Pedicle screw instrumentation and spinal deformities: have we gone too far?

John McCormick · Max Aebi · David Toby · Vincent Arlet

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Abstract

Introduction Placement of pedicle screws within the thoracic and lumbar spine has become the “state of the art” for the treatment of spinal deformities. Newly trained surgeons are often trained only with the placement of pedicle screws within the thoracic and lumbar spine and not with hooks or other means of fixation. However, if the benefits of pedicle screw instrumentation in terms of correction ability cannot be questioned on some issues pertaining to their safety, their rationale for all situations as well as their long-term adverse consequence and or early or late complications start to arise.

Materials and methods We therefore present four case examples that illustrate the advantages, questions and complications inherent to pedicle screw instrumentation in spinal deformities. These four cases serve as discussion supported by a review of the literature. The literature search was performed to include pedicle screws associated risks,

costs and complications. Articles focusing on instrumentation of the thoracic and lumbar spine for the treatment of adult and pediatric scoliosis were reviewed.

Results Pedicle screw instrumentation in the treatment of spinal deformity is here to stay, however a fair number of issues have come up since their widespread use that started 10 years ago: these include their misplacement with the inherent risks to the vascular or neurologic structures, the rate of misplaced pedicle screw not per number of screws inserted, but per patient operated, the number of screws really necessary to achieve a satisfactory outcome while maintaining costs, their contraindications in some very challenging deformities where the risks clearly outweigh their advantage compared to hooks. At last, the use of pedicle screw instrumentation has driven many centers in increasing the safety of such procedures using intraoperative spinal cord monitoring as well as improved imaging technologies.

Conclusion To answer our provocative title “Pedicle screw instrumentation have we gone too far?” Definitely we can answer that for some spinal deformities instrumented with all-pedicle-screw instrumentation, we have observed cases where the surgeons have gone way too far; in other cases, where such instrumentation was used in a comprehensive and rational manner, the answer to “Have we gone too far” is no, and such use of pedicle screw has improved outcome with minimum complications.

Keywords Pedicle screw · Complications · Safety · Costs · Spinal deformities

Introduction

Placement of pedicle screws within the thoracic and lumbar spine is a standard practice in the treatment of spinal

J. McCormick
University of Virginia, P.O. Box 801016,
Charlottesville, VA 22908, USA
e-mail: mccormickjd@gmail.com

M. Aebi
Institute for Evaluation Research in Orthopaedic Surgery,
University of Bern, Bern, Switzerland
e-mail: Max.Aebi@MEMCenter.unibe.ch

D. Toby
University of the West Indies, 101-103 Ariapita Avenue,
Port of Spain, Trinidad and Tobago
e-mail: DToby2000@yahoo.com

V. Arlet (✉)
Penn Orthopaedics, University of Pennsylvania,
235 S 8th Street, Philadelphia, PA 19106, USA
e-mail: Vincent.arlet@uphs.upenn.edu

deformity. Newly trained surgeons are more familiar with the placement of pedicle screws within the thoracic and lumbar spine than hooks. This has been a recent advance. Boucher [1] first introduced the concept of pedicle screws in the 1950s and the concept was revisited by Roy-Camille [2] in the 1980s, and in the 1990s one of us reported for the first time the use of pedicle screw fixation for degenerative lumbar scoliosis [3]. Then spine surgeons begin exploring the instrumentation of the thoracic and lumbar spine to treat both adult and pediatric spinal deformity [3–8] but the concept of pedicle screws within the thoracic and lumbar spine has become a “standard of care” only within the past decade in the treatment of spinal deformities. Dr. Suk first demonstrated the safe placement of pedicle screws within the thoracic spine [7, 9] and a recent PubMed search evaluating the last 10 years shows over 1,300 articles identifying “pedicle screw” as a key item. The purpose of this paper is to evaluate the benefits of pedicle screws for spinal deformity, and look into the future about the rationale, indications and implications, and costs of pedicle screw instrumentation. We will review four case examples that illustrate, followed by a discussion with a review of the literature.

Materials and methods

Case 1 (Fig. 1a–d)

A 12-year-old male presented to a spine clinic for evaluation of his progressive scoliosis. Physical exam revealed no neurologic deficits, no leg length discrepancy, symmetric

reflexes and a prominent right rib hump. Radiographs were obtained and a 60° right main thoracic curve T6–L1 was visualized Lenke Type IAN [10, 11] (Fig. 1). Bending films were performed and the curve corrected to 30° with side bending to the right. After discussion with the family, a decision for operative fixation was selected. The patient underwent a hybrid construct for the treatment of his scoliosis. Posterior-only spinal instrumentation and fusion were performed from T4–L3. Eleven points of fixation were used within the construct. Four pedicle screws were placed within the lumbar spine (L2/L3) and seven supralaminar/infralaminar hooks were used within the thoracic spine and a correction to <20° was achieved in the immediate post-operative period.

The patient was lost to follow-up but showed again 4 years after his initial surgery experiencing back pain. Radiographs were performed that showed a crankshaft phenomenon to be present. The curve was now 58° and the distal rod/screw interface was no longer intact secondary to the child continuing to grow and mature. The child was taken for revision scoliosis surgery. All the instrumentation was removed, a hairline pseudarthrosis was found to be present distally and new hybrid hook and pedicle screw instrumentations were inserted and also multiple Ponte osteotomies were performed.

Case 2 (Fig. 2a, b)

An 18-year-old adolescent female presented to the clinic with an 80° right thoracic curve, Lenke Type 1AN. The physical exam revealed no neurologic deficits, symmetric reflexes and a prominent right rib hump. Bending films

Fig. 1 **a** Preoperative AP view showing a main thoracic curve of 60° prior to correction. **b** Immediate postoperative film illustrating scoliosis correction with a hybrid construct. **c** Radiograph represents

the progressive crank shafting at 4 years out from the initial surgery. **d** Radiograph immediately after the correction of the crankshaft phenomenon

Fig. 2 **a** Clinical photograph and AP radiograph of an 18-year-old adolescent female with an 80° main thoracic curve. **b** 6-month follow-up clinical photograph and AP radiograph after correction with an all pedicle screw construct

were performed. A decision to perform posterior spinal fusion for correction of the scoliosis was made after discussing the risks and benefits with the patient and family. The patient underwent a T4-L3 fusion, 12 vertebrae, with 20 points of fixation. Twenty pedicle screws were placed to facilitate correction of the curve. Postoperative films showed a curve correction of 90 %. The X-rays were very impressive with the surgeon taking pride in his work. Patient resumed her normal activities 4 weeks after the surgery including sports. At the latest follow-up, there has been no progression of the curve and the patient is without complaints and happy with the cosmetic correction. Hospital costs in terms of implants were judged excessive by the hospital administration.

Case 3 (Fig. 3a, b)

A patient with a 65° AIS curve was treated with a pedicle screw construct. Postoperative course is uneventful and patient is discharged on the 4th day. At 1-month postoperative, the patient is doing extremely well; however, long standing scoliosis films identify the left pedicle screw at L1 which looks slightly lateral to the pedicle. Due to concern about an extrapedicular position of the screw a CT scan is ordered. The CT confirms the screw to be extrapedicular near the aorta, yet at a distance non-threatening to the anterior structures. The screw was left in place, the patient definitively fused without any loss of correction.

Case 4 (Fig. 4a, b)

A patient with a 50° right thoracic curve underwent surgical correction with an all-pedicle-screw construct. No intraoperative neuro monitoring was done at the time during surgery. Patient woke up unable to move his legs. Postoperative myelogram shows a misplaced pedicle screw, which most likely resulted in paraplegia.

Clearly, these four case examples are at the opposite extremes of the use of pedicle screws and will serve us as a base for discussion. In the first case presented, the construct, which was a hybrid, was not strong enough to prevent the advancement of the curve. Because of lack of instrumentation that controlled the anterior column, the patient outgrew his rods and developed a crankshaft phenomenon requiring a complex revision 4 years later. The patient and family endured the emotional distress of a complex revision and the extra expense. The second case illustrates excellent curve correction, but one may question if so many pedicle screws were necessary. As for each pedicle screw, there is somewhat an increased risk of misplacement. In the third case: the results look perfect, but clearly the distal screw has been misplaced and could have represented a risk for the anterior structure, would it have been longer. In the last case, this is the most feared complication of spinal deformity correction for a surgeon; the misplaced pedicle screw was inserted and damaged the spinal cord resulting in paraplegia. One may question the lack of use of intraoperative monitoring and the training requirement for surgeons performing scoliosis correction with pedicle screw instrumentation.

Fig. 3 **a** 70° AIS treated with pedicle screw construct: preoperative AP, postoperative AP and lateral radiograph 1 month after surgery. At 1-month postoperative, it is noticed that the left pedicle screw is slightly lateral to the pedicle (*white arrow*). **b** A CT shows the screw

to be extrapedicular but does not threaten the ant structures. The screw will be *left* in place. The patient will go on for definitive fusion without loss of correction. An intraoperative CT scan would have prevented this complication

Fig. 4 **a** 50° right thoracic curve preoperative AP, postoperative AP and lateral. One pedicle screw (white arrow) was misplaced and this resulted in paraplegia. **b** The postoperative myelogram shows the left T9 screw that is displacing the cord: scan confirming the pedicle screw within the spinal canal

Discussion

Outcomes

When evaluating outcomes of all-pedicle-screw versus hooks or hybrid constructs several areas must be addressed.

Does an all-pedicle-screw construct result in an improved correction of the spine?

Pedicle screws have the ability for fixation of both the anterior and posterior column of the spine versus laminar hooks within the posterior elements only and the biomechanical superiority of this fixation construct has been established [12]. Kim et al. [13] retrospectively evaluated 54 patients (hook only cohort vs. all pedicle screw) and found that the all-pedicle-screw construct achieved greater curve correction with maintenance of the curve compared to hook-only constructs [13]. Technically, pedicle screws have been found to achieve a greater degree of correction, maintenance of correction and improvement in sagittal and coronal balance when compared to hook only or hybrid instrumentation [7, 13–16].

Coronal correction

What are the advantages of reducing a 70° Cobb angle thoracic curve to 18° with pedicle screws as opposed to 23° with a hybrid system? The difference in multiple series has been shown to be statistically significant, but such minimum difference in terms of clinical relevance has rarely been addressed. Arlet et al. compared a series of hybrid versus all pedicle screw constructs with judges being blinded. Clearly it was impossible to tell the difference between hybrid and an all-pedicle-screw construct when judges were blinded to the type of instrumentation and could only look at the clinical photos of the patients and the spine X-rays with the instrumentation being blacked out with a square [17]. What are the long-term benefits of all-pedicle-screw constructs compared to a hybrid construct? Is overcorrection a problem? When the senior authors of the papers did their training, they were taught about the shoulder sign after Harrington instrumentation. This meant that after surgery for right thoracic curve if the patient's left shoulder was found to be elevated after curve correction of the spine, distraction occurred and the shoulders were unbalanced.

There has been renewed interest in shoulder balance [18, 19]. The left shoulder sign reported by O'Brien et al. is believed to be related to either too much or overcorrection of the main thoracic curve or lack of correction or instrumentation of an upper left thoracic curve. Increased coronal correction achieved only with pedicle screws versus a hybrid construct may increase the rate of shoulder imbalance.

Pedicle screws and the sagittal plane

One advantage of the modern instrumentation over the Harrington instrumentation was the recreation of lumbar lordosis and therefore the decrease or elimination of flat back in the lumbar spine. However, for the thoracic spine it seems that the pedicle screws have induced hypokyphosis and the more correction achieved with pedicle screws, the more hypokyphosis of the thoracic spine may be observed. Yet, this hypokyphosis is often a radiographic finding and does not always result from patient awareness [20, 21]. Do pedicle screws achieve a better derotation of the spine and correction of the rib humps? Several studies have reported better derotation if one uses pedicle screws [22–25]. No study has reported if the derotation of the last instrumented vertebra was better with pedicle screw than hybrid or hooks alone. However, pedicle screws at the bottom of the spine construct whether hybrid or all-pedicle-screw construct will achieve a better control of the LIV and represent here a definitive advantage [24–26].

Do all-pedicle-screw construct improve patient outcomes?

Patient outcome questionnaires have been used to compare the different instrumentation types. The SRS 24, SRS 30 and the Spinal Assessment questionnaire have been assessed. Total domain scores have yet to bear statistical significance when comparing a hybrid construct to an all pedicle construct [13–15, 27]. However, Smucny et al. [28] recently performed a multicenter prospective evaluation of patient reported outcomes and reported a statistical significance when evaluating shoulder balance, SRS Mental domain and SRS Appearance [28]. Whether these statistical benefits accurately correlate with clinical application is yet to be determined.

Cost

One cannot discuss the evolution of pedicle screws and the instrumentation of the spine in today's era of medicine without discussing cost.

From the simple Harrington rods and 2 hooks to the placement of 20 if not more pedicle screws to achieve correction, the price of instrumentation has followed an exponential increase. There have been multiple studies that have evaluated a cost analysis [15, 29–32]. However, cost is sometimes difficult to determine. Surgeons sometimes have a difficult time in determining the exact cost of the implants. Proprietary contracts can exist between the hospital and the vendor. Determining what the patient is actually charged versus the negotiated cost for the actual screw can be difficult. In addition, vendors may sometimes provide a reduced price for the pedicle screw, but not the actual hook. Therefore, the price of a hybrid constructs may actually be more than an all-pedicle-screw construct. This trend was demonstrated by Kamerlink et al. [31] in retrospective review and showed that the use of a hybrid construct was more expensive than an all-pedicle-screw construct. Other studies have evaluated large idiopathic curves and compared a traditional anterior/posterior fusion versus a posterior fusion only. Luhmann et al. [29] found that when a comparison was made between the treatments of 70° and 100° the radiographic outcome and cost was equivalent between the two procedures.

Lastly, there is the issue of cost and revision surgery. This will have different impacts depending on the country where the revision is performed. In North America bringing a patient back to surgery for a misplaced implant carries huge cost in terms of hospital stay. In other words, will adding more implants at the time of the index surgery to prevent possible revision surgery reduce costs? In other countries the price of hospital stay is not a prominent factor as opposed to the price of instrumentation and therefore in

terms of purely economics erring on the limited number of implants may make more sense.

As spine surgeons, we would like to be able to safely provide a procedure that is long-lasting and revision is not required. Kuklo et al. [33] reviewed their results and found a greater trend revision surgery for hybrid constructs and all hook constructs compared to all pedicle screw constructs. Different instrumentation may also have an impact on the rate of revision. Some instrumentation use top-loading screws with only one set screw mechanism; other systems' locking components vary and have additional modular components. Pedicle hooks may have some small endplate screws to help stabilize the hook. Lastly, familiarity with a system may influence the rate of revision.

Granted, the cost of a hook may be significantly less than a pedicle screw, but as one can see there are many variables that determine the cost. As the frequency and volume of pedicle screws increases globally, costs will decrease. Based on the current data, in the right environment, surgeons can perform posterior all-pedicle-screw instrumentation constructs for comparable costs.

Costs vary from one country to the other; interestingly, the same screw from the same company may be sold for a totally different price sometimes with a threefold price difference depending on the country where it is sold!! Maybe the title of our article: "Pedicle screw instrumentation and spinal deformities: Have we gone too far" should be addressed to implant companies that have kept such a high price for pedicle screws.

Safety/complications

The placement of pedicle screws within the thoracic spine has been established [7, 9, 34]. Suk et al. evaluated over 4,000 thoracic pedicle screws and found a malposition rate of 1.5 %. Kim et al. evaluated the placement of 577 thoracic screws placed by CT scan and found a 93.8 % of appropriately placed screws. Hicks et al. [35] performed a systematic review that evaluated the complications of the insertion of pedicle screws. Their literature review found that 11 % of the patient population had a screw malpositioned and approximately 15 % of screws were malpositioned when CT scan was used for evaluation. Ledonio et al. [36] performed a systematic review evaluating pedicle screw placement in pediatric patients and found an accuracy rate of 94.9 %. Definitely in assessing pedicle screw accuracy in spinal deformity the rate of malpositioned screw should be rendered per patient operated and not per number of screws inserted.

Fortunately, neurologic injury associated with pedicle screw malposition is rare. One author evaluated 3,204 screws and reported no vascular, neurologic or visceral injuries [34]. A second author reported a rate of 0.8 % and

noted the greatest risk to be on the concave side of the deformity [9]. The esophagus, thoracic aorta, azygos vein and inferior vena cava are potential structures that may be injured with an anterior vertebral body breach. In anatomical analysis of the thoracic spine, these structures have been found to be within 5 mm of the anterior vertebral body, yet an evaluation of over 14,000 screws identified no injury to these structures [37, 38]. Case reports concerning visceral injuries have been reported [39]. While little has been written in the recent literature concerning placement of hooks in the thoracic spine, there have been case reports resulting in neurologic injury with the placement of hooks on the concave side of the thoracic curve [40]. One can summarize from the literature that a thoughtful preoperative plan is beneficial, risks and benefits should be assessed, whether using hooks or pedicle screws at the apex of the concave deformity.

Improving safety

A whole paper by Flynn et al. [41] on improving safety in spinal deformity surgery is reported in this issue entitled *Improving Safety in Spinal Deformity Surgery: Advances in Navigation and Neurologic Monitoring*.

Clearly, safety has been derived with the use of intraoperative monitoring and proper imaging technologies and safe insertion of pedicle screws by understanding proper anatomy. Understanding the clinical landmarks for pedicle screw placement cannot be overstated. However, these landmarks and trajectories in spinal deformities may be in cases difficult to delineate. One must also appreciate the rotation of the curve as the instrumentation is being inserted. We recommend the isolation of the isthmus of the pars interarticularis in the thoracic spine and the inferior facet and use the classic landmarks of the junction for the transverse process and the lamina [7, 9, 42–44]. The probing and direction should rely on different instruments whether straight or curved like the “Lenke probe” that is rotated after 15–20 mm of insertion in the pedicle. Care should be taken to feel the cannulated pedicle and ensure a breach is not present in all directions. In some very challenging cases with a severe Cobb angle, previous surgery or adult scoliosis with an autofused concavity and facet hypertrophy on the concave side, it is safer to open up the canal through a small laminotomy or during a Ponte osteotomy for instance to feel the medial wall of the pedicle and then insert the pedicle screw under direct visualization. In some cases the bone is so sclerotic that classic probes cannot be used and could even be dangerous, drilling of the pedicle with a high-speed burr or an oscillating drill under direct control may be safer. One must understand that in some of these extremely challenging cases the accuracy requested is in the order of the millimeters.

The use of MEP and triggered EMG has allowed us to pick up medial breeches of our pedicle screw. Inserting pedicle screw in the thoracic spine without spinal cord monitoring may be judged as a breach of standard of care in the western world. However, spinal cord monitoring may not be available in many spine centers that often have to deal with the worst deformities. In such a case, the use of hooks or hybrid instrumentation using hooks, sublaminar wires and some pedicle screws may be far safer. We routinely perform a running MEP after the insertion of each pedicle screw in the thoracic spine as well as a stimulation of each pedicle screw with triggered EMG to rule out breeching once all of them have been inserted with an accepted threshold at the thoracic level of 6 mA.

The use of fluoroscopy can be a precious aid, yet many surgeons with deformity experience will insert the pedicle screws in a free hand fashion. We recommend at the very least checking with C-arm fluoroscopy the correct positioning of all the screws prior to completing the case. Images should be obtained using an AP radiograph that is appropriately positioned over each vertebra with the angle and rotation appropriately accounted. In revision cases where all the landmarks have disappeared bringing the C-arm and rotate it to visualize the vertebra and the pedicles may help inserting pedicle screws in the area of maximum deformity. As patient safety is becoming more and more of a concern, the use of intraoperative CT scanning with real CT imaging or CT fluoroscopy (O-arm: Medtronic Memphis) of pedicle screws after their insertion may become a standard of care in the future. Flynn [41] reports in this issue the use of the O-arm after free hand probing of the pedicle screw path. Navigation is thought by some teams to represent the way of the future for inserting pedicle screws in the spine. However, the requirement of an accuracy close to 1 mm and the time constraints imposed by navigation have led the use of such technologies to a restricted number of places that still use or believe in navigation.

Despite all these new advances in our technology and safety methods, the choice and type of instrumentation should be individualized. To illustrate this we provide the following example:

A surgical team composed of a senior attending, junior attending and a fellow perform a revision surgery on a complex adult scoliosis. After exposure of the spine, all the anatomic landmarks for safe placement of pedicle screws are not present. Clearly to achieve proper correction and stabilization implants are required. The young attending tries to find a pedicle pathway, but is unsuccessful. The spine fellow suggests spinal navigation may allow the insertion of the pedicle screw. The young attending counters the need of an accuracy of 1 mm to insert his screws and that it may not be provided with navigation. Therefore,

an attempt is made to visualize the pedicles using fluoroscopy. The fluoroscopy machine is used to localize the pedicles in the fusion mass. Even with fluoroscopy, several pedicles become difficult to cannulate. Several attempts are made at one pedicle which results in a medial breach. The three surgeons raise concern for neurologic injury if further attempts continue. 1 h elapses until the senior surgeon decides to drill with a high-speed burr into the fusion mass and insert laminar hooks in fraction of the time that was spent unsuccessfully cannulating the pedicle. The young spine fellow is taken aback as he has never inserted any hooks during his surgical spine training. From this small story one can see the danger of all-pedicle-screw training: our young generation of surgeon is lacking the experience of techniques than pedicle screws to obtain a successful arthrodesis.

Conclusion

Since their introduction to treat spinal deformities in 1992, pedicle screw instrumentation, seem to have become the standard of care, there is no doubt that this technology is here to stay as it offers definitive advantages such as improved correction, stability, and safer osteotomies techniques.

They have therefore dramatically changed how surgeons approach and treat spinal deformity in all age groups. It is still a relative recent technical procedure and 20–30-year outcomes have not been reported at this time. Lenke classification has provided great insight in determining what levels to include within a curve [11, 45], yet a certain degree of approaching curve correction remains the art of medicine, such as the number and type of osteotomies within a construct and the exact number of fixation points that are required. We know as we increase our fixation points we can improve correction [46] and the improved correction within rigid curves occurs with an increase in fixation points [46, 47]. However, we are not at a point where we know the exact number of fixation points to place based on the curve magnitude, preoperative flexibility and the degree flexibility created by soft tissue release and osteotomies.

The long-term safety of pedicle screw instrumentation is however not known and the increasing number of cases report related to pedicle screw complication must be remembered for each case we perform such type of instrumentation. Complications should be reported not per number of screws inserted, but rather per patient operated. Other techniques such as hooks still should be taught and mastered as they may be less dangerous in some specific cases (revision in fusion mass or very thin pedicles). Our young generation of surgeons is lacking experience of

techniques other than pedicle screws and therefore we should still teach other method of fixation. The question “Pedicle screws and spinal deformities: have we gone too far?” is not a yes or no response. It is a thought-provoking question that hopefully promotes a more thoughtful surgeon. One that recognizes any instrumentation on the apex of the concavity has risks and this must be weighed against the benefits, outcomes both technically and patient centered should be considered, and all surgeons rather directly involved with distributor costs or not should understand the financial implications. Definitively we can answer that for some spinal deformities instrumented with all-pedicle-screw instrumentation we have observed cases where the surgeons have gone way too far; in other cases, where the use of such instrumentation was performed in a comprehensive and rational manner, the answer to “Have we gone too far” is no, and such use of pedicle screw has improved the outcome with minimum complications.

Conflict of interest None.

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