Use of anteroposterior view fluoroscopy for targeting percutaneous pedicle screws in cases of spinal deformity with axial rotation

Clinical article

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Object. Over the past decade percutaneous pedicle screws have become popular for the minimally invasive treatment of spinal disorders. However, until the last 5 years the presence of a significant spinal deformity was regarded as a relative contraindication for percutaneous instrumentation. Recent advances in surgical technique and intraoperative technology have made percutaneous fixation in complex spinal pathologies more commonplace. The authors report their experience using a parsimonious method for uniplanar fluoroscopic targeting of pedicles in challenging cases.

Methods. The authors performed a retrospective analysis of patients with adult spinal deformity who underwent percutaneous pedicle screw instrumentation from 2008 to 2013. Cases were included if a spiral slice postoperative CT scan was obtained. All cases had a minimum of 10° of axial rotation and typically had additional accompanying anatomical abnormalities. Screws were assessed for any pedicle violations as well as any impingement of the surrounding facet joints.

Results. A total of 410 pedicle screws were placed in 36 patients with an average 6.4 levels of instrumentation per patient. The mean age was 67 years (range 44–86 years) and there were 25 females. Of the 410 screws, 29 (7.1%) had some medial or lateral pedicle violation. Of these, 15 (3.7%) were Grade 1, 6 (1.4%) were Grade 2, and 8 (2.0%) were Grade 3 violations. Of the Grade 3 violations, 2 each were at the L-4, L-5, and S-1 levels, and 1 each was at the T-10 and L-1 levels. Two of the patients had symptoms and both underwent screw repositioning, one during the same admission and the other in a delayed fashion. Both were at the L-5 and S-1 levels with anatomically highly medialized pedicles. There were no motor deficits, and both resections were for numbness. Of the 72 screws at the proximal end of the construct, there were 6 facet violations (8.3%). Four (5.6%) of these were Grade 1, 1 (1.4%) was Grade 2, and 1 (1.4%) was Grade 3.

Conclusions. The anteroposterior fluoroscopic technique can be effectively used by spinal surgeons to cannulate the pedicles in patients with rotational deformities. The complication rate in this challenging population is acceptable and is in accordance with the existing literature. However, caution should be used at L-5 and S-1 when the pedicle is narrow and highly medialized, rendering an indistinct medial wall on anteroposterior imaging.

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Key Words • minimally invasive • spinal deformity • complication • scoliosis • pedicle screw • percutaneous • adjacent segment • facet joint • technique

Percutaneous pedicle screws are an increasingly popular method for thoracolumbar spinal fixation. The use of percutaneous screws reduces the soft-tissue envelope disruption associated with traditional open surgery. However, the lack of exposed skeletal anatomy can make accurate pedicle cannulation more difficult. This problem is exacerbated when anatomical variations are present, such as in patients with a spinal deformity.

Several studies have examined the rate of pedicle breaches with screw placement, finding that pedicle wall violations can occur in up to 29% of even routine cases.2,13,17,25 Pedicle wall violations increase the risk of neurological injury. Furthermore, violation of the facet joint at the top of an instrumentation construct by the pedicle screw has the potential for increasing the chances of adjacent-level disease.2,4,8,10,18 Previous studies have documented a variable rate of facet joint compromise, ranging from 24% to 100%, and it is unclear in the literature if a percutaneous technique is less likely to cause a facet violation compared with open techniques.

Both open and percutaneous instrumentation can also be more challenging in the setting of spinal deformity due to vertebral body rotation, pedicle asymmetry, small pedicle size, and suboptimal intraoperative imag-
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Methods

Data Collection

We retrospectively analyzed all patients who underwent percutaneous pedicle screw instrumentation over a 5-year period (January 2008 to February 2013). These data were recorded in a prospective fashion by the senior author. We examined patient demographics, clinical diagnosis, type of procedure performed, results, complications, and the type of implants placed. All patients underwent both pre- and postoperative 3D radiological imaging, and only those patients with postoperative CT scans were included in the study. At each treated level pedicle size and caliber, screw diameter, and preexisting degree of rotation of the vertebra were assessed on an electronic film library.

Postoperative spiral slice CT scans were used to assess medial, lateral, superior, or inferior pedicle breaches. Separately, violations of the facet joint just cephalad to the screw level were assessed. Axial images were used along with sagittal and coronal reconstructions for accurate assessments. Each pedicle screw was graded on a 4-point scale based on its position inside the pedicle and the breach of its medial/lateral wall (Grade 0, no pedicle violation; Grade 1, < 2-mm pedicle violation; Grade 2, 2- to 4-mm pedicle violation; and Grade 3, > 4-mm violation) (Fig. 1). Medial and lateral violations were grouped together for analysis based on the degree of breach. In some instances, the pedicles were smaller than the intended screw diameter and in the thoracic spine the “in-out-in” technique was used purposely to enter the pedicle more laterally to avoid a medial pedicle violation. These screws with an intentional rib head violation were not included in the analysis of breaches (Fig. 2).

Facet joint violations were graded as: Grade 0, screw not contacting facet synovium or subchondral cortical bone; Grade 1, screw in lateral facet cortical bone but not involving the synovium; Grade 2, part of screw in the articulating surface less than 1 mm; and Grade 3, screw traveling inside the facet joint space itself (Fig. 3). The grading was done using axial images and correlating with sagittal and coronal reconstructions.

Surgical Technique

All patients underwent surgery using a single standard C-arm fluoroscopic machine in the prone position. Jamshedi needles and K-wires were used to cannulate the pedicles using the AP-only technique, followed by screw placement under lateral fluoroscopy. Prior to cannulation, an AP fluoroscopic image was obtained that was unique to each vertebral level. The axial rotation of the vertebral body on the preoperative CT scan is measured, and this serves as a rough guide on how much to angle our C-arm arc and in which direction. This image is obtained by manipulating the C-arm so that the superior endplate of the vertebra to be instrumented is clearly visualized as a single line (coaxial with the upper endplate) and the spinous process is centered between the two pedicles. Sagittal angulation axial and rotation of the C-arm is needed at each level to compensate for the spinal deformity (Fig. 4).

A Jamshedi needle is then docked on the bony surface at the junction of the lateral facet joint and transverse process (Figs. 5 left and 6A–C). The needle is then advanced into the bone to a depth of 2 cm while ensuring under AP imaging that the needle tip does not pass the medial wall of the pedicle (Figs. 5 right and 6D–F). At this depth the tip of the needle should have passed the spinal canal. The needle is then advanced half way through the vertebral body and is then exchanged for a K-wire. The process is repeated for each level. Preparation of screw tracks and placement of the screw are then done under lateral fluoroscopic imaging (Fig. 6). We do not perform electromyographic stimulation of percutaneous screws. A previous study from our center did not demonstrate any benefit from such neurophysiological testing.

Results

During the study period, 64 patients (646 screws) underwent thoracolumbar fusion using percutaneous pedicle screw instrumentation. Of these patients, 36 patients (410 screws) underwent postoperative thin-cut CT scanning for various reasons and were used for analysis. It is not our policy to obtain postoperative CT scans in all patients, especially if the surgery and postoperative course were straightforward. The mean age was 67 years (range 44–86 years), and there were 25 females and 11 males. A mean of 6.4 levels were instrumented in each patient. All of these patients had adult degenerative deformity of various degrees, with or without stenosis/spondylolisthesis.

There were varying degrees of axial rotation at each vertebral level, ranging from 0° to 32° to the vertical. The
mean rotation was 5° at T-10, 7.4° at T-11, 11.0° at T-12, 13.1° at L-1, 10.9° at L-2, 10.5° at L-3, 6.5° at L-4, 4.5° at L-5, and 3.6° at S-1 (Fig. 7). Most of the patients had mild to moderate spinal deformity. The mean size of the pedicles ranged from 6.3 to 16.6 mm on axial CT in the mediolateral direction. We typically use 6- or 7-mm screws at thoracic and lumbar levels and usually 6-mm screws in the upper lumbar and 7-mm screws in the lower lumbar regions. Sometimes the screw used is marginally bigger than the pedicle size, in which case the screw expands the pedicle from inside. We also use the in-out-in technique sometimes if the pedicle is too small (Fig. 2).

Of 410 screws, 29 (7.07%) showed some degree of pedicle violation. Of these, 15 were Grade 1 (3.65% of total screws), 6 were Grade 2 violations (1.45%), and 8 were Grade 3 violations (1.95%) (Table 1). Of the Grade 3 violations, 2 each were at L-4, L-5, and S-1 levels and 1 each was at T-10 and L-1 levels. The mean angle of vertebral rotation in those with Grade 0, 1, 2, and 3 pedicle breaches were 8.0°, 7.8°, 8.6°, and 5.6°, respectively. The degree of rotation did not determine the accuracy of pedicle screw placement in our study, which again reiterates the point that with careful positioning of the C-arm to obtain a good AP image of the rotated vertebra, even scoliotic vertebral levels can be cannulated percutaneously with good accuracy.

Only 2 patients had symptoms due to screw misplacement, one with pain and numbness and another with only numbness. Both patients underwent reoperation for screw repositioning, one during the same admission and the other months later. These cases involved the L-5 and S-1 levels, respectively, and both had highly angulated and medialized pedicles rendering an indistinct medial wall (Fig. 3C). Both patients improved after the revision surgery.

There were 46 facet violations in 410 screws (11.2%). Most of these were Grade 1 violations (32 Grade 1 violations, 7 Grade 2 violations, and 7 Grade 3 violations of the facet). Of the 7 Grade 3 violations of the facet, 4 were at the L5–S1 joint, 2 were at the L4–5 joint, and 1 was at the T10–11 joint (Table 1). Looking at the facet violations at the top of the construct, there were 6 violations (8.3%) at 72 levels (both sides in 36 patients). Four of these were Grade 1 and 1 each was Grade 2 and Grade 3.

Discussion

Multiple studies have demonstrated the potential benefits of minimally invasive surgery (MIS) approaches to the spine. However, percutaneous pedicle screw insertion has certain drawbacks, including the lack of direct visualization and “feel” of tissues for the surgeon. Thus, surgeons must rely heavily upon intraoperative imaging for safe instrumentation.

Pedicle Wall Breaches

Pedicle wall violations are an obvious concern for surgeons as they place the neural elements at risk. In a clinical series of 150 percutaneously placed screws, Nakashima et al. identified that 12% of screws were “exposed” (defined as < 50% outside the pedicle) and 3.3% of screws were perforated (defined as > 50% screw diameter outside the pedicle). Knox et al. reported a very low cortical violation rate of 2.5% in their series on pa-
Accuracy of pedicle screw placement in AP view

Patients undergoing MIS transforaminal lumbar interbody fusion (TLIF) patients. A more recent prospective study of spinal fractures reported good or excellent placement for 98% of 502 pedicle screws placed using fluoroscopic guidance. Another recent prospective study by the Fessler group revealed a 6.2% pedicle breach rate for 601 screws placed for MIS TLIF procedures. Most breaches were medial; 2 patients were symptomatic, and none of the patients required hardware removal. There is some evidence that computer-assisted navigation can reduce pedicle violation rates. In a prospective comparative multicenter study by Yang and colleagues, the pedicle violation rate was 3% in the navigation group and 7.2% in the fluoroscopy group (p < 0.55). A meta-analysis revealed an average screw placement accuracy of 92.1% with navigation and with 87.3% without navigation. Another study by Ravi et al. found a 23% pedicle screw breach rate with the majority (83.8%) being Grade II.17

In those previous series the majority of patients studied had relatively normal anatomy and short-segment instrumentation. In this series we deliberately selected patients with significant anatomical abnormalities, defined as a spinal deformity with an associated maximal axial rotation of at least 10°. Axial rotation is the abnormality most difficult to compensate for using uniplanar imaging. It is also the alignment abnormality most likely to cause a medial or lateral pedicle breach. In our series, the overall pedicle violation rate was 7.07%. Half of these violations were Grade 1 (< 2-mm breach). Most of these were at the lower lumbar levels (Table 1), which is consistent with the reports in literature.15

Two patients in this series underwent hardware repositioning. The L-5 and S-1 pedicles are typically the largest in size in the lumbar spine. The steep angle of pedicles with the body can sometimes obscure a good view of the pedicles on AP fluoroscopy. The pedicle lateral to medial angle increases about 5° per level as we descend from L-1 to S-1. Both of our repositioning cases occurred at the lumbosacral junction, and both occurred in cases where the pedicle axis was highly medialized. This anatomical variant is common and is also associated with a triangular-shaped L-5 or S-1 vertebral body. In these cases, medialization of the screw is critical to prevent protrusion of the screw through the anterior vertebral cortex. However, a lateral starting point is necessary to prevent a medial violation. In open surgical cases, this requires a wide soft-tissue exposure to obtain the ideal starting point and screw trajectory. Thus, a percutaneous approach allows for a more easily achieved ideal trajectory. However, in these cases the medial wall is poorly visualized on 2D AP imaging, and caution should be used with the AP tech-
nique in these cases. Obtaining an oblique or “owl’s eye” view of these angulated pedicles may be helpful in some cases in which the medial wall is not well visualized on standard AP imaging.

**Superior Facet Violations**

Screw impingement of the superior facet joint at the top of a surgical construct has recently received significant attention. This potentially increases the risk of adjacent-segment disease by placing more stress on a damaged joint adjacent to a long segment fusion. Multiple studies have documented this violation, both in open and percutaneous surgeries, with a range from 24% to 100% in open studies and 11% to 50% for percutaneous studies.2,4,6–8,10,14,18 Shah et al.18 performed one of the first studies to look at the superior facet violations by pedicle screws using postoperative CT scanning and found the incidence to be greater than 20%. It has been identified in 24% of patients undergoing TLIF by open midline approach and 32% of patients undergoing TLIF by the Wiltse approach.11,18 Patel et al.16 observed a facet violation rate of 58% in a cadaveric study looking at fluoroscope-guided placement by 4 different orthopedic surgeons.

In theory, percutaneous pedicle cannulation has the advantage of not being limited by the soft-tissue exposure laterally, allowing a more ideal (lateral to medial) pedicle screw trajectory and potentially avoiding the facet joint. Therefore, the degree of facet violation clearly is related to the surgical technique used, as the surgeon chooses the screw entry point and trajectory. Chen et al.4 found a 100% facet violation rate using the Roy-Camille method and a 25% violation rate using Weinstein’s method. Yson et al.26 found a cranial facet violation rate of 26.5% with open technique and only 4% with percutaneous technique. Knox et al.14 had an incidence of 11.5% of superior facet violation using percutaneous techniques. However, in a comparison of open versus percutaneous cases, other authors have found a higher incidence of both over facet violation and high-grade facet violation in the percutaneous cases.2,6 Because screw trajectory is not limited by the lateral soft tissues in the percutaneous technique, we can eas-
ily start more laterally and aim more medially to avoid the facet joint. This could potentially result in fewer facet joint violations. However, the lack of direct visualization of the facet joint could also lead to its inadvertent injury. In our series, the rate of facet violation overall was relatively low (11.2%) compared with other percutaneous series. Considering only the top of the construct (which is the most important level from a clinical perspective), this rate was even lower (8.3%). This is likely related to the methods used. Other surgeons have used an owl’s eye technique, which targets the pedicle with fluoroscopy directed down the shaft of the pedicle, a method potentially associated with a higher rate of facet violations.

Most of our Grade 3 facet violations occurred at lumbar sacral levels. This is consistent with the experience of other authors and was probably related to the higher prevalence of hypertrophic facet joints in the lower lumbar spine, as it is sometimes difficult to go lateral enough to avoid the joint. Babu et al. also found an increased risk of a facet violation in percutaneous cases, especially in patients younger than 65 years or with a body mass index greater than 30 kg/m². They attributed greater skin elasticity and muscle density in younger patients as potential factors that can interfere with accurate screw trajectory. Obesity as a factor is understandable, as it is harder to visualize the anatomy with fluoroscopy in overweight patients.

There is also evidence that the use of intraoperative CT-guided navigation may result in a lower rate of facet violation. This may be related to the fact that an accurate intraoperative CT scan may allow the surgeon to project the virtual screw trajectory in all 3 planes and adjust the entry point and direction based on pseudo–real-time feedback. However, another study on patients undergoing TLIF did not find a similar benefit with the use of O-arm navigation.

Conclusions

The results of this study show that an AP fluoroscopy technique can be safely used to cannulate thoracolumbar pedicles even in most patients with kyphoscoliotic and rotated spines. The overall incidence of pedicle breaches and facet joint violations was low and is consistent with

<table>
<thead>
<tr>
<th>Vertebral Level</th>
<th>No. of Screws</th>
<th>Mean Pedicle Size (mm)</th>
<th>Mean Screw Size (mm)</th>
<th>Vertebral Angle (°)</th>
<th>Pedicle Breach</th>
<th>Facet Violation</th>
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<tr>
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<td></td>
<td>Grade</td>
<td>No. of Breaches</td>
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<tr>
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<td>6.4</td>
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<td>6.7</td>
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<td>16.6</td>
<td>6.7</td>
<td>3.6</td>
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<td>2</td>
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TABLE 1: The degree of pedicle and facet joint violations in relation to the vertebral level
the rates in existing literature across various techniques. However, caution should be used at L-5 and S-1 when the pedicle is narrow and highly medialized, rendering a less distinct medial wall on AP imaging.

Disclosure

Dr. Wang is a consultant for DePuy Spine and Aesculap Spine and is a patent holder with DePuy Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: both authors. Acquisition of data: Ahmad. Analysis and interpretation of data: Ahmad. Drafting the article: Ahmad. Critically revising the article: both authors. Reviewing the submitted manuscript: both authors. Approving the final version of the manuscript on behalf of both authors: Wang. Administrative/technical/material support: Wang. Study supervision: Wang.

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