatment, one patient had a major complication. Patient 3 required an unplanned surgery 4.5 years after the initial surgery as a result of recurrence of the deformity and lack of growth (Fig. 6). It was also

Table 1. Clinical results before any revision surgery

Patient number	Gender	Diagnosis of scoliosis	Date of surgery	Age at surgery	Age at followup	Instrumented segments	Number growing vertebrae	Curve type Lenke	1° Cobb	2° Cobb
1	M	Infantile	10/27/2003	6 years 3 months	11 years 10 months	T4-L3	8 (T6-L1)	3B n	45°	46°
2	M	Prader Willi	4/13/2005	3 years 10 months	7 years 9 months	T4-L5	10 (T6-L3)	5C +	70°	N/A
3	F	Syndromic hypotonia	3/28/2005	4 years 6 months	8 years 9 months	T1-L5	13 (T3-L3)	6C +	70°	49°
4	F	Cerebral palsy	1/4/2008	8 years 6 months	11 years 1 month	T2-S1	12 (T4-L3)	6C +	59°	36°
5	F	Infantile	3/11/2008	7 years 10 months	9 years 8 months	T3-L1	7 (T5-T11)	1A −	55°	35°
Average				6.5 years			10		60°	42°

Patient number	Postoperative 1° Cobb	Postoperative 2° Cobb	Last followup 1° Cobb	Last followup 2° Cobb	Spinal height postoperatively	Spinal height last followup	Measure growth (cm)	Expected growth: 1 mm × number segments spanned × years	Percent of expected growth
1	17°	7°	23°	17°	16.3	20.4	4.1	1 mm × 8 levels × 5.5 years = 4.6 cm	89%
2	15°	N/A	37°	N/A	20.2	23.0	2.8	1 mm × 10 levels × 4 years = 4.0 cm	70%
3	32°	25°	54°	38°	26.8	27.5	0.7	1 mm × 13 levels × 4.3 years = 5.6 cm	12%
4	26°	13°	30°	18°	32.4	34.4	2.2	1 mm × 12 levels × 2.3 years = 2.7 cm	81%
5	16°	16°	22°	11°	14.6	16.3	1.7	1 mm × 7 levels × 2 years = 1.4 cm	> 100%
Average	21°	15°	33°	21°			2.3 cm	3.6 cm over 3.5 years	63%

M = male; F = female; N/A = not available.

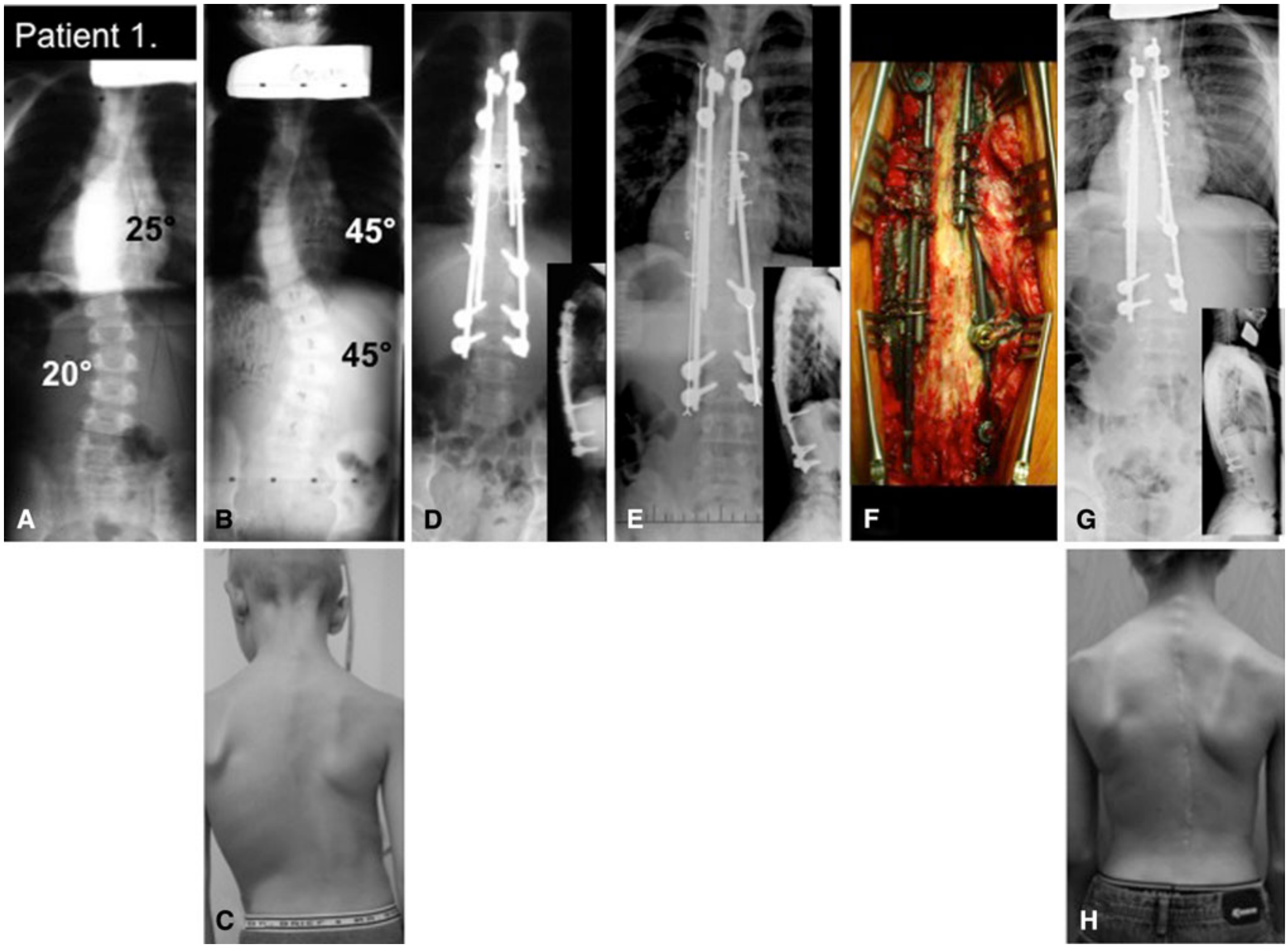

Fig. 5A–D Clinical case, Patient 1. (**A**) The presenting radiograph shows the patient at 3 years of age. (**B**) Curves progress despite serial casting. A radiograph was performed when the patient was 6 years old. (**C**) Preoperative clinical pictures are shown. (**D**) Immediate postoperative radiograph is shown. (**E**) Five years postoperatively the rod is starting to disengage warranting revision surgery. (**F**) Intraoperative finding demonstrates particle debris adjacent to rods, no evidence of fusion, and no implant loosening. (**G**) Postoperative revision surgery with longer rods is shown. (**H**) A clinical picture is shown of the patient at the age of 12 years.

noted that spontaneous fusion had occurred across the convexity just distal to the proximal anchor. The rod was pressing down onto the spine correcting a proximal kyphosis. All five patients' postoperative courses were uneventful; all four ambulatory patients remained active with no undue pain. There were no superficial or deep wound infections or rod breakage. However, radiographs did reveal that three of the 22 sublaminar cables ruptured in two patients but without any clinical consequences.

None of these patients underwent repetitive surgery. Three additional surgeries were performed to extend the constructs; Patients 1 and 2 had outgrown them and one unplanned surgery was performed on Patient 3. In all three cases, the constructs were revised to new self-growing constructs, the spinal deformities were further corrected, and the spines continued to grow (Table 2).

Discussion

Despite major advances in the management of EOS, many questions remain [16]. The fundamental challenge of preventing curve progression while maintaining longitudinal spinal growth in EOS has resulted in novel treatment modalities that unfortunately are also associated with multiple subsequent procedures and relative high complication rates [2, 5, 9, 13, 15, 18]. Our purposes were to determine whether a modern Luqué construct would (1) correct and maintain the spinal deformity in EOS; (2) allow for spinal growth; (3) lead to higher complication rates; and (4) require patients to undergo additional surgeries.

Our case series is subject to several limitations. First, our small numbers cannot generate any relevant statistical

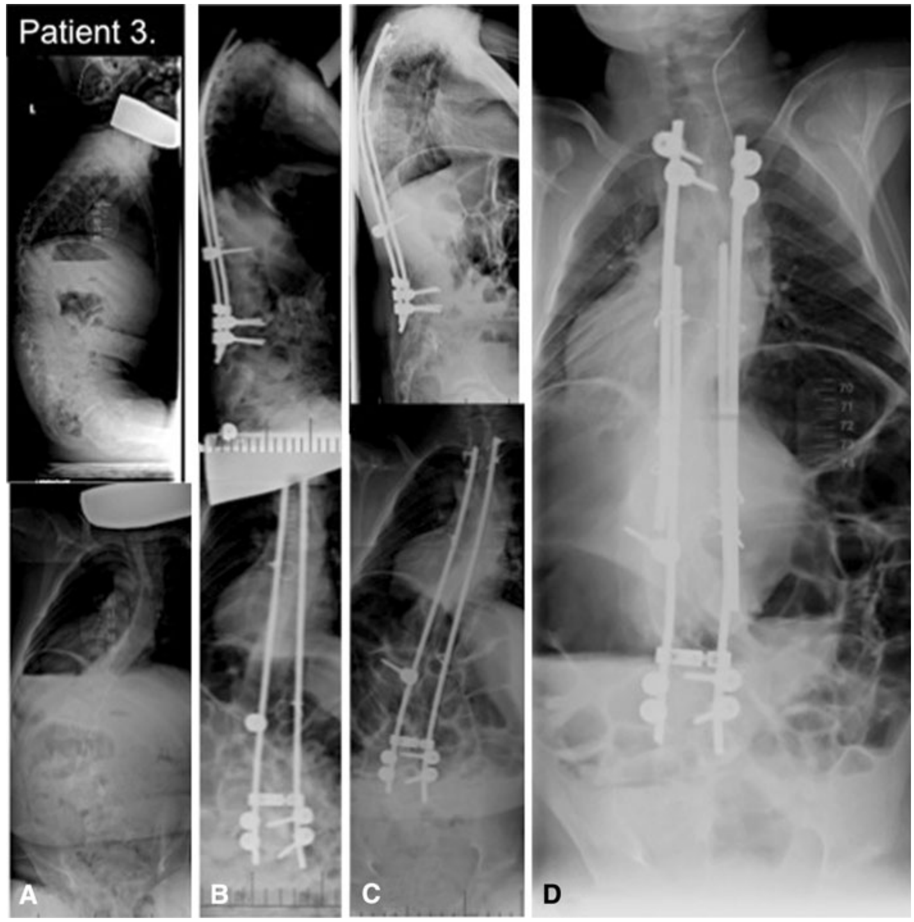

Fig. 6A–D The radiographic evolution of Case 3 is shown. (**A**) A preoperative posteroanterior and lateral radiograph of the spine of a 4.5 year old with global hypotonia is shown. (**B**) The 6-month postoperative posteroanterior and lateral radiograph is shown. (**C**) This 4-year postoperative posteroanterior and lateral radiograph demonstrates recurrence of deformity and worsening apical rotation. (**D**) The 6-month postrevision growing rod surgery shows some correction and good balance in this image.

values and can only be looked at as an initial evaluation to determine if this technique should be further explored. Second, having small numbers with different etiologies makes it difficult to draw any clinical recommendations. Third, our lack of long-term followup is of concern, particularly considering the nature of complications associated with EOS. Lastly, the lack of additional systematic spinal imaging (CT, MRI) makes it difficult to confirm or exclude the presence of spontaneous fusion but can be inferred from worsening Cobb angles or lack of growth (as seen in Patient 3).

Our modern Luqué trolley construct achieved 60% of Cobb correction, leading us to believe that it can correct and maintain spinal deformities in EOS and other techniques when compared with the literature (Table 3). Our observations are similar to those in the literature with the exception of the derotational casting technique in which 25% of patients had complete resolution of their scoliosis and another 50% had residual curves below 40° [19]. DGR reportedly initially decreases deformities by 60% with a residual correction of 50% [3]. The use of VEPTR for noncongenital scoliosis as a purely growing rod technique does not control spinal deformities well (final Cobb correction of only 20%) [9] but controls spinal deformity in patients with congenital scoliosis and chest wall abnormalities [5]. The self-lengthening constructs with apical epiphysiodesis or fusion (ie, conventional Luqué trolley and Shilla technique, respectively) have a similar initial correction of 60% with a latest followup correction of 50% [14, 18].

From a growth perspective, the modern Luqué trolley allowed on average 0.75 cm of spinal growth per year in four of the five patients representing 90% of their expected growth occurring across the instrumented spine. However, one of five patients (20%) only grew 25% (Patient 3). We believe the overall growing construct was less than ideal in this patient; a combination of the inadequate amounts of gliding anchors, the residual coronal deformity, and the sagittal deformity that led the rod to rest directly on the spine inducing a spontaneous fusion contributed to this poor growth outcome. It is difficult to compare our technique's spinal growth with the other techniques because the reporting on growth is not standardized in the literature. At best, we can state that on average the DGR technique appears to provide 1.2 cm of growth per year, whereas the VEPTR technique, in the face of congenital

Table 2. Results including postrevision surgery

Patient number	Gender	Diagnosis of scoliosis	Reason for revision	Number of years after initial procedure	Current age	Instrumented segments	Number of growing vertebrae	Initial 1° Cobb	Initial 2° Cobb
1	M	Infantile	Outgrew construct	6 years 0 month	12 years 6 months	T4-L3	8 (T6-L1)	45°	46°
2	M	Prader Willi	Outgrew construct	5 years 0 month	8 years 6 months	T2-L5	10 (T6-L3)	70°	N/A
3	F	Syndromic hypotonia	Curve progression	5 years 0 month	9 years 5 months	T1-L5	13 (T3-L3)	70°	49°
4	F	Cerebral palsy	None	2 years 3 months	10 years 6 months	T2-S1	12 (T4-L3)	59°	36°
5	F	Infantile	None	2 years 0 month	9 years 8 months	T3-L1	7 (T5-T11)	55°	35°
Average				4 years			10	60°	42°

Patient number	1° Cobb before revision	2° Cobb before revision	Postrevision 1° Cobb	Postrevision 2° Cobb	Initial spinal height (cm)	Last followup spinal height (cm)	Measure growth (cm)	Expected growth: 1 mm × number of segments spanned × years	Percent of growth
1	23°	17°	5°	2°	16.3	20.8	4.5	1 mm × 8 levels × 6.3 years = 5.0 cm	93%
2	37°	N/A	12°	N/A	20.2	25.0	4.8	1 mm × 10 levels × 5 years = 5.0 cm	96%
3	54°	38°	33°	29°	26.8	28.5	1.7	1 mm × 13 levels × 5 years = 6.5 cm	26%
4	N/A	N/A	30° last followup	18° last followup	32.4	34.4	2.2	1 mm × 12 levels × 2.3 years = 2.7 cm	81%
5	N/A	N/A	22° last followup	11° last followup	14.6	16.3	1.7	1 mm × 7 levels × 2 years = 1.4 cm	> 100%
Average			21°	15°			3 cm	4.1 cm	73%

M = male; F = female; N/A = not available.

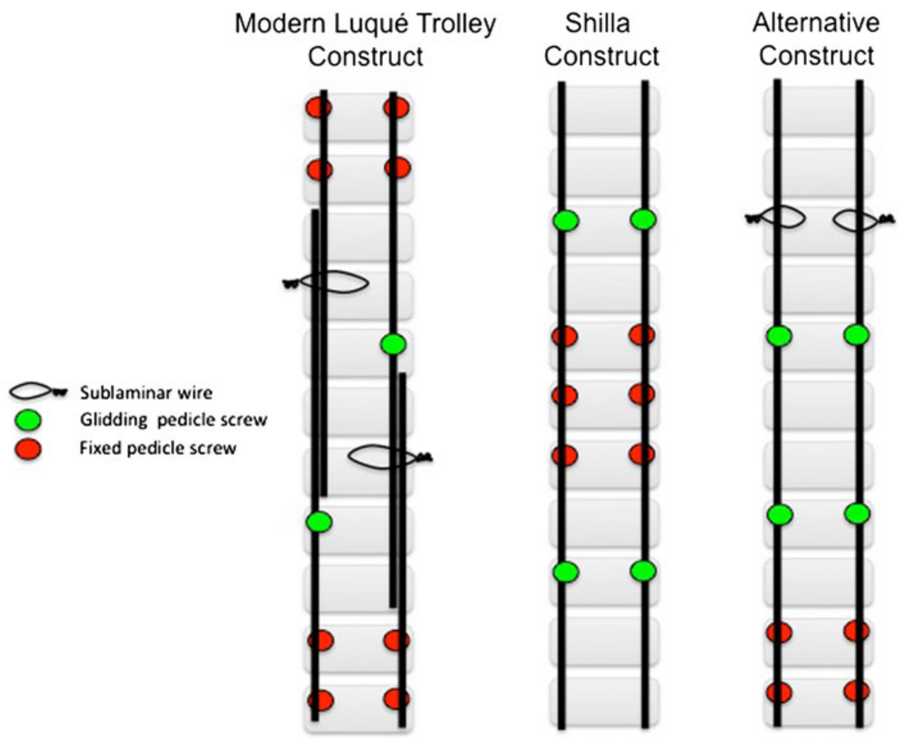

Fig. 7A–D Illustrations show the different self-lengthening growing constructs.

scoliosis and chest wall abnormality, results in 0.8 cm of growth per year. The conventional Luqué trolley with epiphysiodesis resulted in marked growth inhibition (30% of expected growth). It is important to emphasize that the conventional Luqué trolley and the Shilla techniques intentionally inhibit growth by performing either a hemi-epiphysiodesis or a frank fusion across a segment of the spine. The current comparison of growth is specific to spinal growth and not growth in relation to space available for the lung (SAL). We did not analyze the SAL because this technique is not used for thoracic insufficiency syndrome.

The complication rate of the modern Luqué trolley is similar in type and rate of the complications seen with the other growing rod techniques. When comparing it with the original trolley results, it has less implant failures leading to revision surgeries. Spontaneous fusions, as previously discussed, remain a main concern with this technique and as we move forward, a protocol for investigating the presence of fusions will be required.

The apparent benefits for growth using the DGR and the VEPTR are achieved at the expense of additional multiple surgeries. In comparison, the self-lengthening techniques have a substantially smaller number of additional surgeries, but possibly at the cost of less achievable growth. The DGR and the VEPTR have on average an additional 6.6 and 7.1 surgeries per patient, respectively, in contrast to the self-lengthening techniques such as the Shilla and the modern Luqué trolley that have less than one (average of 0.5 and 0.6 additional procedures, respectively) per patient.

It is apparent that the next generation of surgical techniques for the management of EOS will attempt to avoid the need for recurrent lengthening. Gliding anchors will allow us to apply Luqué's concept of self-growth to different construct (Fig. 7), and each construct will bear specific risks and benefits. For example, the patient is at risk of developing proximal or distal junctional kyphosis when the proximal and possibly the distal segment grow off the gliding anchors. Despite the apparent advantages of these self-growing constructs, there still remain unresolved issues. The risk of spontaneous fusion must be balanced with the inadequate control of the spine to determine the number of gliding anchors needed. All these constructs have motion across many interfaces where debris particles are generated with little understanding of their possible local and systemic repercussions [15]. Finally, a persistent shortfall of all these growing rod constructs is our inability to control rotational deformity in the presence of ongoing spinal growth.

In conclusion, the modern Luqué trolley technique combines stable base (end vertebrae) fixation with apical control and gliding anchors, permitting self-lengthening of the construct by guided growth and avoiding repetitive and

Table 3. Comparative results of current treatments for early-onset scoliosis

Author	Sanders et al., 2009 [19]	Pratt et al., 1999 [18]	Akbarnia et al., 2005 [3]	Campbell et al., 2004 [5]	Hasler et al., 2010 [9]	McCarthy et al., 2009 [14]	Ouellet, 2010 (current study)
Techniques Time span	Derotation casting 2003–2008	Luqué Trolley and epiphysiodesis 1983–1990	Dual growing rod 1993–2001	VEPTR	VEPTR	Shilla Apical fusion	Modern trolley
Indication	38 EOS 15 syndesmosis; 3 NM	25 EOS	7 EOS; 3 Cong; 2 NM; 11 Synd	21 Cong et chest abnormality	1 EOS; 12 NM; 0 Cong; 5 syndesmosis; 5 chest	3 EOS; 1 Cong; 2 Synd 4	2 EOS; 1 NM; 2 syndesmosis
No.	55	25	23	21	23	10	5
Minimum and average followup	Minimum 1 year Average 2.1 years	Minimum 5 years	Minimum 2 years Average 4.75 (2–9.25)	Minimum 2 years Average 4.2	Minimum 2 years Average 3.6 years (2–5.8)	Minimum 2 years	Minimum 2 years Average 3.6 (2–5.5)
Average age at initiation of treatment	2.2 years (1.1–6)	3.1 years (1.5–7.4)	5.4 years (1.9–12)	3.3 years	6.5 years (1.1–10.5)	7.6 years (2–10)	6.5 years (3.8–8.5)
Average time of treatment	1 year	5 years	4 years	Not mentioned	Not mentioned	Not mentioned	4 years
Number of additional procedures (planned lengthening)	< 2 years: 2/month < 3 years: 3/month > 4 years: 4/month	13 additional procedures	166 additional procedures 15 unplanned	Not mentioned	149 additional procedures 15 unplanned	5 additional procedure 1 rod exchange do to overgrowth 1 prominent implants 1 rod fracture 2 I&D for infection	3 add procedures 2 rod exchange due to overgrowth 1 rod revision resulting from recurrence deficiency
	Cast change under GA	Average 0.5 per patient	Average 6.6 per patient		Average 7.1 per patient	Average 0.5 per patient	Average 0.6 per patient
Number of vertebrae spanned	All	10 (9–12)	13 (11–17)	Not mentioned	Not mentioned	Not mentioned	10
Growth across the spine	No data	Average 2.9 cm 49% expected With epiphysiodesis Average 2.0 cm 32% expected	Average of 4.8 cm average 1.2 cm/year	Average 3.3 cm Average 0.8 cm/year Prior fusion Average 0.3 cm/year	Not mentioned	Addition of 12%	Average 3 cm average per year of 0.75 cm

Table 3. continued

Author	Sanders et al., 2009 [19]	Pratt et al., 1999 [18]	Akbarnia et al., 2005 [3]	Campbell et al., 2004 [5]	Hasler et al., 2010 [9]	McCarthy et al., 2009 [14]	Ouellet, 2010 (current study)
Complications	No data transient	32%	47%	Not mentioned	100%	50%	40%
	Skin irritation	8 patients with implant failure 1 infection 1 fusion 1 kyphosis	11 patients had total of 13 complications		23 complications 10 skin sloughs, 7 implant failure, 6 infection	1 prominent implants 1 rod fracture 2 I&D for infection	1 patient loss of correction, unilateral convex 4-segment fusion
Percent correction primary curve	¼ > 80% ½ = 50% ¼ < 40%	Initial correction 60% Latest followup 51%	Initial correction 54% Latest followup 53%		Initial correction 30% Latest followup 25%	Initial correction 61% Latest followup 51%	Initial correction 65% Latest followup 61%

VEPTR = vertical expandable prosthetic titanium ribs; EOS = early-onset scoliosis; Cong = congenital scoliosis; NM = neuromuscular scoliosis.

scheduled surgeries. In this small series of five patients, only one was an outright failure, suggesting the initial experience was favorable enough to justify this preliminary report and continue evaluating this procedure.

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