Chapter 9
Modern Trolley Growth Guidance for Early Onset Scoliosis

Jean A. Ouellet and Catherine E. Ferland

Case Presentation

History and Physical Examination

A 5-year-old boy presented with his parents to the outpatient scoliosis clinic for evaluation of his spinal deformity. The parents had noted that over the last 2 years, they were having more and more difficulties keeping him upright in his stroller and his wheelchair. Patient was known to have a severe axonal neuropathy that had led to his progressive neuromuscular scoliosis. His past medical history was unremarkable during the prenatal period, uncomplicated birth history, though it was noted to be quite hypotonic at birth. Patient has had recurrent pneumonia since birth thought to be secondary to poor cough. A series of investigations, including muscle and nerve biopsy, were inconclusive with an ill-defined diagnosis

J.A. Ouellet, MD (✉) • C.E. Ferland, PhD
Department of Paediatric Surgery, McGill University Health Centre and Shriners Hospital, Montreal, QC, Canada

Department of Anesthesiology, McGill University Health Centre and Shriners Hospital, Montreal, QC, Canada
e-mail: jaouellet@hotmail.com

R. El-Hawary, C.P. Eberson (eds.), *Early Onset Scoliosis*,
https://doi.org/10.1007/978-3-319-71580-3_9

of diffuse axonal neuropathy that appeared to be nonprogressive. At baseline, the patient had a mild developmental delay and was able to crawl in the house, although he required a wheelchair to mobilize outside for any long distance. Patient had no prior orthopedic issues and has never had any prior surgeries.

Physical exam did not reveal any dysmorphic features. The patient was sitting with an obvious pelvic obliquity and a global kyphoscoliosis and fairly good head control. Reflexes were diminished both in the upper and lower extremities. Neither clonus nor any Babinski could be elicited. Patient was small for stated age with a low body mass.

Lower extremity exam did not reveal any contractures and had voluntary motor function of both upper and lower extremities with diminished tone and strength throughout. Sensation appeared to be intact.

Diagnostic Studies

Serial radiographs revealed a progressive collapsing kyphoscoliosis (Figure 9.1). Preoperative imaging including the supine bending films revealed a flexible left thoracolumbar curve measuring 75° able to be reduced to 35° on bending films with leveling of the pelvis (Figure 9.2).

Management Chosen

In light of his poor respiratory status, the patient's family wished to avoid repetitive general anesthetics required for repetitive surgical interventions. After discussing different options with the family, it was decided to proceed with a growth guidance spine-based construct in keeping with modern Luque trolley concepts. The concept of self-growing rods by using VEPTR rods (DePuy Synthes, Raynham, MA) is an off-label technique. One intentionally does not place the locking clips, which allows for expansion of the telescopic rods as the spine grows. The added benefits of using this

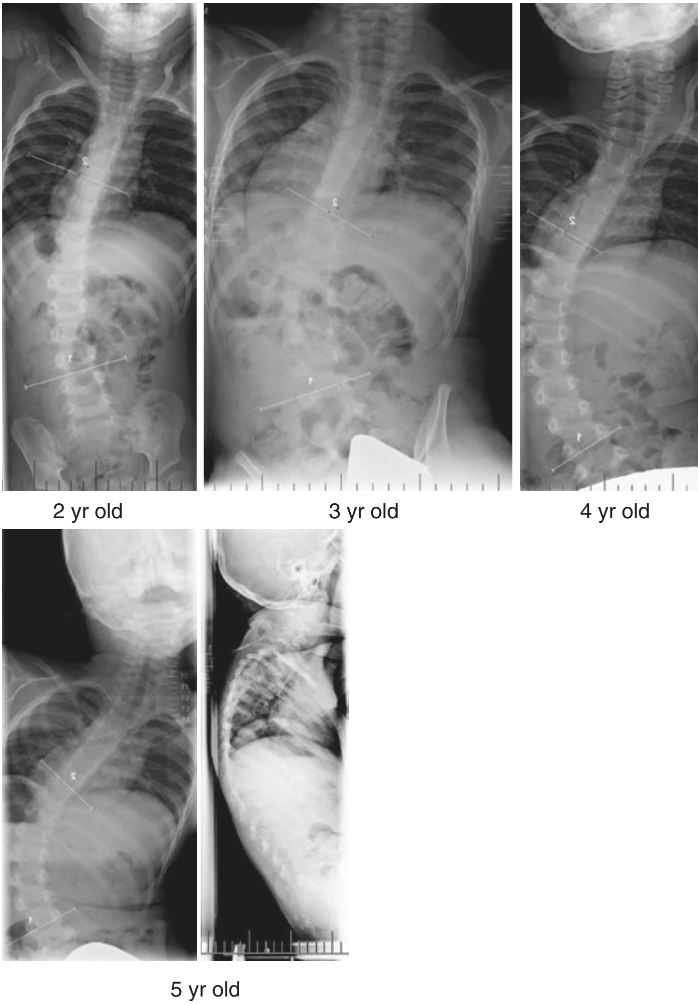

FIGURE 9.1 Serial X-rays from the age of 2–5 years of age illustrating that despite bracing, this child developed a progressive collapsing kyphoscoliotic deformity

implant are that it is extremely robust and also confers some anti-rotational stability because the I-beam design of the VEPTR minimizes rotation.

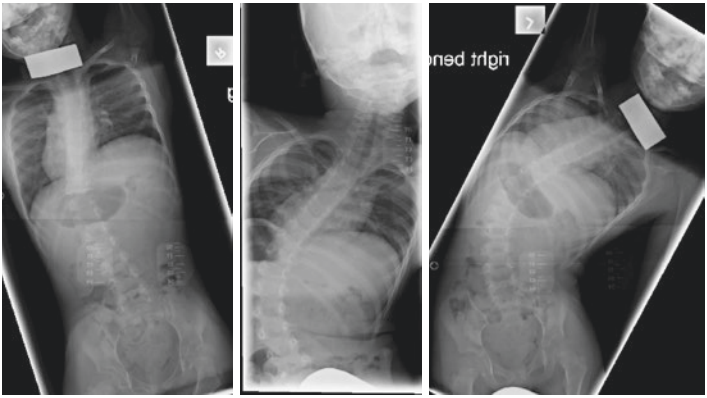

Figure 9.2 Preoperative radiographs illustrate a flexible left thoracolumbar curve

Surgical Procedure

The patient, under a general anesthetic on a radiolucent table with appropriate bolsters, was prepared and draped in a sterile fashion exposing the entire spine. Using intraoperative fluoroscopy, the location of the fixed proximal and distal anchor points were marked on the skin (Figure 9.3a, b). The pedicles of the apical vertebra, as well as all planned location of gliding anchors, should be identified by fluoroscopy to minimize surgical exposure. Using a midline incision, a classic subperiosteal dissection was performed to insert bilateral pedicle screws into T3 and T4 proximally and into L4 and L5 distally (Figure 9.3c, d). These segments were decorticated, and a formal interlaminar and intra-articular fusion was undertaken. Great care was taken to ensure that each fixed angle screw was perfectly placed both in the sagittal and coronal plan to facilitate rod coupling. In addition, pedicle screw diameter is carefully chosen to fill the lumen of the pedicle to optimize immediate fixation (Figure 9.3d).

Once the proximal and distal fixed anchors were placed, we turned our attention to capturing the apical vertebra. For the gliding anchors, preoperative planning and execution are crucial. Incisions must be planned to ensure that no incision lies directly over any spinal implant. Location and density of

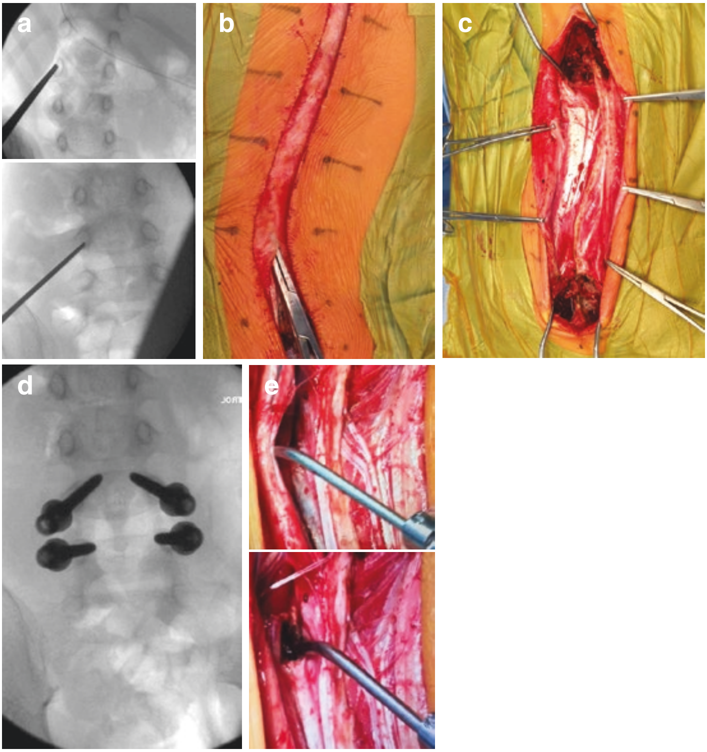

Figure 9.3 Using fluoroscopy, (**a**) Location of the fixed distal and proximal anchor points are marked on the skin. (**b**) A midline skin incision is made along the entire planned instrumented spine. (**c**) Subperiosteal dissection is performed at the proximal and distal fixation. (**d**) Proximal and distal fixed anchors must be perfectly placed. If pedicle screws are used, they should fill the lumen of the pedicle and should have some convergence of the screw to add purchase. (**e**) A Wiltse type approach is performed to ensure a thick layer of muscle and fascia over the gliding anchors without exposing the bone

gliding anchors are dictated by the type and the severity of the deformity. Considering this deformity was very flexible, we choose to only capture the apical vertebra at T12. The overall number of vertebra to be captured by gliding anchors is related to the rigidity of the curve. Flexible curve requires little gliding anchors, while slightly more stiff curves should have greater gliding anchors. Care must be taken not to insert too many gliding anchors as the risk of spontaneous fusion increases. The incision was made directly over the spinous process of T12, thus avoiding the risk that an implant be located below the incision. Once the skin was incised, the fascia was open along the midline and an oblique transmuscular dissection was taken down toward the transverse process on the convexity of the curve. This left a good cuff of muscle and fascia above the planned implant, still ensuring that there is still a layer of the paravertebral muscles and periosteum covering the lamina to avoid spontaneous fusions (Figure 9.3e).

Specific to this case, we used a "post" technique that allowed us to cantilever the apical vertebra across midline which maximizes correction. This was possible by placing a pedicle screw on the convexity of the apical vertebra. This post is a standard non-articulated pedicle screw that is *not* connected to the rod but acts as a fulcrum for the rod to reduce the deformity. The convex VEPTR rod is attached to the proximal anchor points, tunnelled in a transmuscular fashion, and is then translated to align with the distal anchor points. The "post", acting as a fulcrum, translates the apex and corrects the deformity. One must take advantage of the kyphotic sagittal shape of the rod to facilitate capturing the apex. By rotating the rod in the appropriate sagittal orientation, the coronal deformity is corrected as the distal end of the rod is cantilevered and connected to the distal anchors.

After the convex rod was inserted, the concave rod was inserted and an apical sublaminar wire was tensioned in order to achieve additional correction. Of note, in an effort to avoid spontaneous fusion, this sublaminar wire was inserted by performing two small laminotomies in T11 and L1 while avoiding taking down the interlaminar ligament.

Wounds were thoroughly irrigated, and meticulous facial closure above the implants was done taking care not to injure the soft-tissue envelope covering the implants.

Clinical Course and Outcome

This patient has had only one surgical procedure at 5 years of age and has been followed every sixth month for the last

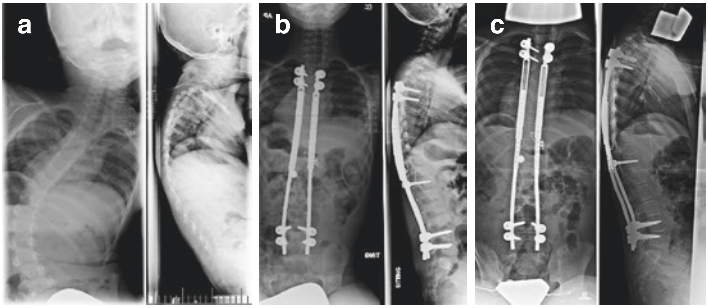

Figure 9.4 (**a**) Preoperative AP/Lat X-ray at the age of 5 years. (**b**) Immediate postoperative X-ray illustrates the power of the "post" cantilever reduction technique. (**c**) Postoperative X-ray at the age of 11 years without the need for any lengthening or any revision surgery. Curve remains controlled, and the spine has grown 5 cm across the instrumented spine as illustrated by the space now seen in the female VEPTR chamber

6 years. Immediate postoperative X-rays confirm almost complete resolution of his scoliotic deformity with maximal apical translation. The subsequent imaging illustrates that without any distraction or revision surgeries, the VEPTR has expanded while maintaining the scoliotic deformity to a minimum (Figure 9.4). This patient has achieved 95% of his expected growth with no revision surgeries, no complications, and complete control of his spinal deformity. At last follow-up, a 10° left -sided curve from T1 to L5 remains with no residual pelvic obliquity. T1–S1 height gained from pre-initial surgery to final follow-up was 8 cm, with 5 cm gained across the instrumented spine from initial postop to final follow-up.

Clinical Pearls and Pitfalls

- Patient selection is crucial to have a predictable outcome with modern Luque trolley constructs.
- Patients with hypotonic collapsing spinal deformities are ideal candidates for modern Luque trolley technique.
- Flexible curves and apical translation are crucial to have good outcome. Capturing and controlling the apex is essential.

- Meticulous preoperative planning and execution is key to avoid complications in this patient population.
- If the apex is not repositioned to midline, curve progression will occur and expected spinal growth will be less.
- By avoiding repetitive lengthening procedures, the overall complication rates are lower.

Literature Review and Discussion

Eduardo Luque described the first self-growing rod construct in 1977 [1] followed by Moe in 1984 [2]. They used segmental sublaminar wires and U- or L-shaped rods to treat young patients (<11 years) that had severe scoliosis that did not respond to bracing. The Luque trolley was described as a rigid internal brace that would allow the spine to grow along the rods as the spine was instrumented but not fused. Luque published his early results showing that the technique had good corrective power decreasing average scoliosis from 72° to 22° while still allowing on average 2.5 cm growth over 2 years [1]. Subsequent long-term results showed poor maintenance of spinal growth (range, 32–49% of expected growth) [3, 4], high spontaneous fusion (range, 4–100%) [3], and a high implant failure rate of 32% [5]. In 1999, Pratt et al. published a 5-year follow-up retrospective study looking at 26 patients with a diagnosis of EOS treated with Luque trolleys where 18 had anterior apical epiphysiodesis in addition to the posterior segmental growth guidance technique. They concluded that the Luque trolley prevented curve progression (from 48° to 25° to a final scoliosis of 43°). They also showed that the Luque trolley allowed for 50% of expected growth if the epiphysiodesis was not done. The addition of the anterior epiphysiodesis improved curve control by decreasing the average preop scoliosis from 65° to 26° to a final scoliosis of 32°; however, the apical hemiepiphysiodes had worse growth potential with an average of 32% of expected growth [5]. Complications remained high mainly secondary to implant failures. The authors concluded that there was a need for improved instrumentation and for new surgical measures to allow better spinal growth and curve control. Patients who did poorly with the classic Luque trolley were those with large rigid curves preoperatively and/or patients who had large residual postoperative curves.

In 2011, Ouellet and et al. published a small series of five patients with EOS treated with a modern version of the Luque trolley that had been followed for 4.5 years. They described a new surgical technique that instrumented the apex of the deformity via minimal invasive muscle sparing exposure coupled with solid proximal and distal anchors [6]. In contrast to the original Luque trolley, where every level was captured with a sublaminar wire and bound to the rod (Figure 9.6a), the new approach used modern spinal implants (pedicle screws) for solid proximal and distal fixed spinal anchors. They used off label modern spinal implants to allow for gliding anchors. For example, using pedicle screws designed for a 6 mm rod were used with a 5 mm rod allowing for motion. At the apex, these mismatched oversized pedicle screws or sublaminar wires allow the rods to glide across the apex (Figure 9.6b). Off-label use of the VEPTR, as illustrated in Figure 9.4, was also used (Figure 9.6c). With a mean follow-up of 4.5 years, the scoliotic deformity on average was decreased from 61° (range, 38–94°) to a mean of 21° (range, 10–33°) with gradual increase back to 35° at the last follow-up. During the same interval, the spine grew on average 67% (range, 26–91%) of expected growth [6]. This small case series demonstrated that self-lengthening growth guidance systems could indeed be successful in reducing the overall number of surgical procedures and to prevent progression of spinal deformity, while maintaining spinal growth. We recently reviewed an additional ten patients with self-growing constructs and found similar results with an average scoliosis reduction of 50% at an average 4-year follow-up. Patients' spines grew on average 63% of the calculated growth and were found to be inversely proportional to the residual postoperative Cobb angle (Pearson's R score of −0.546; $p = 0.035$). Residual Cobb angle less than 25° had close to normal expected spinal growth and had the least amount of correction loss (Table 9.1).

Self-growing rod constructs can vary significantly depending on the type and rigidity of curve. In general, we recommend that a greater number of gliding anchors are used above and below the apex for large deformities. However; if there are too many anchors used, there is a greater risk of spontaneous fusion. For such large and rigid deformities, then classic dual growing rods requiring active distraction may be more appropriate [7, 8]. One can use off-label modern spinal implants to achieve gliding construct as the case we illustrated (Figure 9.4) or use specific implants that have been developed to allow for gliding anchors. Medtronic (Medtronic, Memphis, TN) has obtained FDA approval for its Shilla screws, while DePuy Synthes (Raynham, MA) has an EU mark for the trolley gliding vehicle (TGV) (Figure 9.5). Via the Health Canada's Special Access Program, trolley gliding vehicles are available in Canada. The advantage of using such pedicle-based gliding anchor is its low-profile rod capturing mechanism. To avoid spontaneous spinal fusion, it is critical to keep the rods away from the lamina; hence the gliding screws must be left proud. However, the screw heads must not be prominent as patients with EOS often have little muscle mass and subcutaneous tissue. In addition, the system has been developed with the intent to have the least

Figure 9.5 (**a**) Five-year-old girl with Prader-Willi that failed conservative treatment for her progressing 50° neuromuscular scoliosis. (**b**) New gliding implant: trolley gliding vehicle. It is a pedicle screw with a PEEK cable tie and a ultrahigh-molecular-weight polyethylene liner that captures the rods. (**c**) Transmuscular insertion of the trolley gliding anchors. (**d**) Intraoperative photograph of the final construct with the proximal and distal fixed anchors at T3/4 and L3/4 and gliding anchors at T7,10, and 12. (**e**) Intraoperative X-ray showing the three gliding anchors capturing the apex of the deformity. (**f**) Postoperative X-rays 2 years after surgery, no revision nor lengthening surgery. The spine has grown 1.5 cm across the 10 instrumented vertebra representing 100% of expected growth based on Dimeglio calculation (2 year × 10 vertebral × 0.7 mm = 14 mm)

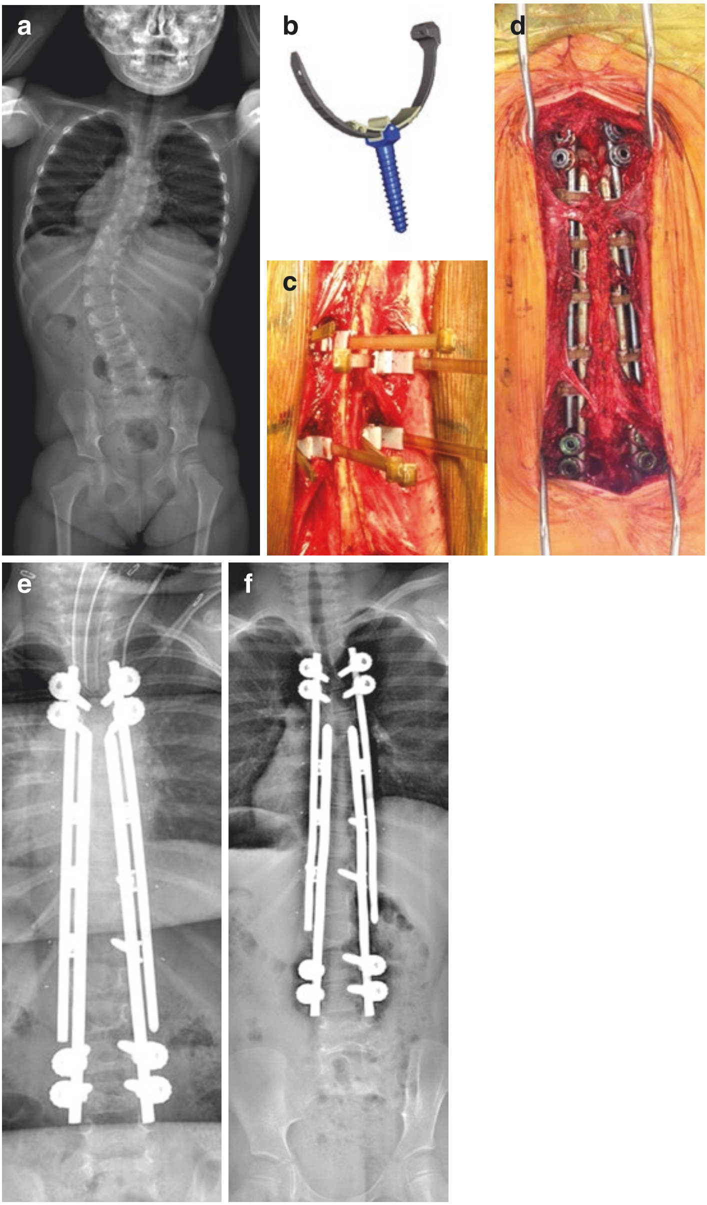
a
b
c
d
e
f

Table 9.1 Instrumented spinal height gain in cm per year of follow-up

Group	PO Cobb range	Mean (cm)	*N*	Std. deviation	Minimum (cm)	Maximum (cm)
1	≤15	2.41	2	2.34	0.76	4.06
2	15.1–25.0	1.44	4	0.61	0.62	2.08
3	25.1–35.0	0.51	6	0.29	0.03	0.91
4	35.1–45	0.47	1	NA	0.47	0.47
5	>45	0.27	2	0.38	0.00	0.53
	Total	0.98	15	1.02	0.00	4.06

resistance across the gliding parts. The rods have been highly polished and are captured by a lined polyetheretherketone (Peek) cable tie with ultrahigh molecular weight polyethylene (UhmwPE). Both systems have been tested in animals showing the systems grow with little to no local inflammatory response [9, 10].

Granted that both the Shilla and the modern Luque trolley are guided growth techniques, they are technically as well as conceptually different. The Shilla-guided growth system is based on a two-rod construct with apical fusions while having the end vertebrae grow away from the apex. In contrast, classic modern Luque trolley relies on solid proximal and distal anchors (similar to those used with traditional spine-based growing rods) with intercalated apical gliding anchors translating the apex back to midline with a four-rod construct (Fig 9.6d). Long-term clinical follow-up remains sparse on either constructs; however guided growth surgery remains an attractive option for specific patients with early onset scoliosis. Skeletally immature patients (younger than 10 years old with open triradiate cartilage) with collapsing progressive flexible scoliosis who are unable to tolerate repetitive anesthesia are ideal candidate for the modern Luque trolley.

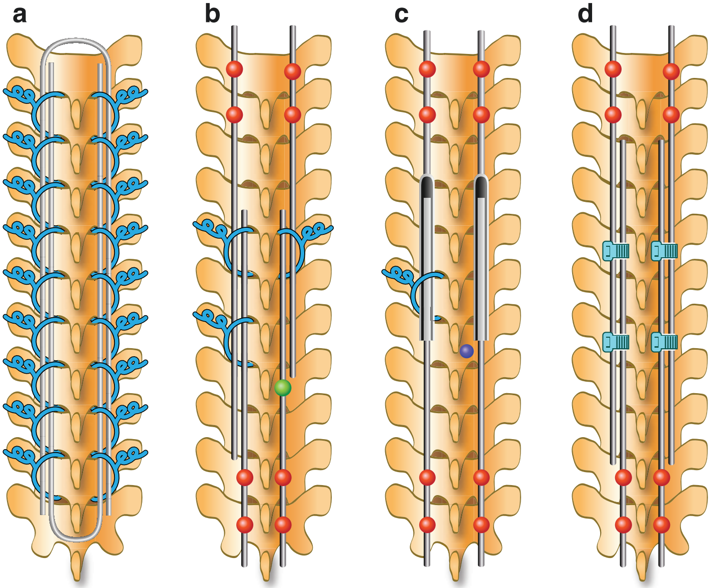

FIGURE 9.6 (**a**) Original Luque trolley. No segment of the spine is fused, but every level is captured with a sublaminar wire and is bound to the rod. (**b**) Modern Luque trolley with off-label use of mismatched oversized pedicle screws and sublaminar wires allowing the rods to glide across the apex. (**c**) Modern Luque trolley with off-label use of an unlocked VEPTR and a post allowing apical translation. (**d**) Modern Luque trolley with new apical gliding spinal implant—trolley gliding vehicle

References

1. Luqué ER, Cardoso A. Treatment of scoliosis without arthrodesis or external support: preliminary report. J Orthop Transl. 1977;1:37–8.
2. Moe JH, Kharrat K, Winter RB, et al. Harrington instrumentation without fusion plus external orthotic support for the treatment of difficult curvature problems in young children. Clin Orthop Relat Res. 1984:35–45.
3. Yang JS, McElroy MJ, Akbarnia BA, Salari P, Oliveira D, Thompson GH, Emans JB, Yazici M, Skaggs DL, Shah SA, Kostial PN, Sponseller PD. Growing rods for spinal deformity:

characterizing consensus and variation in current use. J Pediatr Orthop. 2010;30(3):264–70.
4. Mardjetko SM, Hammerberg KW, Lubicky JP, Fister JS. The Luque trolley revisited. Review of nine cases requiring revision. Spine. 1992;17(5):582–9.
5. Pratt RK, Webb JK, Burwell RG, Cummings SL. Luque trolley and convex epiphysiodesis in the management of infantile and juvenile idiopathic scoliosis. Spine. 1999;24(15):1538–47.
6. Ouellet J. Surgical technique: modern Luque trolley, a self-growing rod technique. Clin Orthop Relat Res. 2011;469(5):1356–67.
7. Skaggs DL, Akbarnia BA, Flynn JM, et al. A classification of growth friendly spine implants. J Pediatr Orthop. 2014;34:260–74.
8. Thompson GH, Akbarnia BA, Campbell RM Jr. Growing rod techniques in early-onset scoliosis. J Pediatr Orthop. 2007;27:354–61.
9. McCarthy RE, Sucato D, Turner JL, et al. Shilla growing rods in a caprine animal model: a pilot study. Clin Orthop Relat Res. 2010;468(3):705–10.
10. Ouellet JA, Ferland CE, Klein K, Racloz G, Klein K, Richter H, Steffen T, von Rechenberg B. Evaluation of the modern Luque trolley construct for treatment of early onset scoliosis using a gliding implant in an immature animal model. Clin Spine Surg. 2017;30(4):E460–5.