Accuracy of free-hand placement of thoracic pedicle screws in adolescent idiopathic scoliosis: how much of a difference does surgeon experience make?

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Abstract The use of thoracic pedicle screws for the treatment of adolescent idiopathic scoliosis (AIS) has gained widespread popularity. However, the placement of pedicle screws in the deformed spine poses unique challenges, and surgeons experience a learning curve. The in vivo accuracy as determined by computed tomography (CT) of placement of thoracic pedicle screws in the deformed spine as a function of surgeon experience is unknown. We undertook a retrospective review to determine the effect of surgeon experience on the accuracy of thoracic pedicle screw placement in AIS. In 2005, we started to obtain routine postoperative CT scans on patients undergoing a spinal fusion. From a database of these patients, we selected AIS patients, who underwent a posterior spinal fusion. Fifteen consecutive patients for each of the following three groups stratified by attending surgeon experience were selected ($N = 45$): A) less than 20 cases of all pedicle screw constructs for AIS (surgeons <2 years of practice), B) 20–50 cases (surgeons 2–5 years of practice), and C) greater than 50 cases (surgeons greater than 5 years of practice). Intraoperative evaluation of all screws included probing of the pedicle screw tract, neurophysiologic monitoring, and fluoroscopic confirmation. A total of 856 thoracic pedicle screws were studied. Postoperative CT scans were evaluated by two spine surgeons and a consensus read established as follows: (1) In: intraosseous

placement or ≤ 2 -mm breach, (2) Out: > 2 -mm breach, either medial or lateral. Of the 856 screws, 104 demonstrated a > 2 -mm breach, for an overall rate of 12.1% (medial = 55, lateral = 49, $P = 0.67$). When the breach rates were stratified by surgeon experience, there was a trend toward decreased rate of breach for the most experienced surgeons, although this did not attain statistical significance (Group A: 12.7%, Group B: 12.9%, Group C: 10.8%, $P = 0.58$). However, the most experienced group (C) had a markedly decreased rate of medial breaches (3.5 vs. 7.4% and 8.4% for groups A and B, respectively, $P < 0.01$). The breach rate for the concave periapical screws was not statistically different from the overall breach rate (13.0% vs. 12.1%, $P = 0.93$). In conclusion, the overall accuracy of placement of pedicle screws in the deformed spine was 87.9%, with no neurologic, vascular, or visceral complications. Meticulous technique allows spine surgeons with a range of surgical experience to accurately and safely place thoracic pedicle screws in the deformed spine. The most experienced surgeons demonstrated the lowest rate of medial breaches.

Keywords Adolescent idiopathic scoliosis · Computed tomography · Surgeon experience · Thoracic pedicle screws

Introduction

As the safety and efficacy of pedicle screws are further established, spine surgeons increasingly use them for a variety of pathologies [5, 8, 23, 31, 32]. Thoracic pedicle screws provide numerous advantages over hook–hybrid constructs, including three-column fixation with improved coronal and axial correction [10, 13, 17, 30] and lower

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revision rates [12]. However, the accurate placement of thoracic pedicle screws in the deformed spine poses unique challenges. The breach rates for thoracic pedicle screw placement vary from a low of 1.5% up to 58% [1, 8, 20, 29]. This large variability likely reflects the radiographic method used to detect a breach, with plain X-rays underestimating the incidence. Suk et al. [29] reported a breach rate of 1.5% on a total of 4,604 pedicle screws. However, the vast majority of these were evaluated with plain X-rays. Belmont et al. [1], using postoperative CT, reported a breach rate of 58% in patients with coronal plane deformity. A few other studies report on breach rates for thoracic screw placement in deformity utilizing postoperative CT [9, 14, 20, 26].

Surgeon experience improves outcomes for a variety of procedures. The association between higher volumes and better outcomes has been established for various orthopedic procedures, such as primary hip and knee arthroplasty, revision hip and knee arthroplasty, and hip fractures [7, 24, 25]. Accurate placement of thoracic pedicle screws may be one determinant of surgical outcome following the deformity correction. With respect to the spine, Lehman et al. [14] reviewed the accuracy of placement of thoracic pedicle screws by a single surgeon over an 8-year period. They reported a decreased rate of medial breaches with time as the number of screws placed on the periapical concavity increased. To the best of our knowledge, this is the first report to evaluate the accuracy of thoracic pedicle screw placement between spine surgeons with varying degrees of experience.

Materials and methods

Patient selection

After obtaining IRB approval, we, retrospectively, identified all patients with AIS treated with an all pedicle screw construct after 2005. Since this time, we have routinely obtained a postoperative CT on patients undergoing a spinal fusion. We selected the first 15 consecutive patients stratified by the following groups: (1) attending surgeon experience of all pedicle screw construct for AIS of 0–20 cases (less than 2 years of practice); (2) 20–50 cases (2–5 years of practice); and (c) >50 cases (greater than 5 years of practice). All surgeons were fellowship trained, with each group containing two surgeons.

Placement of thoracic pedicle screws

Surgeons utilized the free-hand technique of pedicle screw placement as previously described [9]. Neuromonitoring was utilized in all cases and included SSEPs, tcMEPS, and EMG evaluation of the thoracic pedicle screws. We utilize

the EMG criteria established by Raynor et al. [21] when assessing thoracic screws. There were three patients in this cohort who experienced neuromonitoring changes. In two patients, the signals improved with an elevation of blood pressure. In the third patient, the signals improved after decreasing the amount of curve correction. In addition, after the placement of the pedicle screws, intraoperative fluoroscopy, and intraoperative X-rays were taken as per our standard practice. Generally, the left-sided pedicle screws are placed by the attending surgeon and the right side by the spine fellow. However, this is variable and for analysis, we attributed all thoracic pedicle screws placed in the select patient to the attending surgeon. Our justification for this is based on the close attending surgeon supervision of the fellow and the attending ultimately deciding whether or not to reposition a pedicle screw.

Evaluation of pedicle breach

A total of 856 thoracic pedicle screws were evaluated with postoperative CT. The postoperative CT was read by two spine surgeons and a consensus read established as follows: (1) In: intraosseous placement or ≤ 2 -mm breach, or (2) Out: >2 -mm breach, either medial or lateral. All of the pedicle screws placed were stainless steel, which can obscure the cortical margins [3, 4]. The majority of the screws above T10 were 5 mm in diameter, with none greater than 6 mm. Conversely, the majority of the screws between T10 and 12 were 6 mm, with none smaller than 5 mm. We optimized pedicle screw visualization with respect to the pedicle using 3-mm fine axial cut CT with bone windows. However, we determined our ability to discern a breach to be 2 mm, and thus the rationale for our categorization of breaches. Figure 1 a–c provides examples of typical breaches encountered. This is similar to what others have reported [1].

Statistical analysis

Analysis of variance was performed to compare the three groups with respect to: (1) patient age, (2) preoperative Cobb's angle, (3) overall breach rate, (4) medial breach rate, (5) lateral breach rate, and (6) concave periapical breach rate. Student's *t* test (two tailed, $\alpha = 0.5$) was used to compare the overall breach rate versus the breach rate for periapical screws.

Results

Patient demographics

There were 15 patients in each of the three groups, for a total of 45 patients with 856 thoracic screws placed. The

Fig. 1 Classification of breaches. **a** Medial breach of less than 2 mm. This screw is ‘In.’ **b** Medial breach greater than 2 mm and **c** lateral breach greater than 2 mm. These screws are ‘Out.’ The *star* denotes screw of interest

Table 1 Patient demographics for three groups

	Group A	Group B	Group C
Number of patients	15	15	15
Total # TPS	283	286	287
Pre-op Cobb*	60° (45–85°)	62.9° (48–79°)	63.3° (40–78°)
Average age (years)**	13.7 (11–17°)	14.6 (12–18°)	14.0 (10–20°)

* $P = 0.43$

** $P = 0.66$

groups were similar with respect to Lenke classification. The average age for the cohort was 14.1 (range 10–20) years with a preoperative Cobb angle of 62° (range 40°–85°). There was no difference between the groups with respect to average patient age or preoperative Cobb’s angle ($P = 0.43$, $P = 0.66$, respectively) (Table 1).

Breach rates

No neurologic, vascular, or visceral complications were encountered in these patients. From the 856 thoracic pedicle screws, we identified 104 total breaches (medial = 55, lateral = 49, $P = 0.67$), for an overall incidence of 12.1%. The overall breach rate for the groups were Group A = 12.7%, Group B = 12.9%, and Group C = 10.8% (Table 2). There was a trend toward a lower breach rate in the most experienced group; however, it did not attain statistical significance ($P = 0.58$). Similarly, the incidence of lateral breaches was not different between the groups ($P = 0.2$). However, the rate of medial breaches was significantly lower for the most experienced surgeons ($A = 7.4\%$, $B = 8.4\%$, $C = 3.5\%$, $P < 0.01$). Interestingly, this is in accordance with the report by Lehman et al. in

Table 2 Overall breach rate

	Group A	Group B	Group C	Total
Screws In	247 (87.3)	249 (87.1)	256 (89.1)	752 (87.9)
Screws Out (%)*	36 (12.7)	37 (12.9)	31 (10.8)	104 (12.1)
Total	283	286	287	856

* $P = 0.58$

Table 3 Medial breach rate lowest for most experienced surgeons

	Group A	Group B	Group C
Medial breach (%)	21 (7.4%)	24 (8.4%)	10 (3.5%)*

* $P < 0.01$

which a single surgeon’s medial breach rate decreased over an 8-year time period (Table 3).

Periapical screws

The concave periapical (T5–8) pedicles are often deformed and are considered to be the most difficult for pedicle screw placement [2, 16, 18, 26]. Thus, we hypothesized that these pedicle screws would demonstrate the highest breach rates. The total number of periapical screws placed was 169 with 22 breaches (medial = 11 and lateral = 11), for a breach rate of 13.0%. This rate was not different than the overall breach rate of 12.1% ($P = 0.9$). There was no difference between the groups with respect to the number of periapical screws placed ($A = 57$, $B = 58$, $C = 54$, $P = 0.87$). Similarly, the breach rates for the individual groups were not different for the periapical screws ($A = 14.0\%$, $B = 12.1\%$, $C = 13.0\%$, $P = 0.93$).

Discussion

The current study reports an overall breach rate for thoracic pedicle screws of 12.1% with a trend toward a lower breach rate for the most experienced surgeons, although this did not attain statistical significance. However, the medial breach rate was significantly lower for surgeons with the most experience. These results imply that with meticulous attention to insertion technique and appropriate use of intraoperative modalities, such as intraoperative EMG, fluoroscopy, and X-rays, appropriately trained spine surgeons with variable experience levels can safely and accurately place thoracic pedicle screws in the deformed spine. However, those with less experience should be cognizant of the higher medial breach rate for this group.

The long-term implications of asymptomatic thoracic pedicle screw breaches remain largely unknown. In this cohort, there were no neurologic, vascular, or visceral complications which is similar to the low incidence in previous reports [11, 15, 29]. It is likely medial breaches of less than 3 mm are of little clinical significance, as Polly et al. [19] have shown that the volumetric incursion from a large hook is greater than this value. The lateral breaches periapically on the concavity risk abutting the aorta, which is translated laterally and posteriorly in AIS [27]. Although in this cohort, no patients returned to the operating room for the removal of a pedicle screw, we have removed two screws displacing the aorta in asymptomatic patients. These were detected by postoperative CT and the contour deformation confirmed with an aortogram as described by Sucato et al. [28]. The potentially dire implications of these screws were confirmed by the recent report by Kakkos et al. [6]. In this report, the authors describe the formation of aortic pseudoaneurysm in two patients several months following the placement of thoracic pedicle screws.

Interestingly, the breach rate for the periapical screws was similar to the overall breach rate. These pedicles constitute the most deformed and difficult to cannulate in the deformed spine [2, 16, 18, 26]. Smorgick et al. [26] reported a higher breach rate for concave thoracic pedicle screws when compared with the convexity. It is possible that the surgeons in our cohort recognized the potential difficulty with these screws and were more deliberate with placement. The time allotted for placement of each pedicle screw is not available in this retrospective study.

The rate of medial breaches was significantly lower for the most experienced surgeons. This is similar to a single surgeon experience over 8 years in which the medial breach rate decreased over time [14]. The surgeon relies on numerous modalities intraoperatively, when deciding the accuracy of a pedicle screw. This includes the harmonious arc of the screws, tactile determination with a pedicle probe, intraoperative radiography, and EMG. Others have

shown the utility of intraoperative EMG to detect thoracic pedicle screw breach [21, 22]. On the contrary, at our institution, we have deemed EMG to be of limited use in the thoracic spine, and we are in the process of documenting this through a retrospective analysis. We rely more on intraoperative radiography taken both after the pedicle screws have been placed, and again after the deformity correction is completed. Lehman et al. [15] demonstrated the improved ability to palpate pedicle screw breaches with the probe by the most experienced surgeons. This may in part explain the trend toward a decreased overall breach rate, particularly the medial breaches, seen in the most experienced surgeon group.

There are several limitations with our study. First, stainless steel screws were utilized which generate considerable scatter, making it difficult to discern the cortical margins [3, 4]. To account for this inability to precisely determine the extent of breach, we classified the breaches as In (≤ 2 mm) or Out (> 2 mm) because discrimination beyond 2 mm is difficult. The CT sequences were maximized to minimize this scatter and the readings performed on the CT monitor, rather than radiographic films. In addition, the times required to place the pedicle screws were not available and may very well have demonstrated a longer time for the less experienced surgeons. The time required to place the concave periapical screws compared with the others may have demonstrated a similar longer duration. Regardless, the purpose of this study was to determine the rate of breach among surgeons with different levels of experience. Hence, the time required for placing a thoracic pedicle screw was not as important as the final accuracy.

Conclusion

The accuracy of thoracic screw placement in AIS is high for spine surgeons with varying degrees of experience, with lesser experienced spine surgeons causing significantly more medial pedicle screw breaches in comparison to more experienced spine surgeons. However, these breaches do not result in increased neurological injury.

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