Thoracic pedicle screws: postoperative computerized tomography scanning assessment

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Object. The authors evaluated the accuracy of placement of thoracic pedicle screws by performing postoperative computerized tomography (CT) scanning. A grading system is presented by which screw placement is classified in relation to neurological, bone, and intrathoracic landmarks.

Methods. One hundred eighty-five thoracic pedicle screws were implanted in 27 patients with the assistance of computer image guidance or fluoroscopy. Postoperative CT scanning was conducted to determine a grade for each screw: Grade I, entirely contained within pedicle; Grade II, violates lateral pedicle but screw tip entirely contained within the vertebral body (VB); Grade III, tip penetrates anterior or lateral VB; Grade IV, breaches medial or inferior pedicle; and Grade V, violates pedicle or VB and endangers spinal cord, nerve root, or great vessels and requires immediate revision. Based on anatomical morphometry, the spine was subdivided into upper (T1–2), middle (T3–6), and lower (T7–12) regions. Statistical analyses were performed to compare regions. The mean follow-up period was 37.6 months.

The following postoperative CT scanning–documented grades were determined: Grade I, 160 screws (86.5%); Grade II, 15 (8.1%); Grade III, six (3.2%); Grade IV, three (1.6%); and Grade V, one (0.5%). Among cases involving screw misplacements, Grade II placement was most common, and this occurred most frequently in the middle thoracic region.

Conclusions. The authors’ grading system has advantages over those previously described; however, further study to determine its reliability, reproducibility, and predictive value of clinical sequelae is warranted. Postoperative CT scanning should be considered the gold standard for evaluating thoracic pedicle screw placement.

Keywords • pedicle screw • thoracic spine • spinal fixation • computerized tomography

Pedicle screws can be used to stabilize the thoracic spine for various diagnoses including infection, malignancy, trauma, and deformity.1–5,7,10,13–15,23 They offer the biomechanical advantage of three-column stabilization, which, in some cases, can obviate the need for anterior column reconstruction. Although hook or wire constructs can be effective, they are limited to stabilization of the posterior column. With severe VB destruction, hook- or wire-based posterior column stabilization may be prone to late-onset kyphosis and early-onset hardware failure unless structural anterior column support is also provided.

In contrast to the lumbar spine, placing pedicle screws into the thoracic spine is more technically challenging. The pedicles in this region are smaller and exhibit a high degree of inter- and intraspecimen variability.12,21,29 Correct placement depends on a comprehensive familiarity of pedicle anatomy, reliable intraoperative imaging, and meticulous surgical technique.3,30 Screw position is sometimes suboptimal. Computerized tomography scanning has been validated as an accurate method by which to determine screw placement postoperatively.33 Computerized tomography scanning can demonstrate cortical breaches that may occur in different regions of the vertebra. In addition to compromising osseous purchase, pedicle perforations can endanger vital neural and intrathoracic structures.30 Proximity to these structures can influence the decision to revise or remove a misplaced implant.

Previous systems have been developed to grade thoracic pedicle screw positioning. In general, these systems indicate screw position in relation to the pedicle wall.2,5,9,23,31,32 Some systems delineate only two grades ("in" or "out"), regardless of the region of cortical breakthrough.25 In a number of postoperative CT scanning evaluations, placement of the screw is described with respect to the location of the pedicle perforation (medial, lateral, superior, or inferior),5,9 whereas in others malposition is expressed in relation to the percentage of screw diameter lying outside the osseous confines but the region of violation is not indicated.31,32 In other studies the authors have merely reported the incidence of screw malposition without describing the features of the misplacements.27

Abbreviations used in this paper: AP = anteroposterior; ASIA = American Spinal Injury Association; CT = computerized tomography; VB = vertebral body.
These grading systems describe screw position only in relation to the pedicle. Safe screw placement, however, is not limited to the confines of this structure. Recently, the pedicle and its adjacent rib have been termed the pedicle–rib complex. Because of the intimate relationship of these two structures, a screw that penetrates the pedicle’s lateral cortex can still be contained within the bone of the posterior rib. This relationship increases the effective width of available bone in which a screw can be safely placed.

Thoracic pedicle screws can violate the cortices of the VB. Screws can penetrate the anterior or lateral margins. This risk is particularly noteworthy in the T3–6 region where the VBs are small and exhibit a greater triangular morphology. Misplaced screws can endanger the great vessels, the esophagus, and, to a lesser extent, the trachea and lungs. Although screw misplacements in this region have been described, none has been included in previous grading systems.

Clinical Material and Methods

We reviewed records obtained in all patients in whom the senior author (R.F.H.) performed thoracic pedicle screw stabilization for any diagnosis over a 3-year period. Patient age, sex, indication for surgery, and number of instrument-fitted levels were recorded in each case. Neurological status was classified according to the ASIA system.

Preoperative evaluation included high-quality AP and lateral radiographs, thin-section CT scans with bone windows and sagittal reconstructions, and high-resolution magnetic resonance images of the entire thoracic region requiring instrumentation. In addition to characterization of the lesions, the CT scanning was used to assess osseous features and rule out congenital or traumatic deficiencies of the posterior spinal elements that would preclude screw placement. In the thoracic spine, the mediolateral width of the pedicle is substantially smaller than its height. As such, the feasibility of screw insertion into the pedicle was assessed on the preoperative CT scans by measuring the mediolateral width of the pedicles at the levels to be instrumented.

We routinely used either computerized image guidance (StealthSystem; Medtronic Sofamor Danek, Memphis, TN) and/or intraoperative fluoroscopic guidance to assist in screw insertion. The decision to use either of these modalities was based on the difficulty of screw insertion, the level to be treated, and the patient’s neurological status. Computerized image guidance was routinely conducted for insertion of screws into the upper and middle thoracic levels (T1–6). Because of technical constraints due to the patients’ shoulders and scapulae in the upper and middle thoracic spine, lateral fluoroscopy was usually not feasible above the T-6 level. When treating the T1–6 levels, AP fluoroscopic images were used in addition to the computerized image guidance.

In the lower thoracic spine (T7–12), image guidance was performed in intact patients or those with an incomplete neurological deficit. When image guidance was used, intraoperative fluoroscopy was also undertaken to confirm screw placement whenever possible. Fluoroscopy alone was used to guide screw insertion in lower thoracic levels in patients with complete (ASIA Class A) neurological deficits. In cases involving fluoroscopy alone, the insertion point was determined according to the Roy-Camille technique. In cases involving computerized image guidance, the insertion point was spatially determined by the graphic parameters determined in a preoperative planning session. In general, it is our practice to obtain a minimum of 30 intraoperative data points, in a surface-merge technique, for computerized registration of each involved vertebra.

Screw placement was evaluated on all postoperative CT scans. The location of the pedicle screw in relation to osseous and soft-tissue landmarks was recorded. Specifically, it was noted if the screw penetrated the pedicle wall, the lateral or anterior VB, or the medial or lateral aspect of the posterior rib. In addition, the proximity of an anteriorly or laterally misplaced screw to any adjacent intrathoracic structure was noted.

Using CT scanning, screw placement was graded by a single reviewer according to a newly developed system. Grade I denoted a well-placed screw entirely contained within the pedicle and VB (Fig. 1 upper left); Grade II screws violated the lateral pedicle wall but were still contained within the pedicle–rib complex, and the tip of the screw was entirely contained within the VB (Fig. 1 upper center); Grade III implants were those in which the screw tip penetrated the anterior or lateral VB (Fig. 1 upper right); Grade IV screws breached the medial or inferior pedicle borders (Fig. 1 lower left); and Grade V positioning was reserved for screws that endangered the spinal cord, nerve root, or great vessels by violating the VB or pedicle cortices, and that required immediate removal and/or revision of the construct (Fig. 1 lower right).

Based on the unique anatomy of the thoracic spine, subdivisions of similar pedicle morphometry were divided into upper (T1–2), middle (T3–6), and lower (T7–12) regions. Statistical analyses were performed to compare the accuracy of screw placement within each thoracic region, as well as screws placed with and without computerized image guidance (McNemar chi-square analysis or Fisher...
Results

Twenty-seven consecutive patients, 14 male and 13 female, underwent thoracic pedicle screw stabilization and fusion for various diagnoses. Patients were followed clinically and radiographically for a mean of 37.6 months after surgery. The indications for surgery were spinal cord compression, spinal instability, or deformity correction associated with trauma (17 patients), infections (four patients), congenital anomalies (two patients), neoplasms (two patients), deformity (one patient), and degenerative disease (one patient). The mean patient age was 39.1 years (range 6–76 years). Preoperatively, the ASIA classification was determined for each case. There were 12 patients with ASIA Class A deficits, nine with ASIA Class C deficits, one with an ASIA Class D injury, and five with no neurological deficits (ASIA Class E). No patient suffered neurological deterioration postoperatively.

A total of 185 screws were inserted. Screws were placed most frequently in the lower thoracic (T7–12) region (96 screws [52%]). Sixty screws (32%) were placed in the middle (T3–6) region and 29 screws (16%) were inserted in the upper (T1–2) region. A postoperative CT scan was obtained for all patients.

In 18 patients, posterior instrumentation-augmented fusion was performed alone, whereas in nine combined anterior–posterior stabilization and fusion were performed. Computerized image-guided screw insertion was used in 16 patients (59%) for the placement of 128 screws (69%). Intraoperative fluoroscopy alone was used to assist in screw insertion in 11 patients (41%) for the placement of 57 screws (31%). No intraoperative complications related to screw placement were observed.

All 185 screws were evaluated by postoperative CT scanning. According to our thoracic pedicle screw grading system, 160 screws (86.5%) were Grade I, 15 (8.1%) were Grade II, six (3.2%) were Grade III, three (1.6%) were Grade IV, and one (0.5%) was Grade V. A Grade I rating was achieved in 82% of screws inserted with computerized image guidance and in 96.5% of those inserted with fluoroscopy alone (Table 1). These values were not statistically different, although a trend toward higher accuracy with the fluoroscopy alone was noted (p = 0.057).

Grades II, III, IV, and V screw placements were more frequent in the middle (T3–6) region compared with the upper (T1–2) and lower (T7–12) regions (p = 0.0684). No statistically significant difference in the incidence of misplaced screws was detectable when comparing the three regions to each other for either Grade I placements or when Grade I and II placements were considered together (Tables 2 and 3). Comparisons between screws placed with image guidance and those with fluoroscopy alone revealed no statistically significant differences (Tables 4 and 5).

After the postoperative CT scan was reviewed for each patient, follow-up evaluations were performed at regularly scheduled intervals; these involved clinical and plain

exact test). Statistical significance was defined as a probability value less than 0.05.

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radiographic examinations. At latest follow-up evaluation, solid fusion and maintenance of correction were documented in 24 patients. One patient who had sustained a traumatic injury (ASIA Class A spinal cord injury) and who underwent a posterior thoracic procedure died 1 month postoperatively, prior to radiographically demonstrated bone union, of pulmonary complications not related to the spinal procedure. Both patients who underwent posterior surgery for metastatic tumors improved neurologically postoperatively. Both of these patients died within the 1st postoperative year, with stable instrumented constructs. No case of progressive deformity, hardware failure, or postoperative wound infection was observed.

Discussion

Although methods have been developed to improve screw insertion accuracy, thoracic pedicle screw misplacements continue to occur. As the use of thoracic pedicle screws continues to increase, postsurgical protocols for evaluating safe screw insertion become more important. Thoracic pedicle screw grading systems are an integral constituent of such protocols. Although plain radiography is helpful, postoperative CT scanning has become the gold standard for the evaluation of screw position. Most authors seem to agree that an effective grading system should be based on postoperative CT scanning studies. Vaccaro, et al., described the insertion of 5-mm pedicle screws into the thoracic spines of five human cadavers by using the standard Roy-Camille technique. No image intensification was used. Because the incidence of misplaced screws was high (41%), they considered the aorta to be at greatest risk with anterior violation of the VB. Likewise, the spinal cord was at high risk of injury when the medial pedicle wall was penetrated. Although the authors warned of the risks of using these implants, it should be noted that fluoroscopy was not used during insertion, and 5-mm screws were inserted regardless of the size of the patient or the vertebral level. In essence, this was the worst-case scenario of thoracic pedicle screw placement. These authors did not use a grading system for the misplaced screws.

In an anatomical study in which the Roy-Camille technique was compared with the open lamina technique, Xu, et al., inserted 189 thoracic pedicle screws into 10 human cadaveric spines. Fluoroscopy was not used during placement. By direct inspection, they detected more cortical perforations by using the Roy-Camille method (55%) than the open-lamina technique (16%). Because these were all graded according to direct inspection, the ability to distinguish between the individual grades on postprocedural CT scanning was not evaluated.

Guven and associates have assessed the accuracy of in vivo CT scanning–based pedicle screw placement in the thoracic and lumbar spine. Screws were inserted according to the intersection (Roy-Camille) technique without fluoroscopy. The authors classified screw position by the location of the cortical perforation, differentiating between medial, lateral, superior, and inferior misplacements. Although most screws were correctly placed, 3% violated the medial cortex, 5% breached the lateral cortex, and 2% violated the superior cortex. No screw-related complications were reported.

Sapkas, et al., graded thoracic and lumbar pedicle screw placement as either “in” or “out” according to postoperative CT scans and plain radiographs obtained in 35 patients. The investigators concluded that CT scanning depicted screw misplacements more clearly than plain radiography. Screws were inserted according to the technique described by Steffee, et al., by using intraoperative lateral radiographs. Ninety-seven percent of screws were graded as “in.” The authors did not characterize the location or severity of misplaced screws.

Some authors have noted that the location of pedicle violation is important. Guven and associates have highlighted the fact that lateral pedicle violations are less likely to cause significant clinical sequelae. As O’Brien, et al., have demonstrated, perforation of the lateral pedicle wall can be effectively compensated by the adjacent rib.

### Table 1

<table>
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<th>Placement Grade (no. of screws)</th>
<th>Image Guidance</th>
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Vaccaro, et al., 30 have demonstrated, violation of the confines of the VB can endanger important intrathoracic structures. Thus, it was our goal to include perforations of the VB in a more comprehensive system.

It is our belief that a Grade II thoracic pedicle screw placement that violates the lateral wall of the pedicle, is contained within the adjacent rib, and terminates within the VB proper is acceptable in terms of safety. Particularly in the middle thoracic region (T3–6), the pedicle width is frequently too narrow to accept an adequate-sized screw. As such, when the pedicle width is less than 5 mm, we have used 5.5-mm screws intentionally placed through the pedicle–rib complex, as described by O'Brien, et al. 20 This mandates the classification of a Grade II misplacement. Of the 185 screws inserted in this study, placement of 175 (95%) was rated as Grade I or II. Because there was neither hardware nor fusion failure in this study, it is our opinion that the added stability provided by larger screws placed through the pedicle–rib complex is not only acceptable but preferable.

The accuracy results reported by Kamimura, et al., 11 Amiot, et al., 3 and Youkilis, et al., 33 are in contrast to our findings. Only 82% of computerized image-guided screws were rated Grade I (“perfect” placement), whereas 96.5% of those inserted using plain fluoroscopy were accurately placed without cortical perforation. These values can erroneously lead one to believe that fluoroscopy alone is more accurate. This discrepancy, however, is most likely secondary to selection bias. The Stealth computer guidance system was used in the more difficult cases with greater anatomical constraints—in particular, the upper and middle thoracic regions. In fact, a statistically greater proportion of the screws were placed using computerized image guidance rather than fluoroscopy alone in the middle thoracic region (p = 0.018). Screw insertion at these levels would be more difficult regardless of the insertion method. In the lower thoracic region, fluoroscopy alone was more commonly used (p = 0.019). Because the pedicles are larger in this area, insertion is less technically challenging and more frequently leads to Grade I placements.

When comparing the results of screw accuracy in our study with previous studies of thoracic pedicle screw stabilization, it is important to recognize which levels were fitted with instrumentation in each study. In the present report, nearly half of the screws (48%) were placed in the technically challenging upper and middle thoracic regions. In the only study in which the majority of pedicle screws (60%) were placed between the T-1 and T-6 vertebral levels in cadavers, Xu, et al., 31 demonstrated an overall pedicle violation rate of 35%. Of the other published reviews on the accuracy of thoracic pedicle screw inser-
tion, none was associated with placements predominantly in the upper and middle thoracic regions.3,9,11,17,20,25,26,30,33

In the lower thoracic vertebrae, a larger (5.5- or 6.25-mm) screw is more easily contained within the confines of the pedicle facilitating a Grade I placement. In the middle region (T3–6), a screw that is larger than the pedicle may sometimes be optimal. By considering the pedicle–rib complex, the effective osseous pathway is greater. This allows for insertion of a larger screw than could be contained within the pedicle alone.20 Although lateral cortical perforation may theoretically jeopardize the nerve roots, the rib immediately lateral to the pedicle provides a margin of safety. Thus, because larger screws may provide greater fixation strength, we often intend Grade II placements in the T3–6 vertebrae. In the upper (T1–2) region, preservation of the nerve roots is critical to upper-extremity function. Consequently, a smaller screw is frequently placed to ensure better Grade I placement.

Based on the present data, there appears to be a regional predisposition for screw misplacement when the upper and middle regions are compared with the lower thoracic region. Because the effective thoracic pedicle width decreases from the lower to the middle thoracic regions, it is thought that screw insertion into the more cranial vertebrae is more difficult.29 Despite anatomical data suggesting that the effective pedicle width is smaller in the middle than the upper and lower regions,8 we found only a marginal predisposition for misplaced screws between these two groups (p = 0.0684). If both Grade I or II placements are accepted acceptable, the rates of misplacements between the middle and the upper/lower thoracic regions are more comparable (p = 0.272). With proper insertion technique and selection of screw size, placement complications can be minimized in any anatomical region.

Because it is our philosophy that Grade II placements are acceptable in the thoracic spine, statistical comparisons were performed that included both Grades I and II together. No statistical analysis demonstrated significant differences in screw accuracy whether image guidance or fluoroscopy alone was used. Furthermore, when each region of the thoracic spine was analyzed separately and compared with the other two regions, no statistically significant differences were found.

We are aware of this study’s limitations. As a preliminary investigation, it was our main focus to evaluate objectively screw placement by using postoperative CT scanning data. It is important to note that screws were graded by one reviewer. To improve the validation of such a system, inter- and intraobserver reliability and reproducibility must be evaluated by κ statistic. Furthermore, the clinical significance of each grade must be considered.

This is best determined by undertaking a prospective clinical investigation. It is our future goal to determine the natural history of Grade II through IV screw misplacements and whether implants in these locations lead to the manifestation of sequelae. At present, we strongly believe that Grade V screws should be carefully removed or revised in the operating room as soon as possible.

Conclusions

In this study we described a grading system based on evaluation of postoperative CT scans. In any studies involving the use of plain radiography to evaluate thoracic pedicle screw placement accuracy, investigators will likely underestimate the number of misplaced screws. In addition, because of the narrow width of the thoracic pedicles in the middle region, studies involving insertion of a higher percentage of screws in this region will have a greater number of screws placed outside the pedicle.

We routinely used computerized image guidance (StealthSystem) in the upper and middle thoracic regions for two reasons: the pedicles are narrower and intraoperative lateral fluoroscopy is not technically feasible. As a result, the higher incidence of screws misplaced using computerized image guidance in this study is not due to a failure of the computerized guidance system, but rather a selection bias resulting from the use of this technique in the more challenging anatomical regions of the thoracic spine.

We have defined screw placement based on its relationship to the osseous, neurological, and intrathoracic structures. The presented grading system has several advantages over those previously described; however, further investigation will be necessary to determine its reliability, reproducibility, and predictive value of clinical sequelae. Because of the high risk of screw misplacement in the thoracic spine, particularly in the middle (T3–6) region, we recommend routine use of postoperative CT scanning in all cases in which thoracic pedicle screws have been placed.

References


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