Accuracy of percutaneous lumbar pedicle screw placement using the oblique or “owl’s-eye” view and novel guidance technology

Clinical article

CARY IDLER, M.D., KEVIN W. ROLFE, M.D., M.P.H., and JOSÉ E. GOREK, M.D.

1Orthopaedic Specialists of North Carolina, Wake Forest, North Carolina; 2Department of Orthopaedic Surgery, Harbor-UCLA Medical Center, Torrance, California; and 3Spine Center, Kaiser Oakland Medical Center, Oakland, California

Objective. This study was conducted to assess the in vivo safety and accuracy of percutaneous lumbar pedicle screw placement using the owl’s-eye view of the pedicle axis and a new guidance technology system that facilitates orientation of the C-arm into the appropriate fluoroscopic view and the pedicle cannulation tool in the corresponding trajectory.

Methods. A total of 326 percutaneous pedicle screws were placed from L-3 to S-1 in 85 consecutive adult patients. Placement was performed using simple coaxial imaging of the pedicle with the owl’s-eye fluoroscopic view. NeuroVision, a new guidance system using accelerometer technology, helped align the C-arm trajectory into the owl’s-eye view and the cannulation tool in the same trajectory. Postoperative fine-cut CT scans were acquired to assess screw position. Medical records were reviewed for complications.

Results. Five of 326 screws breached a pedicle cortex—all breaches were less than 2 mm—for an accuracy rate of 98.47%. Five screws violated an adjacent facet joint. All were at the S-1 superior facet and included in a fusion. No screw violated an adjacent mobile facet or disc space. There were no cases of new or worsening neurological symptoms or deficits for an overall clinical accuracy of 100%.

Conclusions. The owl’s-eye technique of coaxial pedicle imaging with the C-arm fluoroscopy, facilitated by NeuroVision, is a safe and accurate means by which to place percutaneous pedicle screws for degenerative conditions of the lumbar spine. This is the largest series reported to use the oblique or owl’s-eye projection for percutaneous pedicle screw insertion. The accuracy of percutaneous screw insertion with this technique meets or exceeds that of other reported clinical series or techniques. (DOI: 10.3171/2010.4.SPINE09580)

Key Words • percutaneous pedicle screw • image guidance • owl’s-eye projection • lumbar spine

Accurate placement of pedicle screws during the implantation of spinal instrumentation is critical. Inaccurate placement not only reduces the mechanical strength of the construct but can cause neurological or vascular injury. Malpositioned screws lead to pedicle breaches in 5%–41% and neurological injury in 1%–11% of patients who undergo open, lumbar spinal instrumentation procedures despite the aid of biaxial, intraoperative fluoroscopy and anatomical landmarks.4,6,7,8,13,16,19,20,23,25,28,35,42,45

At present, open procedures are being increasingly abandoned for minimally invasive procedures, including percutaneous pedicle screw placement, because of purported benefits such as decreased blood loss, perioperative morbidity and pain, expedited ambulation, shorter hospital stays, and faster return to work.14,31 However, reduced visualization of bony landmarks and tactile feedback while performing percutaneous procedures can hinder accurate screw placement and has required greater reliance on fluoroscopy or computer-assisted navigation systems.21

Although numerous authors have reported on the accuracy of percutaneous pedicle screw placement, little attention has been given to simple coaxial imaging of the pedicle using the owl’s eye view in favor of more complex 3D navigational and guidance systems. Herein, we report the accuracy of percutaneous lumbar pedicle screw placement in 85 consecutive patients in whom we used the owl’s-eye technique in conjunction with a new technology that facilitates reproducible attainment of the view with a standard fluoroscope.
Methods

After receiving institutional review board approval, we reviewed data obtained in 85 consecutive adult patients in whom placement of percutaneous pedicle screws in the lumbar spine using the owl’s-eye technique was performed between January 2007 and September 2008. Patient medical records were reviewed to identify the diagnosis, procedure, and incidence of postoperative neural deficit. Screw length and diameter were documented from the operative records. Postoperative fine-cut CT scans (2.5-mm axial slice thickness overlapped at 1.25-mm intervals with coronal and sagittal reformats) were obtained in all patients and scrutinized for incidence of pedicle screw cortical breach as well as facet joint or disc space violation using all images by 2 of the authors (C.I., K.W.R.). Screw medialization angles were determined from axial images using angle-measuring software provided by a digital radiography system (Stentor iSite, Stentor, Inc.).

All surgeries were performed at a single institution, Kaiser Oakland Medical Center, and all cases performed using this technique were included for analysis. Four different spine surgeons performed the surgeries, with over 80% performed by one of the authors (J.G.).

Technique

All pedicles were cannulated using the owl’s-eye technique. We reserve the term owl’s eye for the singular “down the barrel” radiographic view obtained when the radiation beam is centered on the pedicle and coaxial with it in the transverse and sagittal planes. A unique image guidance system (NeuroVision M5, NuVasive, Inc.) afforded a means to approximate the owl’s-eye view of any pedicle and to reliably reproduce it with the C-arm during the procedure. The actual oblique views acquired during the procedures may have varied slightly from the true owl’s eye and were obtained as follows.

The image intensifier of a standard C-arm unit is fitted with a detachable apparatus containing 1) a reticle (radiographic crosshair), 2) an accelerometer (tilt sensor that determines the inclination of the C-arm in various planes), and 3) projected laser crosshairs. The apparatus is connected to the NeuroVision guidance system, a small, portable computer with touch-screen monitor (Fig. 1). Using accelerometer technology, the monitor screen displays the exact number of degrees the C-arm is tilted in the cranial/caudal direction (sagittal plane) and the AP/lateral direction (transverse plane) relative to vertical. Medialization angles for each pedicle to be instrumented can be entered and stored in the computer for easy recall. These angles are premeasured from a preoperative CT or MR image and represent the pedicular axis in the transverse plane of the spine for use in approximating the owl’s-eye view with the C-arm (Fig. 2). The patient is positioned prone with cushioned hard boards under the legs to minimize body movement and to avoid encroachment of the knees into the radiation field. A lateral lumbar image is taken with the C-arm, and the cranial/caudal pedicle screw angles in the sagittal plane are captured using a virtual protractor on the NeuroVision touch screen (Fig. 3). The owl’s-eye trajectory can now be approximated for each pedicle to be instrumented using its respective cranial/caudal and medialization angles.

The C-arm is repositioned for an AP image and then tilted the correct number of degrees in the cranial/caudal direction for the vertebral body of interest. The NeuroVision screen displays the number of degrees of tilt. An image is taken to ensure the transverse radiographic crosshair bisects the center of the right and left pedicles. Right and left owl’s-eye projections of the pedicles are then viewed in sequence by first rotating the C-arm to the respective medialization angle and then laterally translating the C-arm such that the pedicle is the center target of the radiographic crosshairs. The approximate owl’s-eye view is accepted, if satisfactory. Otherwise, fine adjustments are made and recorded for final operative use. The true owl’s eye view should produce the widest medial-lateral dimension of the pedicle in the oblique position. The laser crosshairs of the C-arm project onto the patient’s skin and reveal the desired skin entry point (Fig. 4). Skin incision sites are marked with indelible ink and the process is repeated for each vertebral body with pedicles to be instrumented. The incisions are made after sterile preparation and draping.

Fig. 1. A: Apparatus containing reticle and accelerometer technology. B: Apparatus seen after attachment to the image intensifier portion of the C-arm. C: The NeuroVision components needed to complete the setup include a small guidance computer and touch-screen monitor.
Owl’s-eye view for percutaneous pedicle screws

An insulated Jamshidi needle (I-PAS II, NuVasive, Inc.) fitted with a sterile, integrated clip provides the NeuroVision system with the trajectory of the device using the same accelerometer technology used for the C-arm. The needle is manually advanced through the targeted skin site and dorsal spinal musculature along the owl’s-eye trajectory, which is confirmed by the on-screen cranial/caudal and medialization angles as well as “green to go” light emitting diode indicators. By following this trajectory through the skin and soft tissue, the needle encounters bone very near the appropriate pedicular starting point. Small translation-adjustments of the needle tip are made to dock on the dorsal bony cortex overlying the center of the pedicle and confirmed with fluoroscopy. The Jamshidi needle is held at the targeted trajectory using the LED indicators and/or the projected laser crosshairs and then advanced down the center of the pedicular barrel. Additional fluoroscopy is used as needed to verify placement. The depth may be confirmed via an integrated mechanical depth gauge unique to the I-PAS Jamshidi needle or via a lateral fluoroscopic projection. A K-wire is placed through the Jamshidi cannula into the vertebral body to maintain position for percutaneous screw placement. The Jamshidi assembly is removed over the K-wire, and the process is repeated for each pedicle to be instrumented. When all pedicles have been cannulated, lateral fluoroscopy is used to check and measure depths of the K-wires. The procedure is then completed using the lateral fluoroscopic view. Percutaneous pedicle screw placement and fixation are carried out according to the screw system used.

Results

We used the aforementioned technique to place 326 pedicle screws from L-3 to S-1 in 85 consecutive adult patients (50 female, 35 male). The majority of cases were supplements to anterior approaches, and all posterior work was performed in the same anesthetic session as the anterior procedure. Indications for surgery were degenerative disc disease (28 cases), lumbar spinal stenosis with degenerative spondylolisthesis (29 cases), recurrent herniated nucleus pulposus (2 cases), lytic spondylolisthesis (22 cases), postlaminectomy instability (3 cases), and adjacent-segment disease (1 cases). All cases included interbody bone grafting for fusion.

Five of 326 screws penetrated the pedicle cortex. Three of these breaches were medial (1 at L-4, 2 at S-1) and 2 were lateral (both at L-4). The pedicle breach rate was therefore 1.53% (0.92% medial, 0.61% lateral) for an overall accuracy of 98.47% (Table 1). All pedicle penetrations were less than 2 mm (Fig. 5). No patient experienced new or worsening neurological symptoms or required revision, yielding an overall clinical accuracy rate of 100%.

Pedicle screw starting points were classified as either “in” or “out” of an adjacent facet or disc space. There were no screw violations of any disc space. Five (1.5%) of 326 screws were deemed to penetrate a facet joint. All 5 were at S-1 as part of an L5–S1 fusion construct and therefore not clinically significant. Thus, there were no violations of any facet at a mobile segment adjacent to a fusion (Table 1).

Pedicle screw diameter and length were documented from the medical record, and medialization angles were determined from postoperative CT scans (Table 2). On average, longer screws were placed into L-5 than S-1, despite the fact that, on occasion, we purposefully obtained bicortical purchase through the anterior cortex at S-1 to improve fixation.

Discussion

As percutaneous pedicle screw placement techniques evolve, methods for optimizing safety, accuracy, and reproducibility should be sought. Difficulty arises because there may be competing demands between screw accuracy and percutaneous insertion without the aid of local anatomy or tactile feedback. The solution has included the use of computer-assisted navigation systems. Studies show that these navigation systems reduce screw malpositioning but are often associated with increased cost, set-up time, or technical difficulty, all impediments to widespread use.3,8,14,15,19,29,32,39,42 In this series, we revisit the owl’s-eye technique as a satisfactory alternative.
The owl’s-eye view represents the true en face radiographic look at any pedicle down its axis and varies by spinal level. With this view, the pedicular cortical boundaries and isthmus are easily visualized, as is the adjacent facet (Fig. 4). The surgeon can perform percutaneous cannulation with confidence in the safe boundaries using real-time images. Repeated AP and lateral repositioning of the C-arm is not necessary with the owl’s-eye view. This reduces technical difficulty as well as contamination of the operative field associated with the C-arm.2

Like many surgeons, we had previously avoided the owl’s eye because of the perceived difficulty and radiation exposure when obtaining it, despite the well-documented inadequacies of the AP view of the spine for guiding the anatomy of the pedicle.1,11,43,46 A new guidance system, NeuroVision, uses accelerometer technology to simplify the technique by displaying the trajectory of the C-arm or Jamshidi needle in degrees in the sagittal and transverse planes. Ultimately, this is a simple, 2D guidance system that facilitates use of the owl’s-eye technique with fluoroscopy.

Accuracy

In the present series, percutaneous lumbar and sacral screw placement was accurate in 98.47% of 326 screws placed in 85 patients, with no breach greater than 2 mm and no neural injuries. Of 5 cortical breaches, 2 were at S-1, both medial. All 5 facet violations occurred at the ar-}

<table>
<thead>
<tr>
<th>Pedicle (no. of screws)</th>
<th>Cortical Breaches</th>
<th>Spinal Level</th>
<th>Disc Space Violations</th>
<th>Facet Violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-3 (15)</td>
<td>0</td>
<td>L2–3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-4 (79)</td>
<td>3</td>
<td>L3–4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-5 (126)</td>
<td>0</td>
<td>L4–5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S-1 (106)</td>
<td>2</td>
<td>L5–S1</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

total no. screws = 326

* The breach rate was 1.53%, and the accuracy rate was 98.47%. All breaches were less than 2 mm, and none caused neurologi-

cal injury. The facet violation rate was 1.5%, and all facets were part of a fusion construct and not clinically significant.
Owl’s-eye view for percutaneous pedicle screws

C- or O-arm systems, which can be used for open or percutaneous procedures, have begun to supplant these early systems.\textsuperscript{11,15}

With 3D navigation systems, perforation rates of 1.7\%–7.5\% have been reported in the thoracic or lumbar spine, nearly as low as the 1.53\% rate reported in the current study.\textsuperscript{8,27,42} The study reporting a 1.7\% perforation rate represented open surgeries and included both thoracic and lumbar screws, but it did not include breaches less than 2 mm in the figure.\textsuperscript{11} Two studies reported even lower perforation rates, but they were underpowered.\textsuperscript{15,32,44} In the first, 30 percutaneous cadaveric lumbar screws were placed using 3D navigation with no perforations.\textsuperscript{15} Even if the perforation rate was 1\%–2\%, 2 to 3 times that number of screws would have been required to likely see even the first perforation. An in vivo study with 71 screws placed in 3D-navigated open lumbar procedures suffered similarly.\textsuperscript{44}

Despite well-known descriptions, only a few studies have critically assessed the accuracy of pedicle screw insertion using the owl’s-eye view since Magerl’s initial recommendation\textsuperscript{22} in 1984, and they have also been limited by numbers. In 1993, a cadaveric study revealed a 3.4\% perforation rate with no breach greater than 3 mm; the authors used the fluorescent owl’s-eye view and no other form of guidance for 90 pedicle screws placed in an open procedure after which full dissection and inspection were used to verify placement.\textsuperscript{41} In 2000, a similar cadaveric study revealed a 2.4\% perforation rate for 83 lumbar screws placed while following the trajectory of laser crosshairs emitted from the C-arm unit.\textsuperscript{36} No breach was greater than 1 mm after full dissection despite the use of surgeons inexperienced with the technique. Finally, in an alternative paradigm for staging pedicle screws, an interventional radiologist placed 24 in vivo percutaneous pedicle screws in the radiology suite using the owl’s-eye view without other guidance.\textsuperscript{35} This was followed about 5 days later by an open procedure performed by a spine surgeon. The authors reported 100\% accuracy but did not include breaches less than 2 mm. There were 2 such breaches for an actual 92\% accuracy.

Of course, screw accuracy, as defined by a pedicle breach, is mainly a surrogate for the risk of neurological injury. Although accurate screw placement may be easier in the lumbar spine than the thoracic spine, this does not necessarily mean a lower risk for lumbar neurological injury.\textsuperscript{18,27,30} With open 3D navigation, Nottmeier et al.\textsuperscript{27} reported an inaccuracy rate of approximately 9.2\% in 238 thoracic screws and 6.4\% in 765 lumbosacral screws. Two neurological injuries occurred: permanent numbness in an S-1 distribution, and new radiculopathy of L-5 requiring screw removal and return to the operating room. Lumbosacral roots may be more susceptible to injury from pedicle screw encroachment than thoracic roots, thereby requiring the highest degree of accuracy to avoid damage. Villavicencio et al.\textsuperscript{42} had a perforation rate of 1.8\% (4 of 220) for percutaneous 3D navigated lumbosacral screws. Two patients were treated for postoperative radiculopathy and 2 others had postoperative numbness and dorsiflexion weakness that subsequently resolved. Of the 4 breaches,

\begin{table}[h!]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Spinal Level (no. of screws) & Screw Length Mode (range) & Screw Diameter (5.5, 6.5, 7.5) & Mean Medialization Angle (range) \\
\hline
L-3 (15) & 50 (45–55) & 0\% & 80\% & 20\% & 17 (14–23) & 19 (17–21) \\
L-4 (79) & 55 (45–55) & 7\% & 63\% & 30\% & 22.8 (12–36) & 23.7 (15–36) \\
L-5 (126) & 50 (40–55) & 8\% & 62\% & 30\% & 29.5 (16–45) & 28.2 (16–46) \\
S-1 (106) & 45 (40–55) & 2\% & 67\% & 31\% & 27.0 (12–41) & 27.0 (14–38) \\
\hline
\end{tabular}
\caption{Summary data for percutaneous pedicle screws using owl’s-eye technique*}
\footnote{* Units for screw length and diameter are millimeters. The mode was the most common size used. Percentages for diameter were rounded to the nearest whole percentage. Units for medialization angles are degrees. The mean was the average angle for all screws at a given level. Note: There was not an even number of screws at all levels because occasionally open screws were placed on one side in patients requiring posterior decompression. Otherwise, instrumentation was placed bilaterally with percutaneous screws in all cases.}
\end{table}
there was a 5-mm breach at L-4 and a 6-mm breach at L-5 (requiring reoperation). Nottmeier et al. similarly reported multiple breaches greater than 2 mm in their study on open 3D navigated screws. In the present series, there were no neurological injuries and no breach more than 2 mm, suggesting that the precision of 3D navigation systems may be lower, despite excellent accuracy. A high degree of precision was also noted in the other studies involving the owl’s-eye technique discussed above, with only 1 breach reaching 3 mm. This may have to do with the virtual nature of the 3D systems. After an automated registration process, the images are virtual and not live, real-time, so inaccuracies or errors may be great, especially for percutaneous cases without directly visible anatomy. Current 3D systems also depend on a dynamic reference array placed partially into bone (for example, posterior superior iliac spine). The apparatus protrudes from the bone like an antenna and must remain immobile to preserve accuracy and precision. These systems also suffer from line-of-sight issues for the optical tracking of instruments and possibly decreasing accuracy the longer the procedure and time from last registration.27,29 The owl’s-eye technique provides live, real-time imaging with similar or better screw accuracy and a narrower range of misplacement without the need for or reliance on a dynamic array tracking device.

The owl’s-eye view is also useful when considering screw proximity to an adjacent, mobile facet joint or disc space. In an investigation of 212 upper-level lumbar screws placed via a Wilte approach, Shah et al.32 found that 20% of screws violated the cephalad facet. Moshirfar et al.26 reported that 15% of screws penetrated the cephalad facet through a midline approach in 204 patients. Finally, Chen et al.5 explored the incidence of cephalad facet joint violation using 2 different screw placement methods, as advocated by Roy-Camille et al.33 and Weinstein et al.43. They found that the rate of cephalad facet violation was 100% of 40 screws when using the Roy-Camille method and 25% of 143 screws when using the Weinstein method. With the owl’s-eye view, the facet complex is more easily visualized and avoided (Fig. 4). In this series, there were zero violations of an adjacent, mobile facet or disc space after scrutiny by CT scanning despite an all-percutaneous insertion technique.

The accuracy and precision associated with the owl’s eye technique may also benefit construct stability. Several biomechanical studies have demonstrated that larger pedicle screws placed with a more medial trajectory have greater pullout strength and increase the overall stability of a construct.13,14,17,24,35,38,40 If the screw starting point for a pedicle is not its true center, then screw diameter will not be maximal without breach. Similarly, if the true medialization angle is not followed, screw diameter and length cannot be maximized. Unlike screw diameters, medialization angles should not be maximized, but optimized. If a trajectory greater or less than the actual medialization angle is used, screw size cannot be maximized without causing a breach. Thus, actual limits to medialization angles and screw sizes without perforation are dictated by pedicular anatomy, which varies by spinal level and patient. The owl’s-eye view provides a true look at the pedicle center and down the pedicle barrel so that mediallyization angles and screw sizes may be optimized. The standard AP/lateral technique fails to identify the true pedicle center and medialization angle, which leads to smaller screws or breach.11,14,36 Modern 3D navigation systems also allow optimization but possibly with less precision associated with virtual imaging.

Limitations

This series is limited in that only L3–S1 levels were instrumented for elective conditions of the degenerated spine, so extrapolation of use to other levels and clinical situations (especially unstable trauma) remains unverified. Furthermore, this is the first study to use this technique and technology, and it has yet to be verified by other authors.

The NeuroVision system, itself, is limited in that, although it appears to reduce, it does not eliminate, the use of fluoroscopy. Also, once the angles for the owl’s-eye view are determined, the operating room table may not be adjusted in the sagittal or transverse planes (that is, head up or down, airplane left or right) without recalculating. The goal of the guidance system is to facilitate easy achievement of an oblique view as close to the true owl’s-eye view as possible, but it is always within the scope of the surgeon to judge whether the view is appropriate.

Conclusions

This is the largest series reported to assess the accuracy of percutaneous screw placement using the oblique fluorographic projection of the pedicles in the lumbar spine. This study provides strong evidence that the owl’s-eye technique, especially as facilitated by the NeuroVision system, provides greater accuracy, precision, and avoidance of adjacent facet or disc spaces compared with standard fluoroscopic and other more complex image navigation techniques. It appears highly reproducible and most importantly, safe. This technique and technology together represent an acceptable and perhaps superior alternative to existing methods.

Disclosure

Dr. Gorek consults for, owns stock in, and sold a patent (2005) to NuVasive Inc. Dr. Idler is a consultant for NuVasive Inc.

Author contributions to the study and manuscript preparation include the following. Conception and design: Gorek. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Rolfe, Idler. Critically revising the article: Rolfe, Gorek. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Rolfe.

References


C. Idler, K. W. Rolfe, and J. E. Gorek
Owl’s-eye view for percutaneous pedicle screws


Manuscript submitted July 9, 2009.
Accepted April 6, 2010.
Address correspondence to: Kevin W. Rolfe, M.D., M.P.H., Department of Orthopaedic Surgery, Harbor-UCLA Medical Center, 1000 West Carson Street, Torrance, California 90509. email: kwrolfe@gmail.com.