Growth-Guided Instrumentation: Luqué Trolley

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Key Points

1. The key to successful management of EOS is the prevention of curve progression while maintaining spinal growth with the least amount of complications.
2. Self-guided growth surgical techniques have been developed to negate the need of repetitive lengthening required for the classic posterior distraction-based techniques (vertically expandable prosthetic titanium ribs/dual growing rods).
3. Implantation of self-guided growth construct is technically demanding and is best done in patients with flexible curves where the apex can be translated to midline, slightly older age group (6–10 years old) with underlying diagnosis of flaccid neuromuscular scoliosis such as spinal muscular atrophy.
4. There are two described self-guided growth constructs: the Shilla and the modern Luqué trolley. The main difference between the two constructs is that the Shilla procedure captures and fuses the apex of the deformity and allows the proximal and distal segments to grow away. The modern Luqué trolley construct consists of rigidly capturing the proximal and distal segments of the spine, while the apex of the deformity is

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translated and captured by gliding anchors.
5. Achieving apical translation is crucial to maximizing spinal height while minimizing the risk of curve regression as it realigns the axial forces of the spinal growth.
6. The gliding spinal anchors are inserted through muscle-sparing extraperiosteal "keyhole" dissections to avoid spontaneous fusion. At the apex of the deformity, gliding anchors are placed for maximal apical translation and deformity correction.

42.1 Introduction

The management of early onset scoliosis (EOS) carries significant challenges. Knowing that severe spinal deformities or early spinal fusion leads to poor lung development [1], new growth-sparing surgical techniques have evolved. The key to successful management of EOS is the prevention of curve progression while maintaining spinal growth [2, 3] with the least amount of morbidity. These new growth-sparing surgeries have been classified into three broad categories: distraction based, guided growth, and convex compression growth inhibition [4]. When deciding which of these growth-sparing procedures should be used, one must take into account the patients' underlying etiologies and their comorbidities. The most studied surgical options that have provided some hope for successful management of these challenging patients are the spine-based dual growing rods (DGRs) [5–8] and rib-based vertical expandable prosthetic titanium ribs (VEPTRs) [1, 9–11]. These two techniques carry a high complication rate with one major drawback: once implanted, the patients need to be returned to the operating room approximately every 6 months for lengthening procedures.

Recent literature revived interest in the previous concepts of Luqué of a spinal construct that allowed self-lengthening with growth [12–14]. The obvious advantage of this guided growth technique is that patients do not need repetitive surgical interventions to lengthen the implants. Both the Shilla procedure and the modern Luqué trolley consist of capturing the spine in such a way that gliding spinal anchors travel along fixed rods, preventing further spinal deformity while still allowing relatively normal spinal growth. The main difference between the Shilla and the modern Luqué trolley is that the Shilla procedure derotates and fuses the apex of the deformity and allows the proximal and distal segments to grow away, while the modern Luqué trolley consists of one pair of rods fixed proximally and one pair of rods fixed distally while the apex of the spine is translated and captured by the four rods. As the spine grows, the overlying rods glide away. The modern Luqué trolleys take advantage of modern spinal implants and of a better understanding of the physiology of the young growing spine. Patient selection is crucial when using the modern Luqué trolley treatment modalities to optimize successful management.

42.2 Philosophy

There is a general consensus among treating surgeons that conservative treatment consisting of serial casting, plus or minus bracing, is warranted as an initial treatment in all EOS cases [3]. It is true that casting can be successful in treating EOS in very young patients, particularly with small flexible curves [15]. It has been demonstrated that casting is also useful as a delay tactic buying time until the child is older to proceed to either a final fusion surgery or a growth-sparing procedure using DGRs or VEPTRs [16]. It has been demonstrated that by adopting such an approach, the overall complication rates in managing EOS will be decreased. By delaying the initiation of classic growth-sparing surgeries, one decreases the overall number of surgeries, delays the law of diminishing return [17], and decreases the overall potential for complications that have been quantified to be as much as 24 % for each additional surgery [5]. Currently, conservative treatment is just not feasible for certain patients (respiratory compromise, neuromuscular etiology) or it is simply not successful (malignant curve progression despite casting). For such patients, only then, is surgery recommended.

When adopting growth guidance surgery such as the modern Luqué trolley, one must take a more proactive approach. Early surgical intervention is recommended rather than waiting until there are severe rigid spinal and/or chest wall deformities. However, such a philosophy must be based on strict guidelines as not to initiate unnecessary surgery. One needs to document curve progression in a child that remains skeletally immature and where there is a high likelihood that the curve will continue to progress. Thus, knowing that both the conservative treatment (serial casting) and classic posterior-based growth-sparing procedures require repetitive surgical intervention every 6 months, it is preferable to initiate self-growing rods to avoid these repetitive procedures, which carry a significant impact on the overall physical and mental health of the children. Pratt et al. concluded that the use of braces or plaster jackets for prolonged periods for EOS leads to an emotional scar [18]. They advocated the use of a self-lengthening construct such as the Luqué trolley, as a favorable option for EOS. They believed that the surgical scar could be more easily hidden and forgotten, in contrast to casting that is continually reminding the child of their abnormality. Therefore, they felt that the total physical and psychological trauma to the patient was smaller in children undergoing passive-guided growth surgery compared to bracing. Such surgery needs to be performed on curves that remain flexible and where the apex can be translated to midline. By achieving such correction, the axial forces of spinal growth will be "harnessed," maximizing spinal height while minimizing the risk of curve regression.

In addition to the benefit that the children do not need to be operated on serially, this growth-friendly surgery avoids the spinal elements (e.g., vertebral growth plates, disks, facets, and the spinal musculature) to be subjected to cyclical distractive and fixed constraints. Such unnatural loads across the spine during the classic repetitive lengthening may well contribute to the law of diminishing return seen with VEPTRs and DGRs [17]. Another physiological benefit of this guided growth surgery is that there are no posterior-based distractive force-inducing junctional kyphotic moments leading to sagittal imbalance. As the gliding anchors can travel up and down the rods matching the sagittal profile, there is also no set sagittal segment that needs to be straight for the growth to occur.

These self-guided growth constructs are particularly well adapted for patients with early onset neuromuscular scoliosis, particularly patients with spinal muscular atrophy (SMA). Type 2 SMA patients are particularly at risk of precocious severe spinal deformities, seeing the onset of the disease between 6 and 18 months and the onset of the spinal deformity by the age of 3 years [19]. These curves are at high risk of rapid progression resulting in significant deformity by the age of 7 years [19, 20]. The rationale for early surgical intervention in early onset neuromuscular scoliosis is to provide a straight and stable spine in order to allow proper-guided growth of the spine. Corrective spinal surgery protects the normal development of the lungs. In addition, it can help these patients to achieve a stable sitting balance and improved head control and overall posture, thus facilitating their caregivers' handling and improving their quality of life.

Patients with early onset or juvenile idiopathic scoliosis, congenital scoliosis, and to a lesser extent, spastic neuromuscular scoliosis are all candidates for guided growth. A key limitation behind this surgical technique is that if the spinal deformities require significant forces to straighten and maintain the spine straight, it will most likely not do well. For example, the spastic severely rigid neuromuscular patient may not grow as much as the flaccid collapsing neuromuscular scoliosis and its spinal deformity may return faster than the latter. Certain deformities require active distraction to ensure spinal growth, hence should be treated with classic DGRs and VEPTRs to maintain spinal correction and persistent spinal growth.

42.3 Background

The original Luqué trolley was described by Luqué and Cardoso in 1977 [21]. They developed the first self-growing rod construct consisting of two L- or U-shaped rods fixed to the spine in a segmental fashion using sublaminar wires. Patients were selected for rigid internal fixation without fusion on the basis of young age (<11 years), severe long curves (e.g., wanting to avoid early long fusion), difficulty in casting (neuromuscular curves), and progressive curves [21]. As the spine grew, these rods were able to glide and "guide" the spine during longitudinal growth while maintaining the spinal correction. The short-term results of 2-year follow-up minimum were promising with mean major curve correction from 72° to 22° and spinal growth across the instrumentation of 2.5 cm. However, the use of the Luqué trolley has been abandoned as long-term result showed poor maintenance of spinal growth (range, 32–49 % of expected growth) [18, 22], high spontaneous fusion (range, 4–100 %) [22], and a high implant failure rate of 32 % [18].

Pratt et al. in 1999 published the long-term results of the Luqué trolley for the management of infantile and juvenile idiopathic scoliosis that were previously performed by Webb [18]. This retrospective study compared the Luqué trolley fixation with ($n = 18$) and without ($n = 8$) apical convex epiphysiodesis. In the Luqué trolley group without epiphysiodesis, the mean age was older (7 years old); the mean preoperative major curve was 48° and decreased to 25° immediate postoperatively. Over the next 5 years, all major curves worsened. Six of the seven patients underwent a second procedure consisting of the definitive spinal fusion with segmental spinal instrumentation. The major curves were corrected from 56° (range, 46–67°) to 43° (range, 24–55°), with a final major curve of 43°. With respect to spinal growth of the instrumented spinal segment at the 5-year follow-up (FU), it was 2.9 cm, representing 49 % (range, 31–71 %) of the expected growth for age- and gender-matched reference. For the other group of patients treated with the Luqué trolley with apical convex epiphysiodesis, the mean preoperative major curve was 65° (range, 40–95°). The mean major curve was 26° (range, 8–66°) after the combined anterior posterior surgery and 32° (range, 0–86°) at the 5-year postoperatively. Over a mean of 5 years postoperatively, the major curve worsened in seven patients, remained unchanged in four patients, and improved in two patients. While achieving better curve control (mean loss of correction of only 6°), spinal growth across the instrumented spinal segment at 5-year FU was only 2 cm, which represents only 32 % of that expected for age- and gender-matched norm groups. In the entire study group, there were three patients with broken rods and wires, two patients with broken wires alone, and three patients with rod prominence. A junctional kyphosis developed at the caudal end of two Luqué trolleys. At surgical revision, the instrumented vertebrae were found to be fused. One patient developed a postoperative pneumonia. There were no neurological complications. The authors concluded that there was a need for improved instrumentation and for new surgical measures to allow better spinal growth and curve control.

When choosing a growth guidance system, one needs to properly understand the shortfalls of the classic Luqué trolley. Patients who did poorly with the classic Luqué trolley were those with large rigid curves preoperatively and/or patients who had large residual postoperative curves. The usage of wires as the spinal instrumentation contributed directly to the causes of the high complication rates, including spontaneous fusion, implant failure, and poor deformity control. The dissection required to pass sublaminar wires at every level, and the binding of the rod down onto the lamina obviously led to a high rate of spontaneous fusion leading to growth inhibition. This posterior fusion, in turn, may have also contributed to a certain amount of curve progression in the form of crankshaft phenomenon. Despite such spontaneous fusion, previous authors have observed spinal growth across such extensive dissected spines [18]. Our belief is that the fusion mass is thin and does not impede the anterior spinal growth as long as proximal and distal fixation points are well anchored. Having converted Luqué trolley to final fusion, we have noted that these spontaneous fusions are generally thin and may explain persistent spinal growth. With respect to implant failure, it is not surprising that

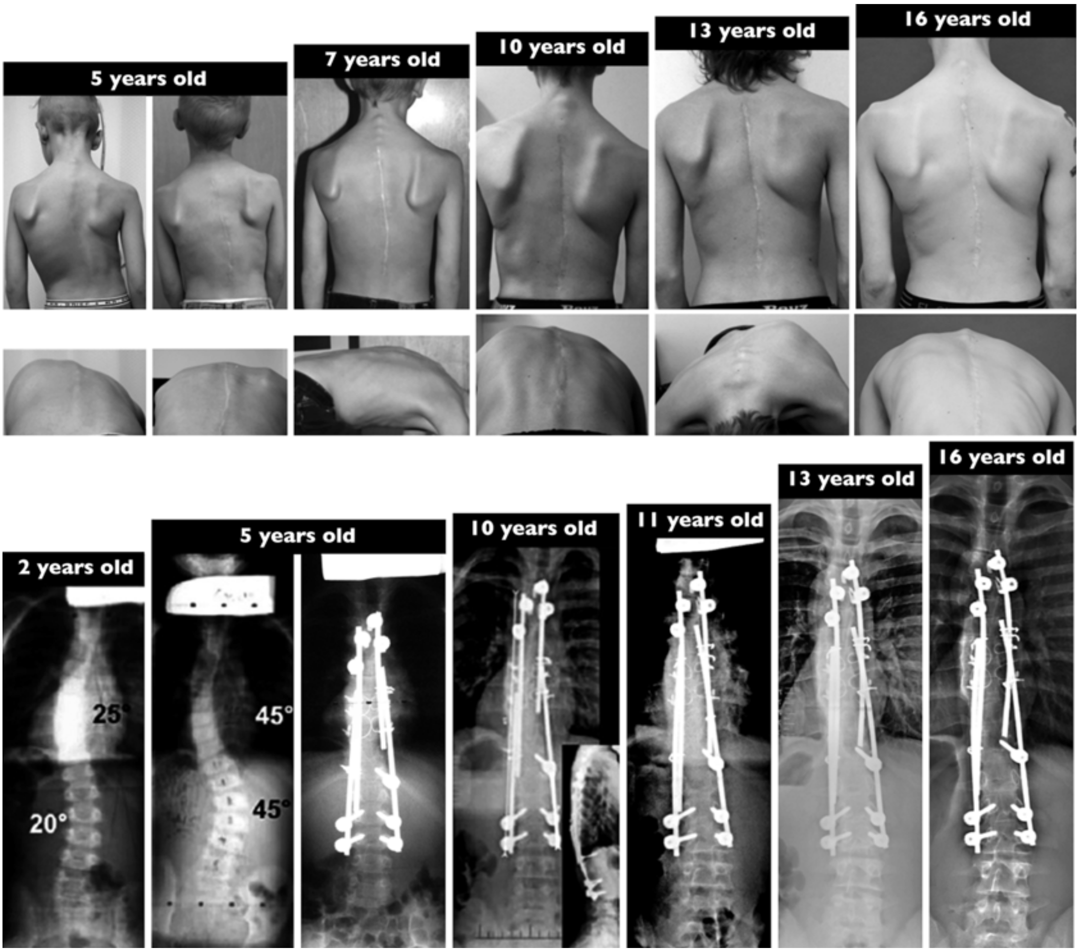

Fig. 42.1 Clinical example of a 2-year-old male with a progressive idiopathic early onset scoliosis undergoing a self-guided growth surgery. Despite serial casting from the age of 2–5, the deformity progressed. Patient was treated with a modern Luqué trolley construct, which grew over the next 10 years. He required only one revision surgery at the age of 5 as he outgrew the guided growth construct

there was a high rate of implant failure as the main implants used were simple wires. Rods could not be held in place solidly with only the wires; hence these had a tendency to migrate. With the use of wires, there was no ability to capture and control the anterior spinal column. Despite having every level "captured," the construct had to be loose to allow the rods to glide. With such fixation, the spinal stabilization was relatively poor, leading to poor curve control and therefore, contributing to the gradual loss of deformity correction. The patients in the study by Pratt et al. with the apical epiphysiodesis illustrated that curve control was improved significantly. However, it resulted in significant loss of spinal height, thus illustrating that apical control is indeed important for deformity control as long as one does not cause fusion across the apex.

In 2011, Ouellet published a small series of 17 patients with EOS of which 5 were treated with a modern Luqué trolley construct (Fig. 42.1) [12], reintroducing the concept of self-lengthening growth guidance systems [4]. The surgical technique consisted of using off-label modern spinal implants allowing for gliding spinal anchors and taking advantage of muscle sparing minimally invasive exposure to instrument the spine. The case series compared 12 patients treated with conventional growth-sparing treatment (four patients treated with serial casting, four with DGRs, and four with VEPTRs) to 5 patients treated with a modern Luqué trolley. The etiologies of the deformities in these five patients were two patients with idiopathic EOS, two patients with syndromic scoliosis (Prader-Willi syndrome and a child with dysmorphic feature with global hypotonia of unknown etiology), and one patient with neuromuscular scoliosis (cerebral palsy). The mean age of the serial casting and distraction-based patients was 4.5 years old (range, 0.9–8.5 years) compared to 6.5 years old (range, 3–8.6 years) for the modern Luqué trolley group. Mean preoperative major curves were 61° (range, 38–94°) and 60° (range, 45–75°) and decreased to a mean of 21°(range, 10–33°) and 35° (range, 23–46°), respectively. Mean follow-up was 4.5 years (range, 2.5–6 years) and 5 years (range, 3–8 years) for the two groups. At the last follow-up, the mean major curve had increased to 31° (range, 14–54°) in both groups. At 5 years post-operatively, four out of five subjects (80 %) had required revision surgery. Three had their initial self-guided growth implants converted to new distraction-based implants as they had outgrown the initial construct. A fourth patient, with syndromic scoliosis, required final spinal fusion before reaching skeletal maturity because the curve had progressed (54°) and had minimal remaining spinal growth (26 % expected). The fifth patient was still immature and growing. Comparing the two groups, the first treatment group had a total of 89 procedures over a 4.5-year period, with a mean of 7 procedures per patient and 1.7 procedures per year, per patient. In contrast, the modern Luqué trolley had a total of 9 procedures over a 5-year period, resulting in 1.8 procedures per patient and 0.3 procedures per year. In respect to spinal growth, after the mean follow-up of 5 years, the spine grew on average 67 % (range, 26–91 %) of expected growth.

At the 2013 Scoliosis Research Society's Annual Meeting, Mehdian et al. presented their experience with the self-growing rod (SGR) system in patients with neuromuscular scoliosis (Fig. 42.2) [23]. Their SGR system is a growth guidance construct and is, in effect, equivalent to the modern Luqué trolley. They reported a total of 15 consecutive patients (Table 42.1). There were eight male and seven female patients, with a mean age of 7.4 years (range, 4–9 years). The instrumentation extended from T2 to the pelvis (including sacrum) in all patients. The diagnosis included SMA type 2 in six patients, SMA type 3 in three patients, hypotonia in two patients, and congenital muscular dystrophy in four patients. The mean blood loss and percentage of blood volume was 523 ml/19.7 % (range, 420 ml/17–640 ml/26 %). The mean follow-up was 3.5 years (range, 2–6 years). The mean length of pediatric intensive care unit stay was 2.7 days (range, 2–6 days) and mean hospital stay was 9 days (range, 7–11 days). The mean operation time was 5.3 h (range, 4–8 h). The mean preoperative major curve was 69° (range, 40–110°), 16° (range, 6–20°) immediately after surgery ($p=0.001$), and slight loss of correction with a 18° Cobb angle (range, 7–41°) at final follow-up ($p=0.001$). The mean preoperative thoracic kyphosis was 75° (range, 57–98°), 23° (range, 15–34°) immediately after surgery ($p=0.001$), and 28° (range, 22–38°) at final follow-up ($p=0.001$). Patients maintained their sagittal alignment without the appearance of any junctional kyphotic deformity. The maintenance of correction was statistically significant (Table 42.2). The mean preoperative coronal balance was 12 cm (range, 7.5–16 cm), 4 cm (range, 1–6.5 cm, $p=0.005$) postoperatively, and 8 cm (range, 3.5–15 cm, $p=0.036$) at final follow-up. The mean preoperative pelvic obliquity was 35° (range, 28–41°), 5° (range, 0–14°, $p=0.001$) postoperatively, and 12° (range, 3–21°, $p=0.005$) at final follow-up. The values for both measurements were statistically significant at final follow-up. In respect to spinal growth, the mean preoperative T1–S1 height was 25 cm (range, 22–30 cm), 32 cm (range, 28–35 cm) postoperatively, and 37 cm (range, 32–42 cm) at final follow-up. The T1–S1 height change was statistically significant ($p=0.002$). The mean yearly growth of the spine was 1.4 cm (range, 0.7–2.5 cm). There were no lengthening procedures performed in any of the cases. These

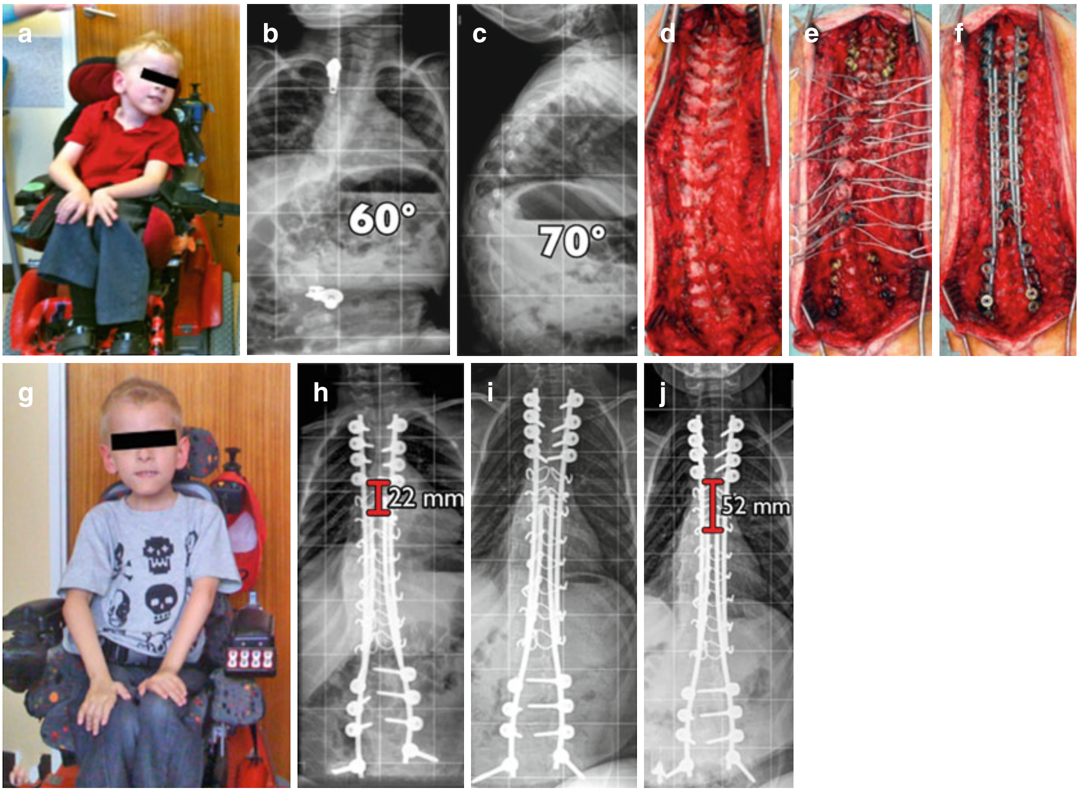

Fig. 42.2 Clinical example of a self-guided growth construct as described by Mehdian et al. treating an early onset neuromuscular scoliosis in a child with spinal muscular atrophy. (**a**) Preoperative clinical pictures. (**b**, **c**) Sitting AP and lateral x-rays pre-op. (**d**) Intraoperative pictures illustrating direction. (**e**) Multiple segmental sublaminar wires fixation points. (**f**) Intraoperative correction with four rods. (**g**) Postoperative clinical pictures. (**h**–**j**) Postoperative x-rays immediate, 1 year, 3 years, respectively, confirming spinal growth of 30 mm

results are markedly different than the unfavorable long-term result from Mardjetko et al. [22]. Mehdian et al. [23] also studied the impact of growth guidance surgery on the chest width and lung function. The mean preoperative chest width T6/T12 ratio was 0.8 (range, 0.7–0.9), 0.7 (range, 0.6–0.8, $p = 0.004$) postoperatively and 0.7 (range, 0.6–0.8) at final follow-up. The mean preoperative functional vital capacity was 64 % (range, 59–74 %), 67 % (range, 61–77 %) postoperatively, and 57 % (range, 50–61 %) at follow-up. Two of the 15 patients (13 %) experienced complications. One patient had failure of fixation due to distal screw pullout from the iliac wing and required revision surgery. A second patient developed spinal infection that was treated with antibiotics for 6 weeks.

42.4 Surgical Technique

For the modern Luqué trolley, patients are positioned prone on a radiolucent table under a total intravenous general anesthetic compatible with multimodality spinal cord monitoring. Preoperative planning is mandatory to plan the skin incision as well as the location of the gliding anchors. Classic midline incisions are to be made ensuring that no prominent spinal implant will be directly below the skin incision. Either one single skin incision is made spanning the entire planed instrumented spine (Fig. 42.3a). Two or three separate skin incisions can be made over the proximal, apical, and distal segments (Fig. 42.3b). Currently, only the Shilla system has been FDA approved as gliding anchors; it has a

Table 42.1 Control of spinal deformity of patients with early onset neuromuscular scoliosis treated with the self-growing rod (SGR) system

ID	Sex	Diagnosis	Complication	Age	Follow-up (years)	Preoperative scoliosis (degrees)	Final scoliosis (degrees)	Preoperative kyphosis (degrees)	Final kyphosis (degrees)
1	F	Hypotonia	None	9	6	40	7	58	22
2	F	SMA	Failure of fixation due to pullout from the iliac wing	9	6	60	41	98	38
3	F	Hypotonia	None	9	5	92	8	76	31
4	M	SMA	None	9	5	78	38	71	32
5	M	Muscular dystrophy	None	9	3	71	7	76	30
6	M	SMA	None	8	5	73	7	81	29
7	M	Muscular systrophy	None	6	4	68	30	89	29
8	F	SMA	None	6	3	72	16	63	31
9	M	Muscular dystrophy	None	8	2	60	11	71	26
10	F	SMA	None	6	4	40	7	57	22
11	M	SMA	Superficial wound infection that was treated with antibiotics	7	2	110	21	81	23
12	M	SMA	None	6	2	59	25	93	31
13	F	SMA	None	4	2	70	17	68	27
14	M	Muscular dystrophy	None	8	2	72	20	74	29
15	F	SMA	None	7	2	77	23	76	27
Mean				**7.4**	**3.5**	**69.47**	**18.53**	**75.47**	**28.47**

SMA spinal muscular atrophy

Table 42.2 Mean (range) of preoperative, postoperative, and final measurements of patients with early onset neuromuscular scoliosis treated with the self-growing rod (SGR) system

	Preoperative	Postoperative	Final
Scoliosis	69° (40–110°)	16° (6–20°)	18° (7–41°)
Kyphosis	75° (57–98°)	23° (15–34°)	28° (22–38°)
Coronal balance	12 cm (7.5–16 cm)	4 cm (1–6.5 cm)	8 cm (3.5–15 cm)
Pelvic obliquity	35° (28–41°)	5° (0.3–14°)	12° (3–21°)
T1–S1 height	25 cm (22–30 cm)	32 cm (28–35 cm)	37 cm (32–42 cm)
T1–S1 height growth	Average yearly 1.4 cm (0.7–2.5 cm)		
T6–T12 ratio	0.8 (0.7–0.9)	0.7 (0.6–0.9)	0.7 (0.6–0.8)
FVC	64 % (59–74 %)	67 % (61–77 %)	57 % (50–61 %)

FVC functional vital capacity

special locking cap that does not bind to the rods. There is also a trolley-gliding vehicle that is currently only available in Europe that captures the rod with a cable tie mechanism allowing for gliding. Other implants can be used in such a fashion allowing for certain gliding properties. The

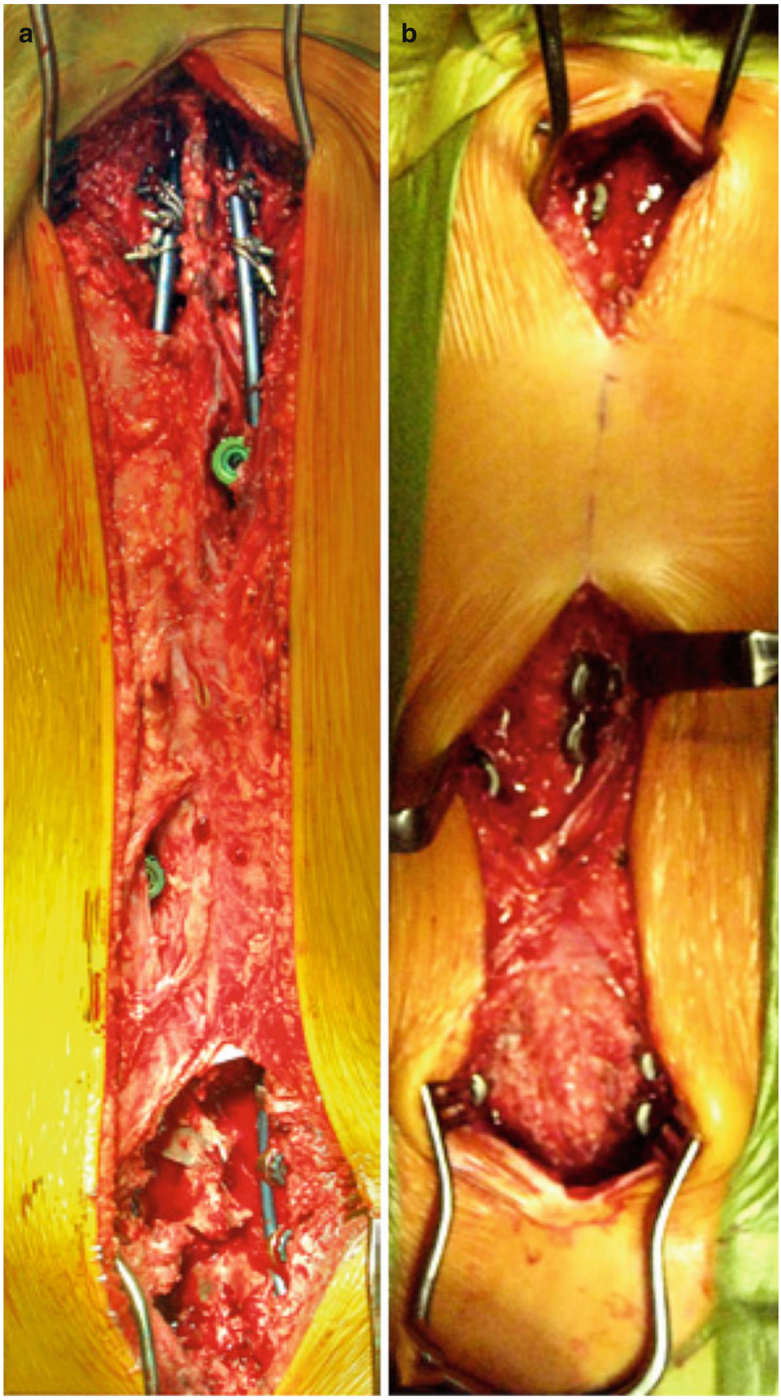

Fig. 42.3 Midline incisions: either one single skin incision spanning the entire planed instrumented spine (**a**), or two or three separate skin incisions over the proximally, apical and distal segments (**b**) can be performed

oldest segmental fixation is a sublaminar wire and it can be used as a gliding anchor. The other possibility is to purposely use a smaller diameter rod (5 mm) in a pedicle screw-based system designed to capture a larger diameter rod (6 mm). For example, the pedicle screws of the AO universal spine system can be used with its small stature AOUSS 5-mm rods. Obviously, using spinal instrumentation in this way is off-label and is not recommended by any of the manufacturers.

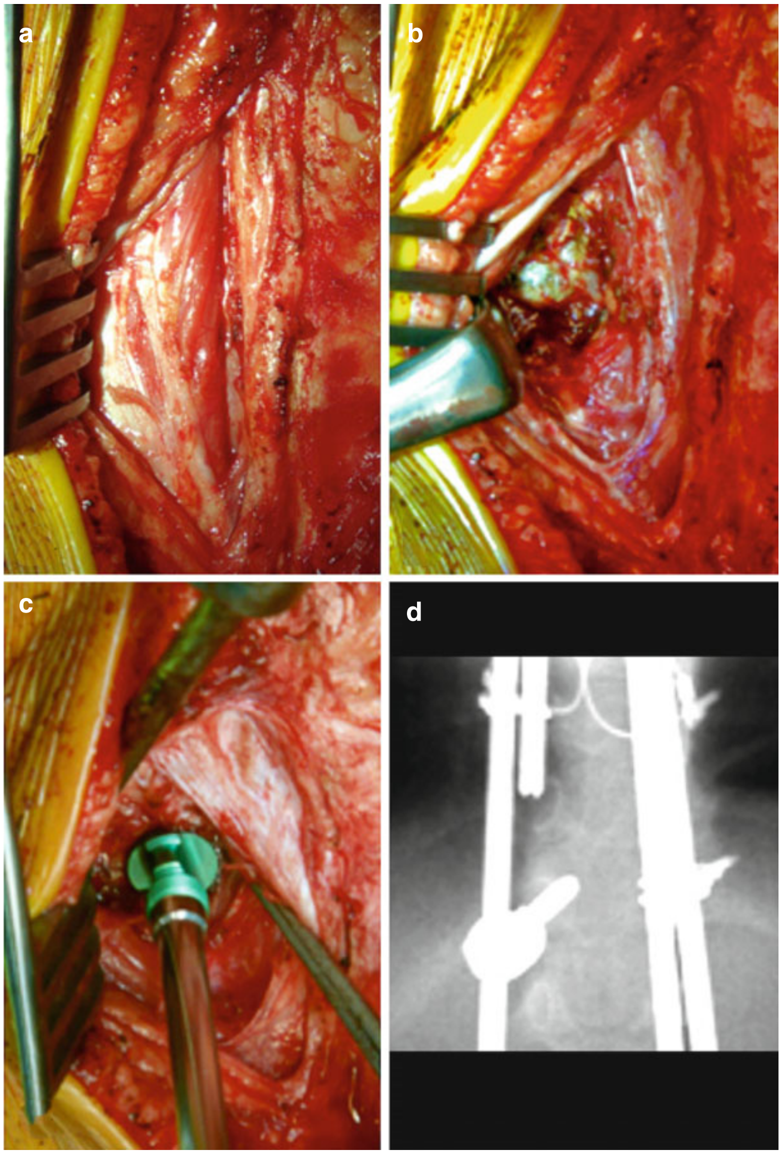

Fig. 42.4 The erector spinae are split with the multifidus and spinalis spinous process left medially with the longissimus and iliocostalis reflected lateral (**a**). Transverse process is visualized (**b**). Freehand or fluoroscopic-assisted gliding screws are inserted (**c**). Example of a gliding screw translating apex across midline (**d**)

The classic modern Luqué construct consists of fixed proximal and distal anchorage points. A classic subperiosteal dissection is performed at the proximal and distal segment, as these segments need to be fused to achieve long-term solid anchors. Fixed spinal anchors such as standard screws or hooks locked to the rods are inserted. The gliding spinal anchors (either gliding screws or sublaminar wires free to travel along the rods) are inserted through muscle-sparing "keyhole" dissections (see Fig. 42.3a, b). At the apex of the deformity, gliding anchors are placed for maximal apical translation and deformity correction. The dissection at the gliding anchors must be kept to a minimum using extraperiosteal and muscle-sparing techniques to avoid spontaneous fusion. In the lumbar spine, the gliding pedicle screws are inserted through a Wiltse approach sparing the joints and minimizing bony exposure. In the thoracic spine, the gliding pedicle screws are inserted laterally to the midline erector spinae, dissecting directly onto the transverse process avoiding exposure of the lamina (Fig. 42.4a, c). Pedicle screw insertion should be done with the

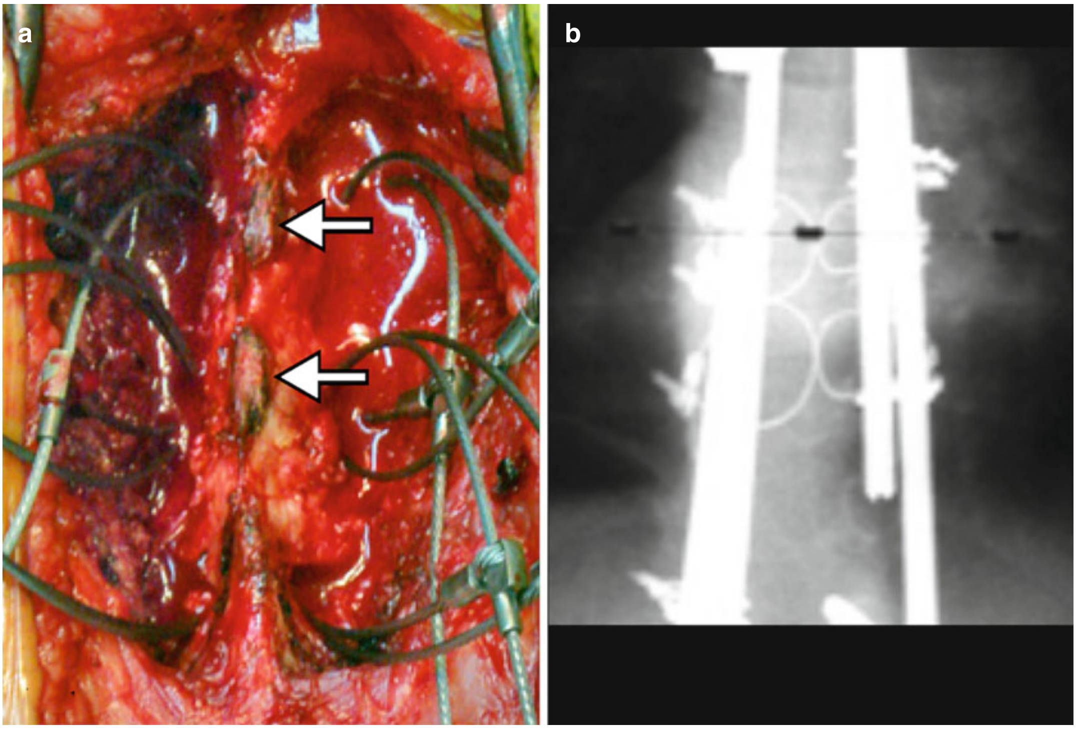

Fig. 42.5 Wires are inserted not via the standard midline ligamentum flavum resection but rather via small lateral laminectomy leaving the periosteum intact (*arrows*) (**a**). Example of apical sublaminar wires capturing the overlapping rods (**b**)

use of intraoperative imaging. Fluoroscopy can be used to confirm the pedicle entry point, and using a freehand technique, the gliding screws can be inserted at strategic points allowing for maximal apical translation. These gliding screws capture a 5-mm rods with a locking cap designed for 6-mm rods, thus permitting motion. At segments where sublaminar titanium cables are to be passed, the dissection is carried from midline to the medial border of the facet. Careful attention should be paid in order to leave the periosteum on the bone even with some muscle still attached. Dissection is to be performed with bipolar cautery and forceps at hand to control blood loss and minimize disruption of the periosteum. Avoid removing the spinous processes to prevent stripping the periosteum off the lamina and creating a raw bone surface. Small lateral laminectomies are to be done leaving the periosteum intact, while giving access to the ligamentum flavum. Once the central ligamentum flavum is removed, passage of sublaminar cables can be performed (Fig. 42.5). Once the fixed and gliding anchors are placed, two pairs of 5-mm titanium rods are tunneled in a subfascial/intramuscular fashion (below the fascia, above the periosteum) from the opened proximal and distal incisions. Each rod needs to only have one end rigidly anchored to the spine. In the intermediate segments, a series of gliding spinal anchors maintains the correction by keeping the rods parallel and engaged. As the spine grows, the rigidly proximally fixed rods will move away from the distally fixed rods (Fig. 42.6a). One can also only use two rods rather than four and have them fixed distally and have the spine grow off the proximal end (Fig. 42.6b). Correction of the spinal deformity is achieved with either a classic rod derotation maneuver (Fig. 42.7a) or an apical translation reduction maneuver (Fig. 42.7b) or in combination. As the rods are tunneled and partially engaged in the fixed and gliding anchors, and by rotating or translating

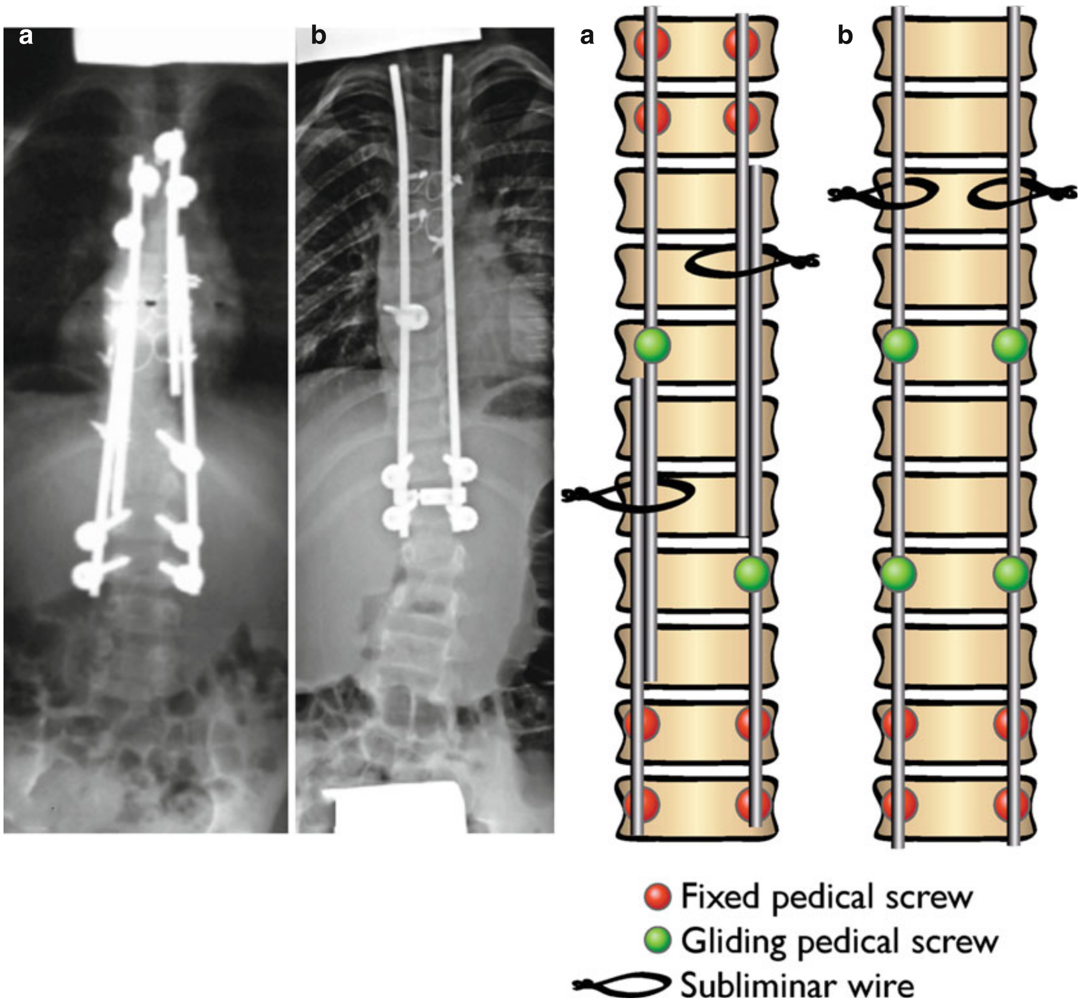

Fig. 42.6 Radiographic and schematic differences between two self-growing constructs: the modern Luqué trolley (**a**) and an alternative-guided growth construct (**b**). A series of gliding spinal anchors maintains the correction by keeping the rods parallel and engaged. As the spine grows, the rigidly proximal-fixed rods will move away from the distally fixed rods

the rods, the correction is achieved. The goal is to ensure that the four rods are parallel to each other. The number of gliding anchorage points will influence the ability to correct and maintain the deformity. If the number of the gliding anchors is kept to a minimum, the risk of spontaneous fusion is minimized. However, the risk of residual and recurrence of the spinal deformity is greater (Fig. 42.8). In contrast, if every spinal segment is instrumented then there is a lower risk of curve progression but a higher risk for growth retardation as spontaneous fusions may occur. The key is to have an adequate number of gliding anchors to translate the apex of the deformity toward midline, ensuring adequate correction and control of the spinal deformity without inducing spontaneous fusion. Different gliding constructs can be tailored to different spinal deformities (Fig. 42.9). This case illustrates the power of cantilevering a rod across the apex of a deformity. The spine was captured with fixed spinal anchors proximally (hooks and screws) and was then cantilevered across the two eggshell resections of the hemivertebra with an apical gliding screw

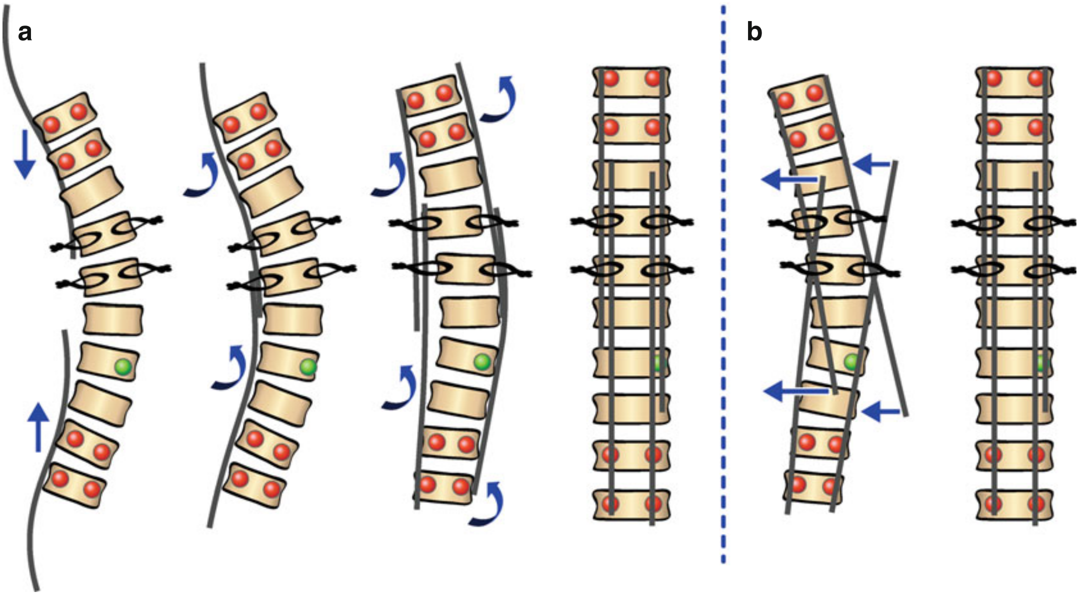

Fig. 42.7 Schemes of the technique of reduction. Correction relies on rod rotation and apical translation. Rods are attached to proximal and distal anchors. The latter are then cantilevered and/or rotated across the midline achieving parallel end vertebra

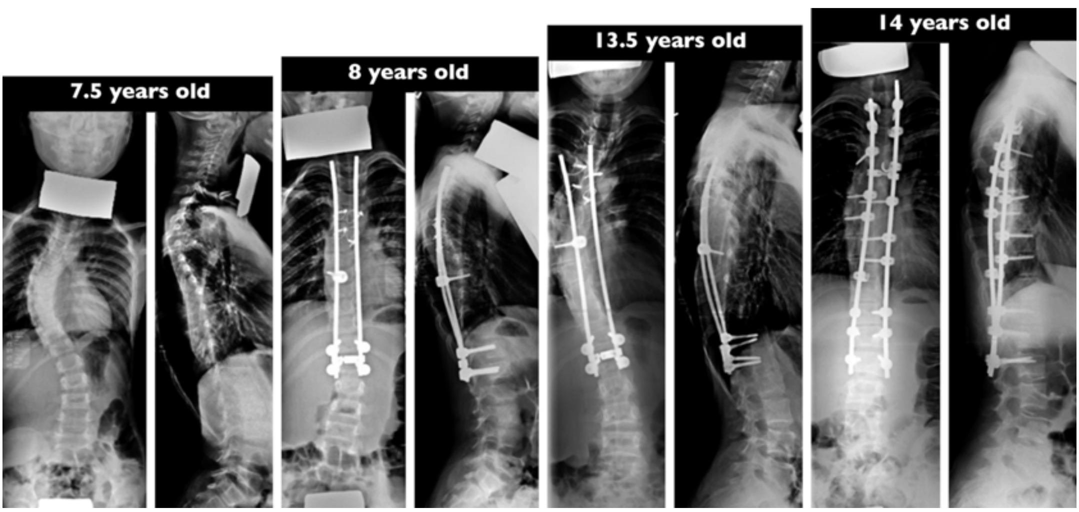

Fig. 42.8 Clinical example of a modern Luqué trolley with inadequate numbers of gliding anchors. Initially, deformity appeared under control. However, over the next 4 years, due to inadequate number of gliding anchors, deformity recurred requiring formal posterior spinal fusion observed 6 months following surgery (8 years old). Five years post-initial trolley (13.5 years old), a loss of proximal fixation, growth across the instrumentation, and a 75 % of normal growth without any lengthening surgery could be observed. Final fusion occurred at 14 years of age

and a set of gliding anchors distally. Follow-up radiographs confirm ongoing growth of the spine. Initially, the left rod extended below the disk of L5/S1 and now is at the level of the L5 pedicle screw. On the right side, a VEPTR 2 implant was used without the locking mechanism that allows for passive-guided growth. The gradual appearance of space within the male-female inlay of the

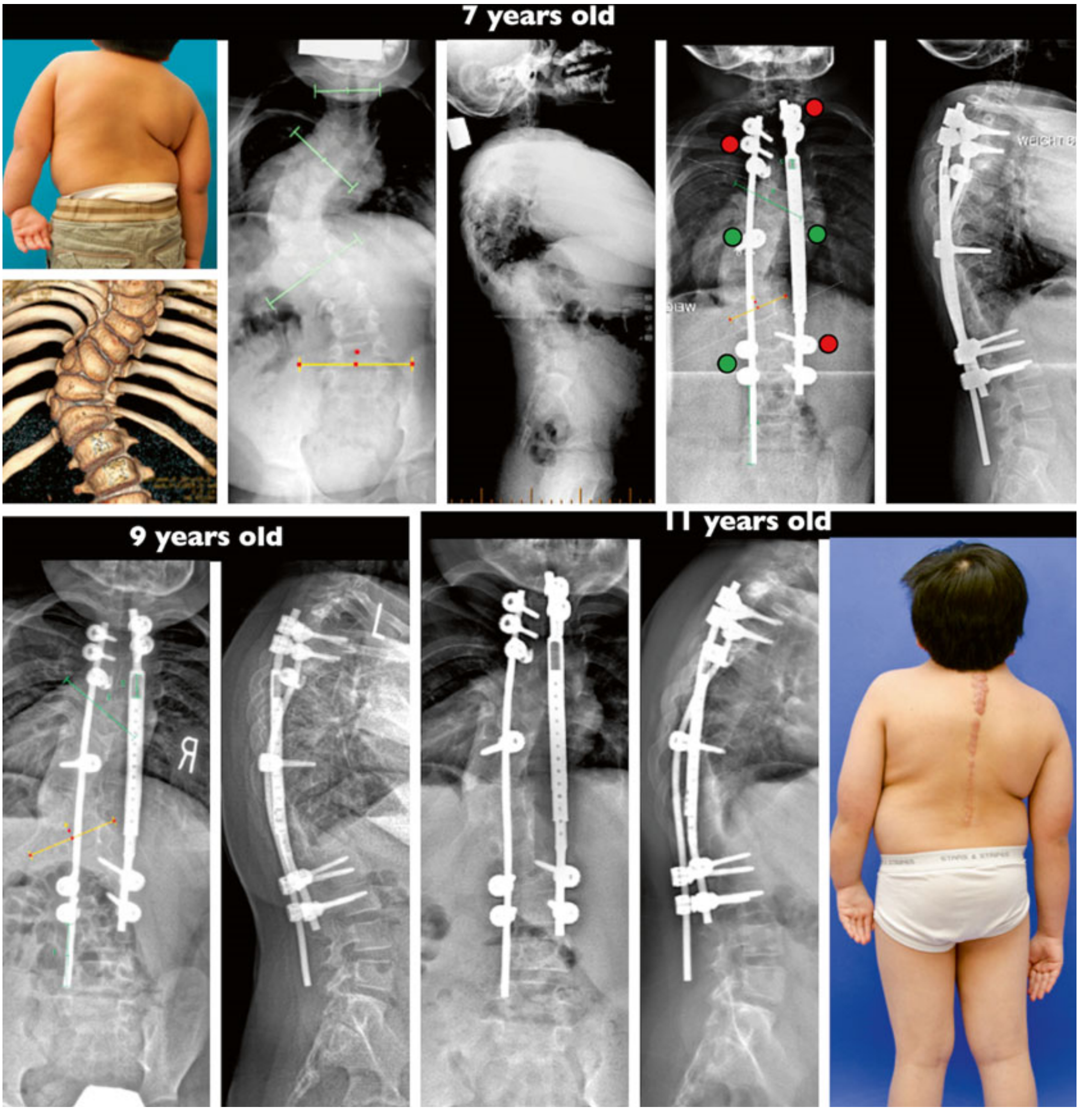

Fig. 42.9 Modified modern Luqué trolley treating early onset scoliosis in a 6-year-old male patient with severely rigid congenital scoliosis with radial hypoplasia. Hybrid construct with a left-sided proximally fixed rod with mid- and distal gliding screws. The right-side construct is a VEPTR used off-label that is not locked, thus allowing for self-growth

VEPTR implants represents the spinal growth across the instrumented spinal growth.

The surgical technique, as described by Mehdian et al. [23], has a similar four 5-mm rod construct with solid proximal and distal fixed anchor having more than six fixation points, which distally includes the pelvis. It differs from the modern Luqué trolley as to the more extensive classic spinal surgical dissection where every intercalated vertebra is exposed and captured with sublaminar wire (Fig. 42.2). Despite such extensive dissection, multiple cases have shown ongoing spinal growth (Fig. 42.10). Sublaminar wiring can be time consuming and possibly risky. Two 5-mm stainless steel rods are then contoured to accommodate thoracic kyphosis and lumbar lordosis. Rods are secured to the proximal and distal screws on either side or the middle section by sublaminar wires. Pelvic fixation should always

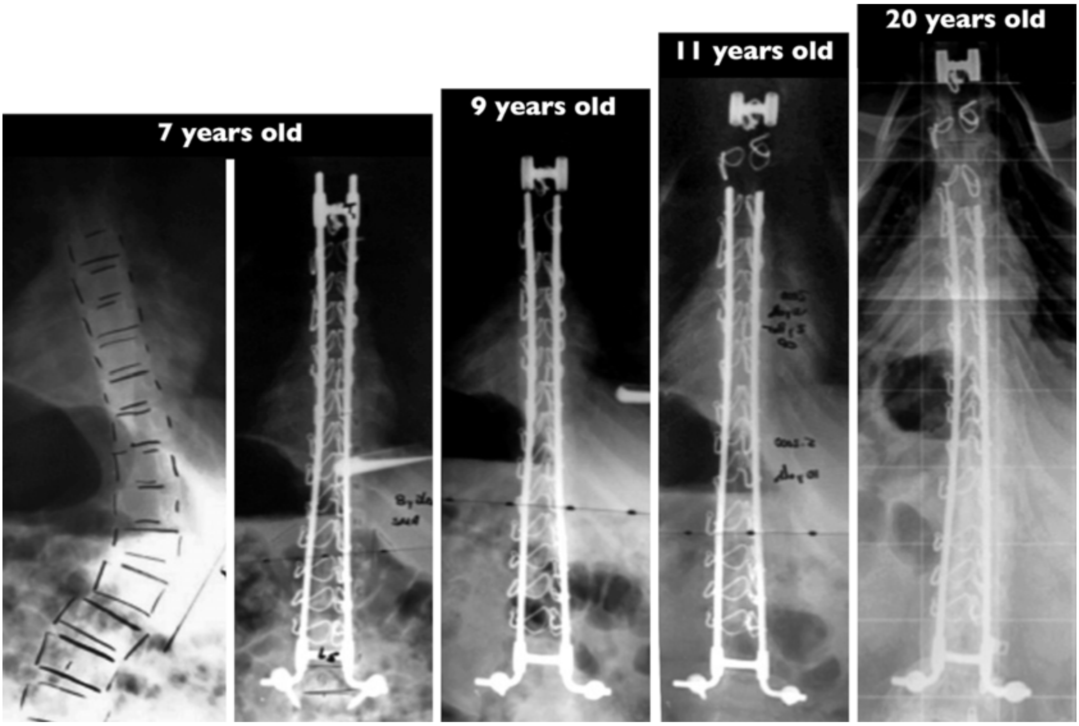

Fig. 42.10 Evidence of guided growth (10 cm) over a 13-year follow-up period

be considered in children with neuromuscular scoliosis due to the collapsing nature of the deformity and the propensity to pelvic obliquity [24]. The extension of the instrumentation from T2 to the pelvis not only corrects the pelvic obliquity but also prevents failure of distal fixation as it reduces the chances of loss of sagittal and coronal balance in the long term. Additionally, fixation to the pelvis in patients confined to the wheelchair is beneficial for maintaining the sitting balance during their life span. We feel that fixation to the pelvis is preferable in all patients with neuromuscular condition as this reduces the chances of loss of sagittal and coronal balance in the long term due to paralytic nature of the deformity.

42.5 Discussion

Guided growth construct is one among many surgical options for the management of EOS. This surgical technique is technically demanding and requires strict patient selection to ensure a predictable outcome. The use of sublaminar wiring can be time consuming and has possible risk in the hands of inexperienced surgeons. The risk of neurological complications has been well published in the literature [25–27], but in the hands of experienced surgeon, such complications are rare [28–30]. Passing the rods, engaging the fixed and gliding anchors through the muscle-sparing incision while achieving spinal correction, requires significant experience in deformity surgery. New gliding implants are starting to be available and may help to simplify the surgical technique and hopefully negate the need of sublaminar wires.

Patients with comorbid factors carrying additional risks associated with repetitive anesthesia are the ideal candidates for this technique. Patients with SMA and any other flaccid neuromuscular scoliosis are good candidates for this technique. Seeing that any attempt at prophylactic treatment with early bracing in these patients has not prevented curve development nor progression [7], and that early spinal fusion impacts negatively on the development of the lungs and can cause death due to pulmonary failure [31, 32], this technique offers the best option to correct and control long c-shaped paralytic scoliosis during their growth and to an extended period.

Another favorable factor predicting good surgical outcome using this technique is the ability to translate the apex of the spinal deformity back to the midline and reestablishing the normal axis of spinal growth. The risks of add-on below the corrective growth-sparing implant are significant. Hence, having solid proximal and distal fixations is also very important. Even though we tend to try to keep our proximal and distal anchors to a minimum, we often regret not going just a bit longer to ensure no add-on occurs. If patient's morphology allows, the addition of cross-link is suggested across the fixed anchors, particularly if the pelvis is not incorporated into the distal anchor. In all patients with neuromuscular scoliosis, fixation to the pelvis is preferable as this reduces the chances of loss of sagittal and coronal balance in the long term due to the paralytic nature of their deformity. In such distal fixation, cross-links are not needed.

Passive-guided growth seems to be safe with a low complication rate. As predicted, there are fewer surgeries using this technique and fewer hardware failures. Despite no active distraction, all patients grow across the instrumented segments. We recommend that management of EOS, and particularly neuromuscular scoliosis, should be performed in a specialized center, where a high volume of procedures are carried out, in order to maintain safety and prevent significant complications. Having good medical support staff to deal with these high-risk patients is essential to achieve good results [33].

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