

# A brief overview of 100 years of history of surgical treatment for adolescent idiopathic scoliosis

Carol C. Hasler

Received: 25 February 2012 / Accepted: 9 March 2012 / Published online: 5 December 2012  
© EPOS 2012

**Abstract** The history of surgical correction for adolescent idiopathic scoliosis reaches back about 100 years: the natural course of progressive, crippling and sometimes even life-threatening deformities which could not be controlled by external means called for effectual, invasive procedures. Hibbs 1911 aimed at halting progression by long, uninstrumented fusions. However, the lack of true correction, long rehabilitation times, high pseudarthrosis and infection rates, and a fusion mass which bent further once exposed to gravity again were not satisfying. The transition from slowing progression to halting progression and truly correcting the deformity lasted almost another half a century: Paul Harrington, confronted with many scoliotic polio patients, successfully introduced a hook–rod system for concave-distraction and convex-compression at the end of the 1950s. Many implant failures, a still-considerable pseudarthrosis rate, flattening of the sagittal profile and the lack of true three-dimensional (3D) correction were the shortcomings. In the 1970s the Frenchmen Cotrel and Dubousset took scoliosis surgery to the next level by introducing a versatile hook system and curve-pattern-adapted correction modes. The basics of the so-called derotation-manoeuvre consists in strategic distribution of the anchors along the curve, bending the rod accordingly, and rotating it back into the sagittal plane. The overall correction, stability and the fusion rates improved significantly. However, the effect on the sagittal and transverse plane were still limited. Lately, a better biomechanical understanding and bilateral, polysegmental strong three-column fixation with pedicle screw has become the benchmark method: in conjunction with posterior release techniques,

osteotomies or even vertebral column resections for severe cases, it allows better 3D control (vertebral column manipulation), faster rehabilitation and better patient satisfaction.

**Keywords** Idiopathic scoliosis · Surgery · History · Adolescent

## Introduction

Surgical correction of marked idiopathic scoliosis is deemed beneficial for the patient's life satisfaction [1]. The hierarchy of therapeutic goals reflects its historical and still ongoing evolution:

1. Halting of curve progression
2. Solid bony fusion
3. Safe and solid instrumentation
4. Coronal plane correction and balance
5. Sagittal plane correction and balance
6. Surveillance and preservation of spinal cord and nerve root function
7. Better understanding the 3D biomechanics of the normal and scoliotic spine
8. 3D spine and trunk correction
9. Preservation of function
10. Non-fusion techniques

The final common pathway of the first 100 years of operative treatment and of 50 years of instrumented correction of scoliosis is long bony fusion of a once-mobile polysegmental organ. However, the alternative, to leave a scoliotic spine to its natural fate, is cosmetically unacceptable (rib hump, waist asymmetries, shoulder imbalance, etc.) for many patients (50–80° curves) or leads to significant cardiovascular and pulmonary impairment in case of severe curves >80–90°. Moreover, severe scoliotic

---

C. C. Hasler (✉)  
Orthopaedic Department, University Children's Hospital,  
PO Box, 4031, Basel, Switzerland  
e-mail: carol.hasler@bluewin.ch

spines will also stiffen over time. True 3D correction, spinal and shoulder balance and an as-short fusion as possible are the cornerstones of modern scoliosis treatment. The last 100 years of development were rocky, and the final goal—correction with full preservation of function—is still under construction. This article highlights the developmental milestones of *posterior* corrective surgery for idiopathic scoliosis. A concise summary for anterior approaches is given in the article of Ilka Helenius, *Anterior surgery for adolescent idiopathic scoliosis*.

### The first steps—from Hibbs to Harrington

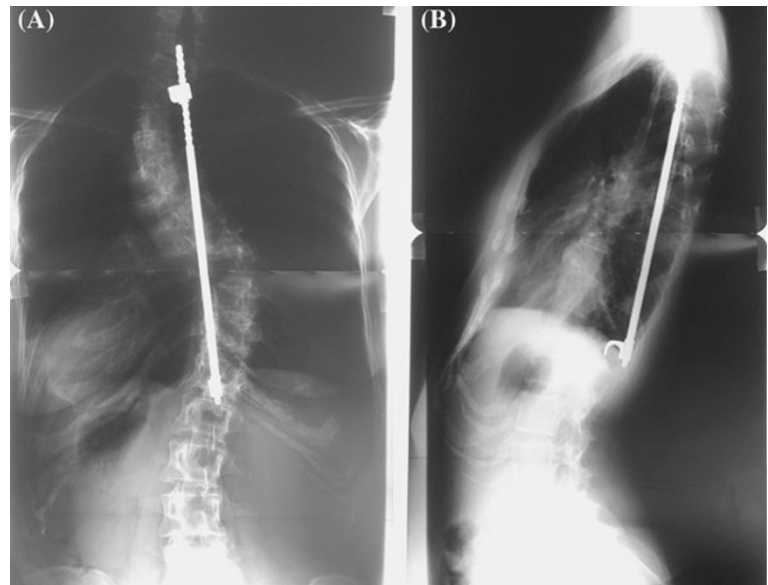
The natural evil evolution of neuromuscular and post-tuberculosis deformities, which could not be controlled by external means or myotomies, were the starting point for invasive fusion strategies, which later were also applied to marked idiopathic scoliosis and still represent the fundament of any definitive corrective scoliosis surgery. Russell Hibbs (1911) was the first to publish on a series of patients who underwent long, uninstrumented *in situ* fusions and a long-lasting immobilization in a cast [2]. Above all, the goal was to halt curve progression. Limited correction resulted from the prone position during surgery. The spine was exposed from posterior and fusion was induced by crushing the spinous processes, facetectomies, decortication of the laminae and finally by local bone harvesting and placement along the exposed spine. However, despite the long immobilisation time, the lack of true correction, as well as high pseudarthrosis and infection rates rendered this pioneering work an unpredictable endeavour. Once exposed to gravity without instrumental support, the fusion mass often continuously re-bended and secondary curve progression occurred. Functionally and cosmetically the results were not satisfying. A combination of uninstrumented fusion and a so-called Risser cast improved the correction and lowered the pseudarthrosis rate, but was still not satisfying [3]. Probably the two world wars, which captured much of the intellectual and industrial power at that time, caused another 50 years of standstill in the development of scoliosis surgery. As the world war veterans with their infected pseudarthrosis and malunited fractures urged Gavril Ilizarov to develop ring fixators and callotasis, the poliomyelitis epidemics in the United States (worst in Houston, Texas in the early 1950s) left countless unsuccessfully treated neuromuscular scoliosis patients. Paul Harrington, who moved to Texas after the war, is acknowledged to be the first to use implants for scoliosis correction and to support fusion. First, *concave-distraction* over a stainless steel rod with a ratchet and a collar end attached to the spine at the curve top and bottom with hooks alone (nonsegmental instrumentation), and later a

*convex-compression* rod in addition, were the cornerstones of his method. Originally the intention was mere instrumentation without fusion, but the complication rate was significant. However, pseudarthrosis, implant corrosion and breakage, as well as hook dislodgements, still led to frequent revisions, also with concomitant fusion since the constructs were not rigid enough. The limited stability required long-lasting postoperative immobilisation [4, 5]. The major drawback of unidirectional distraction is flattening in both the coronal and sagittal plane (Fig. 1). The latter leads to the typical flatback deformity, named “flatback syndrome” if it also causes pain [6]. As a further development for severe curves (100–200°), Pierre Stagnara from France obtained preoperative partial reduction by distraction casts or halo traction followed by one- or two-stage Harrington instrumentation (through the cast fusions) [7, 8]. Over two decades, the Harrington rods and technique remained the gold standard for scoliosis treatment. However, modern scoliosis surgery and the increasing surgeon’s and patient’s demands for 3D correction led to the Harrington rod phasing out.

### From stability to 3D biomechanical understanding

The next development was initiated by the treatment of neuromuscular scoliosis: Eduardo Luque, from Mexico City, started to use sublaminar steel wires in combination with L-shaped rods in the 1970s. After partial removal of the ligamentum flavum to gain access to the spinal canal, the prebent wires are manually guided around the front side of the laminae through the space between the lamina and spinal cord. The two ends are passed around the rods and then tightened sequentially. As this mechanism is applied multisegmentally, the spine is gradually *translated* and reduced to the rod [9, 10]. This cheap, low-profile and effective segmental fixation method is particularly apt for neuromuscular scoliosis since it provides load distribution in osteoporotic bone. Later it was also applied to idiopathic curves since its high primary stability omits the need for postoperative plaster or brace immobilization and the costs are lower than for pedicle screw constructs [11]. The major concern is the risk of neurologic injury. However, in clinical series sublaminar placement of wires in idiopathic scoliosis proved to be safe [12, 13]. The corrosive combination of steel wires with modern titanium, TAN and cobalt chrome rods is not recommended, but modern sublaminar implants like titanium cables and polyester bands (universal clamps, Zimmer Spine, Bordeaux/France) meet the material requirements [14]. Bands provide more contact area than wires or cables and hence bear a lower risk for cut out through the lamina. A versatile and modular hook-and-screw system for *translation* correction emerged

**Fig. 1** 40-year-old woman with a 26-year follow-up after single Harrington distraction rod instrumentation. Uneventful fusion occurred and the uninstrumented lumbar spine remained stable over time. Slight loss of balance to the left in the coronal plane (a). In the lateral view (b) loss of balance in posterior direction, flattening of the instrumented thoracic spine and a significant rib hump are present

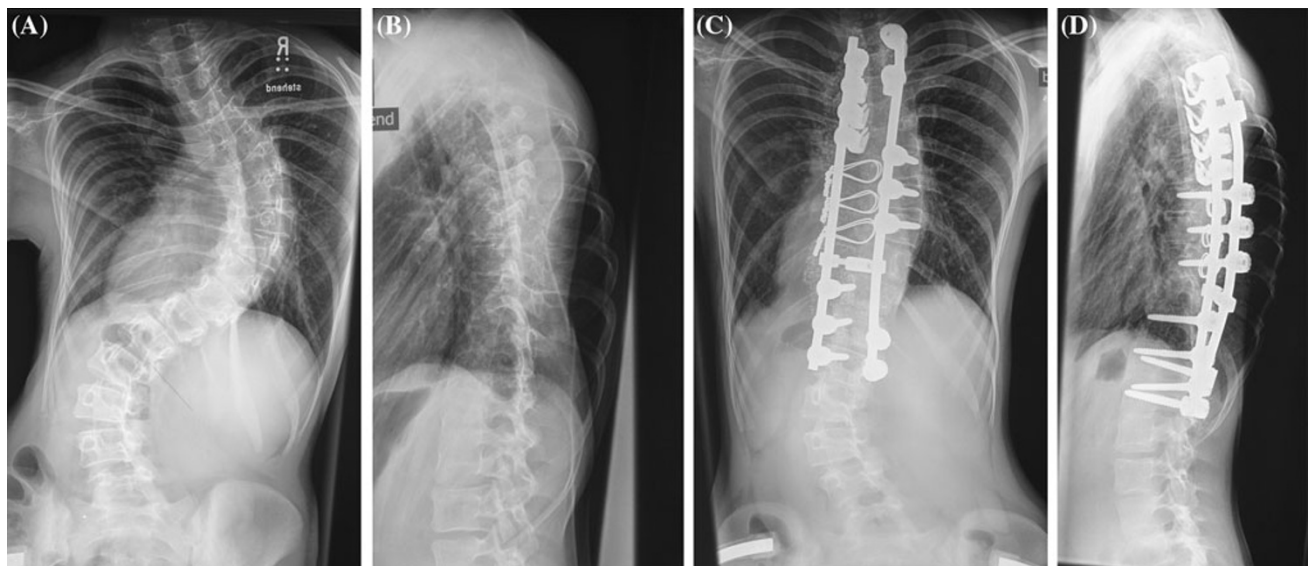


in the 1990s, the Universal Spine System (USS, Synthes, Oberdorf, Switzerland). Instead of accessing the spinal canal with sublaminar anchors, the reduction manoeuvre relies on anchors (hooks or screws) with side openings (side loading) for the reception of the rod, which is provided by a strong instrument—the “persuader”—for posterior pull and medial translation of the vertebral anchors. The next practice altering instrumentation was that of Cotrel-Dubousset (CD, Medtronic, Memphis/USA former Sofamor-Danek) released at the beginning of the 1980s which for the first time aimed at a 3D correction. Later, many similar devices were manufactured (Moss Miami, Isola, Texas Scottish Rite, etc.). They all incorporate a frame construct of two rods and transverse connectors, and multiple point fixations including laminar hooks, pedicle hooks, but also pedicle screws (thoracolumbar or lumbar level) at selected vertebrae. This implant versatility provides the flexibility to create custom-made constructs according to the requirements of the deformity (3D curve pattern, stiffness) [15, 16]. Strategic segmental anchor placement is the first step, followed by placement of the bent, concave rod into the anchor heads coming from their tops (top loading). The rod matches the deformity. Hence, its material properties needs to allow segmental bending and its pliability prevention of anchor pullout during the reduction *derotation* manoeuvre: held by special forceps, the rod is slowly rotated back from the frontal into the sagittal plane, thereby translating the apex towards the midline. In contrast to the initial belief, though convincing in theory, the 3D effect in the sagittal and transverse plane is very limited: rod rotation does not lead to significant periapical detorsion of the spine as shown with CT scans [17, 18]. Some change in axial plane alignment is usually attributed to the placement of the second, differently bent

rod. In addition, rod derotation in case of selective thoracic fusion can lead to increased rotation of the non-instrumented lumbar spine and to loss of coronal balance (Fig. 2).

### Three column fixation and direct vertebral manipulation

The use of pedicle screws was first described by the French spine surgeon Roy-Camille [19]. Constructs with bilateral *pedicle screws* on all instrumented scoliotic levels became a benchmark operative strategy in the 1990s. They provide stable, three-column vertebral fixation and safe manipulation of single vertebral bodies [20, 21]. They are believed to provide superior 3D correction in comparison to all previous methods [17]. Screw placement may be demanding, mainly on the concave curve side of significant curves with dysplastic pedicles [22]. The proximity of the spinal cord medially and the aorta anteriorly, particularly at the mid thoracic spine, warrants utmost caution, anatomic knowledge about entry points and pedicle directions, experience and imaging support [23]. The probability of non-optimal screw placement (medial, lateral, superior, inferior breaches or overlength) was found to be about 20 % in postoperative CT scans [24, 25]. However, most do not require revision [26]. Neurological, vascular or visceral compromise is rare [27]. All pedicle screw constructs offer an à la carte application of all available corrective techniques, such as derotation, translation, segmental distraction–compression and in situ bending. Moreover, during the last decennium, recent developments and implants have provided the additional option of *vertebral column manipulation* (VCM), also called *direct*



**Fig. 2** **a** 13-year-old girl with fast progressive adolescent idiopathic scoliosis. 95° main right thoracic and compensatory 60° left lumbar curve with 3 cm loss of trunk balance to the right and shoulder imbalance. Clinically 30° rib hump and 20° lumbar prominence. **b** The *lateral view* displays a hypokyphotic thoracic profile and the significant rib hump. **c** To prevent primary long fusion to L4, it was decided to selectively instrument and fuse the thoracic spine from T3 to L1 with a hook-wire-screw hybrid construct. In view of the dysplastic concave mid-thoracic pedicles sublaminar classic Luque

wires were used in combination with periapical convex pedicle screws. The right shoulder was pulled down with a pedicle hook-transverse process hook-claw construct and the left shoulder lifted with pedicle hooks and slight distraction. Solid thoracolumbar pedicle screw foundation bilaterally. Two years postoperatively, well balanced trunk, with a 30-30° right thoracic-left lumbar double curve and leveled shoulders. **d** The *lateral view* shows a residual, but improved rib hump and a normalized sagittal profile

*vertebral derotation (DVD)*: the connection of two screws of one single vertebra with a transverse bar (triangulation) or several levels with longitudinal and transverse bars allow for reduction of single vertebral bodies or an apical multilevel block in the transverse plane [28]. Proper screw placement is mandatory for safe derotation and prevention of screw plowing [29, 30]. Though full derotation is only possible in flexible spines, there are fewer indications for thoracoplasties due to the direct transmission of reduction forces to the vertebrae. However, in most cases some degree of asymmetry remains which is attributed to the physiologic lack of full symmetry, intrinsic rib deformities on the convex site of severe curves and intravertebral torsion between the upper and lower endplate [31, 32]. For larger rib prominences thoracoplasty alone or in combination with DVD may therefore yield better results than an attempt of DVD only [33]. Although a severe rib hump mimics hyperkyphosis in the lateral clinical view, the true apical sagittal profile is mostly hypokyphotic or even truly lordotic. Powerful rotation of those segments back into the anatomic sagittal plane may lead to its flattening. This point of criticism towards vertebral column manipulation does not hold true in recent clinical series [34] but may become relevant if derotation is combined with a “push down” manoeuvre on the convex side which itself may accentuate the lordosing effect [35]. In order to restore or at least preserve the sagittal profile, the derotation manoeuvre

should be combined with posterior translation to a pre-contoured rod. The latter should be strong enough to withstand the high forces [36]. Effective derotation leads to perfect overlap of the two rods on a lateral radiograph. Another concern with rigid, all pedicle screw constructs and flattening of the thoracic spine is junctional kyphosis at the upper end of the fusion. Some spine surgeons believe that a hybrid construct consisting of pedicle screws around the apex for a forceful 3D restoration and a pedicle hook-transverse process hook-claw at the upper end provide optimal correction and a smooth transition from the uppermost instrumented to the first cranial uninstrumented segments.

#### Additional improvements over time

Not only have implants become more powerful, safe and reliable, and instrumentation more comfortable for the surgeons, but different adjunct modalities have boosted the striving for excellence in scoliosis surgery: one- or two-stage anterior releases are almost completely substituted by a case-based selection of preoperative halo traction, intraoperative skull-femoral traction (slow stretch out and staged correction, easier determination of fusion level), posterior release techniques (ribs, supra-, interspinous ligaments, facets, ligamentum flavum), osteotomies (Smith-Peterson



SPO, pedicle subtraction PSO) or even vertebral column resections (VCR) for severe stiff deformities [37–40]. As all those supportive tools and strategies are burdened with some hazards, they should be applied with care [41–43]. The risk of a new neurological deficit (nerve root, cauda equine and spinal cord) after surgery for idiopathic scoliosis during growth is reported to be around 0.7 % according to the most recent report of the Scoliosis Research Society Morbidity and Mortality database [44]. Since the early 1970s until the 1990s the Stagnara *wake-up test* was the only option for intraoperative detection of surgery-related neurologic deficits. A direct view of the (hopefully moving) patient's feet at the end of the instrumentation eventually revealed the truth, sometimes after a long period of waiting, depending on the anaesthetist's capabilities to reach an adequate level of patient wakefulness and responsiveness [7]. In contrast, modern multimodal *spinal cord monitoring* offers more reliable, timely, faster and safe detection over the whole course of the intervention [45–47]. Use of synthetic *antifibrinolytic drugs* (tranexamic and epsilon-aminocaproic acid) may reduce the perioperative blood transfusion requirement [48, 49]. Pre- and postoperative *3D low dose whole body radiographic imaging* (e.g., sterEOS) enhances the biomechanical understanding and supports preoperative planning [50, 51]. Intraoperative use of *navigation* to place pedicle screws steepens the learning curve and aids instrumenting in difficult anatomic situations [22, 52–54].

## Conclusions

Our biomechanical understanding of curve patterns and their behaviour over time with and without surgery, adequate choice of fusion levels, and the power, safety, stability and reliability of instrumentation have tremendously improved over the last 100 years, although the basic principle—multisegmental bony fusion—persisted [55]. The modern patient's and surgeons' demands on optimal 3D scoliosis and trunk correction is reflected by high implant density, extensive use of pedicle screws, and shorter hospital stays, but with rising costs [56]. It remains to be proved if the overall higher expenditure is equally and justifiably transmitted into higher satisfaction and quality-of-life improvement [57–59]. In view of the many function-preserving and -restoring innovations in modern orthopaedic surgery over the last decades, above all in total joint replacement, scoliosis surgery is still stigmatized with a rather archaic way of sacrificing function in young and otherwise healthy individuals. The path of instrumented fusion seems to end at a high but still not fully satisfying level. It is to be hoped and to be stipulated with sound scepticism that new function-preserving technologies—preventive or curative—will emerge soon to take us to the next level of astonishment.

**Conflict of interest** I have not received funds for this study.

## References

- Zhang J, He D, Gao J et al (2011) Changes in life satisfaction and self-esteem in patients with adolescent idiopathic scoliosis with and without surgical intervention. *Spine (Phila Pa 1976)* 36:741–745
- Hibbs RA (2007) An operation for progressive spinal deformities: a preliminary report of three cases from the service of the orthopaedic hospital. 1911. *Clin Orthop Relat Res* 460:17–20
- Zielke K (1971) The so-called Risser plaster technic. *Z Orthop Ihre Grenzgeb* 109:341–344
- Harrington PR (1962) Treatment of scoliosis. Correction and internal fixation by spine instrumentation. *J Bone Joint Surg Am* 44-A:591–610
- Harrington PR (1963) Present status of spine instrumentation in scoliosis. *Am J Orthop* 5:228–231
- Aaro S, Dahlborn M (1982) The effect of Harrington instrumentation on the longitudinal axis rotation of the apical vertebra and on the spinal and rib-cage deformity in idiopathic scoliosis studied by computer tomography. *Spine (Phila Pa 1976)* 7:456–462
- Dubousset J (1996) A tribute to Pierre Stagnara. *Spine (Phila Pa 1976)* 21:2176–2177
- Stagnara P, Fleury D, Fauchet R et al (1975) Major scoliosis, over 100 degrees, in adults. 183 surgically treated cases. *Rev Chir Orthop Reparatrice Appar Mot* 61:101–122
- Luque ER (1982) The anatomic basis and development of segmental spinal instrumentation. *Spine Phila Pa* 7:256–259
- Luque ER (1982) Segmental spinal instrumentation for correction of scoliosis. *Clin Orthop Relat Res* 163:192–198
- Raney EM (2011) Hooks and wires—tried and true plus how to: POSNA1-DayCourse, April 29, 2009. *J Pediatr Orthop* 31:S81–S87
- Girardi FP, Boachie-Adjei O, Rawlins BA (2000) Safety of sublaminar wires with Isola instrumentation for the treatment of idiopathic scoliosis. *Spine (Phila Pa 1976)* 25:691–695
- McMaster MJ (1991) Luque rod instrumentation in the treatment of adolescent idiopathic scoliosis. A comparative study with Harrington instrumentation. *J Bone Joint Surg Br* 73:982–989
- Mazda K, Ilharreborde B, Even J et al (2009) Efficacy and safety of posteromedial translation for correction of thoracic curves in adolescent idiopathic scoliosis using a new connection to the spine: the universal clamp. *Eur Spine J* 18:158–169
- Cotrel Y, Dubousset J (1984) A new technic for segmental spinal osteosynthesis using the posterior approach. *Rev Chir Orthop Reparatrice Appar Mot* 70:489–494
- Cotrel Y, Dubousset J, Guillaumat M (1988) New universal instrumentation in spinal surgery. *Clin Orthop Relat Res* 227:10–23
- Asghar J, Samdani AF, Pahys JM et al (2009) Computed tomography evaluation of rotation correction in adolescent idiopathic scoliosis: a comparison of an all pedicle screw construct versus a hook-rod system. *Spine (Phila Pa 1976)* 34:804–807
- Moens P, Vanden Berghe L, Fabry G et al (1995) The Cortel-Dubousset device: prospective study on derotation. *Rev Chir Orthop Reparatrice Appar Mot* 81:428–432
- Roy-Camille R, Roy-Camille M, Demeulenaere C (1970) Osteosynthesis of dorsal, lumbar, and lumbosacral spine with metallic plates screwed into vertebral pedicles and articular apophyses. *Presse Med* 78:1447–1448
- Suk SI, Lee CK, Kim WJ et al (1995) Segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis. *Spine (Phila Pa 1976)* 20:1399–1405

21. Suk SI, Kim JH, Kim SS et al (2012) Pedicle screw instrumentation in adolescent idiopathic scoliosis (AIS). *Eur Spine J* 21:13–22
22. Abul-Kasim K, Ohlin A (2012) Patients with adolescent idiopathic scoliosis of Lenke type-1 curve exhibit specific pedicle width pattern. *Eur Spine J* 21:57–63
23. Takeshita K, Maruyama T, Sugita S et al (2011) Is a right pedicle screw always away from the aorta in scoliosis? *Spine (Phila Pa 1976)* 36:E1519–E1524
24. Liljenqvist UR, Halm HF, Link TM (1997) Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. *Spine (Phila Pa 1976)* 22:2239–2245
25. Belmont PJ Jr, Klemme WR, Dhawan A et al (2001) In vivo accuracy of thoracic pedicle screws. *Spine (Phila Pa 1976)* 26:2340–2346
26. Li G, Lv G, Passias P et al (2010) Complications associated with thoracic pedicle screws in spinal deformity. *Eur Spine J* 19:1576–1584
27. Di Silvestre M, Parisini P, Lolli F et al (2007) Complications of thoracic pedicle screws in scoliosis treatment. *Spine (Phila Pa 1976)* 32:1655–1661
28. Lee SM, Suk SI, Chung ER (2004) Direct vertebral rotation: a new technique of three-dimensional deformity correction with segmental pedicle screw fixation in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 29:343–349
29. Wagner MR, Flores JB, Sanpera I et al (2011) Aortic abutment after direct vertebral rotation: plowing of pedicle screws. *Spine (Phila Pa 1976)* 36:243–247
30. Parent S, Odell T, Oka R et al (2008) Does the direction of pedicle screw rotation affect the biomechanics of direct transverse plane vertebral derotation? *Spine (Phila Pa 1976)* 33:1966–1969
31. Janssen MM, Kouwenhoven JW, Schlosser TP et al (2011) Analysis of preexistent vertebral rotation in the normal infantile, juvenile, and adolescent spine. *Spine (Phila Pa 1976)* 36:E486–E491
32. Birchall D, Hughes D, Gregson B et al (2005) Demonstration of vertebral and disc mechanical torsion in adolescent idiopathic scoliosis using three-dimensional MR imaging. *Eur Spine J* 14:123–129
33. Samdani AF, Hwang SW, Miyajima F et al (2012) Direct vertebral body derotation, thoracoplasty or both: which is better with respect to inclinometer and SRS-22 scores? *Spine (Phila Pa 1976)* 37(14):E849–E853
34. Hwang SW, Samdani AF, Gressot LV et al (2012) Effect of direct vertebral body derotation on the sagittal profile in adolescent idiopathic scoliosis. *Eur Spine J* 21:31–39
35. Imrie M, Yaszay B, Bastrom TP et al (2011) Adolescent idiopathic scoliosis: should 100% correction be the goal? *J Pediatr Orthop* 31:S9–S13
36. Mladenov KV, Vaeterlein C, Stuecker R (2011) Selective posterior thoracic fusion by means of direct vertebral derotation in adolescent idiopathic scoliosis: effects on the sagittal alignment. *Eur Spine J* 20:1114–1117
37. Jhaveri SN, Zeller R, Miller S et al (2009) The effect of intraoperative skeletal (skull femoral) traction on apical vertebral rotation. *Eur Spine J* 18:352–356
38. Hamzaoglu A, Alanay A, Ozturk C et al (2011) Posterior vertebral column resection in severe spinal deformities: a total of 102 cases. *Spine (Phila Pa 1976)* 36:E340–E344
39. Zhou C, Liu L, Song Y et al (2011) Anterior and posterior vertebral column resection for severe and rigid idiopathic scoliosis. *Eur Spine J* 20:1728–1734
40. Bridwell KH (2006) Decision making regarding Smith-Petersen vs. pedicle subtraction osteotomy vs. vertebral column resection for spinal deformity. *Spine (Phila Pa 1976)* 31:S171–S178
41. Limpaphayom N, Skaggs DL, McComb G et al (2009) Complications of halo use in children. *Spine (Phila Pa 1976)* 34:779–784
42. Lewis SJ, Gray R, Holmes LM et al (2011) Neurophysiological changes in deformity correction of adolescent idiopathic scoliosis with intraoperative skull–femoral traction. *Spine (Phila Pa 1976)* 36:1627–1638
43. Xie J, Li T, Wang Y et al (2012) Change in Cobb angle of each segment of the major curve after posterior vertebral column resection (PVCr): a preliminary discussion of correction mechanisms of PVCr. *Eur Spine J* 21(4):705–710
44. Hamilton DK, Smith JS, Sansur CA et al (2011) Rates of new neurological deficit associated with spine surgery based on 108,419 procedures: a report of the scoliosis research society morbidity and mortality committee. *Spine (Phila Pa 1976)* 36:1218–1228
45. Pereon Y, Nguyen The Tich S, Delecrin J et al (1999) Somatosensory- and motor-evoked potential monitoring without a wake-up test during idiopathic scoliosis surgery: an accepted standard of care. *Spine (Phila Pa 1976)* 24:1169–1170
46. Sutter M, Eggspuehler A, Grob D et al (2007) The validity of multimodal intraoperative monitoring (MIOM) in surgery of 109 spine and spinal cord tumors. *Eur Spine J* 16(Suppl 2):S197–S208
47. Schwartz DM, Sestokas AK, Dormans JP et al (2011) Transcranial electric motor evoked potential monitoring during spine surgery: is it safe? *Spine (Phila Pa 1976)* 36:1046–1049
48. Sethna NF, Zurakowski D, Brustowicz RM et al (2005) Tranexamic acid reduces intraoperative blood loss in pediatric patients undergoing scoliosis surgery. *Anesthesiology* 102:727–732
49. Grant JA, Howard J, Luntley J et al (2009) Perioperative blood transfusion requirements in pediatric scoliosis surgery: the efficacy of tranexamic acid. *J Pediatr Orthop* 29:300–304
50. Ilharreborde B, Steffen JS, Nectoux E et al (2011) Angle measurement reproducibility using EOS three-dimensional reconstructions in adolescent idiopathic scoliosis treated by posterior instrumentation. *Spine (Phila Pa 1976)* 36:E1306–E1313
51. Illes T, Tunyogi-Csapo M, Somoskeoy S (2011) Breakthrough in three-dimensional scoliosis diagnosis: significance of horizontal plane view and vertebra vectors. *Eur Spine J* 20:135–143
52. Kuraishi S, Takahashi J, Hirabayashi H et al (2011) Pedicle morphology using computed tomography-based navigation system in adolescent idiopathic scoliosis. *J Spinal Disord Tech* [Epub ahead of print]
53. Silbermann J, Riese F, Allam Y et al (2011) Computer tomography assessment of pedicle screw placement in lumbar and sacral spine: comparison between free-hand and O-arm based navigation techniques. *Eur Spine J* 20:875–881
54. Fuster S, Vega A, Barrios G et al (2010) Accuracy of pedicle screw insertion in the thoracolumbar spine using image-guided navigation. *Neurocirugia (Astur)* 21:306–311
55. Fischer CR, Kim Y (2011) Selective fusion for adolescent idiopathic scoliosis: a review of current operative strategy. *Eur Spine J* 20:1048–1057
56. Roach JW, Mehlman CT, Sanders JO (2011) Does the outcome of adolescent idiopathic scoliosis surgery justify the rising cost of the procedures? *J Pediatr Orthop* 31:S77–S80
57. Bago J, Perez-Grueso FJ, Pellise F et al (2012) How do idiopathic scoliosis patients who improve after surgery differ from those who do not exceed a minimum detectable change? *Eur Spine J* 21:50–56
58. Yang S, Jones-Quaidoo SM, Eager M et al (2011) Right adolescent idiopathic thoracic curve (Lenke 1 A and B): does cost of instrumentation and implant density improve radiographic and cosmetic parameters? *Eur Spine J* 20:1039–1047
59. Smucny M, Lubicky JP, Sanders JO et al (2011) Patient self-assessment of appearance is improved more by all pedicle screw than by hybrid constructs in surgical treatment of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 36:248–254