Analysis of CT-based Navigation System for Pedicle Screw Placement

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abstract

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The incidence of pedicle screw breech varies based on anatomic location, body habitus, surgeon experience, spinal deformity, and surgical technique. Pedicle breeches have been reported to occur in up to 40% of screws. The purpose of this retrospective study was to compare the rates of revision of pedicle screw placement when using intraoperative C-arm vs O-arm (Medtronic, Memphis, Tennessee) assessment of pedicle screws. An economic analysis was also performed based on the estimated cost of pedicle screw revision.

Four (1%) of 386 control patients required pedicle screw revision for a breeched pedicle screw not identified with intraoperative C-arm fluoroscopy. In the study group, none of the 331 patients returned to the operating room when O-arm was used to assess pedicle screw placement. Based on the 1% rate of returning to the operating room in the control group, the annual rate of cases nationwide requiring pedicle screw revision would be approximately 2300, with a cost of approximately $40,595,000.

These results suggest that the use of intraoperative O-arm can reduce the need for revision of a breeched pedicle screw. This can potentially lead to a major cost savings.
Pedicle screw instrumentation is commonly used by spine surgeons to augment fusion and provide structural support. If the pedicle screws are placed with a breach of the pedicle wall, they can injure or compress the exiting nerve roots. This can lead to radicular reports of pain, paresthesias, or weakness postoperatively. The incidence of pedicle screw breach varies based on anatomic location, body habitus, surgeon experience, presence of spinal deformity, and surgical technique. Pedicle breeches have been reported to occur in up to 40% of screws.1

Numerous techniques are used for pedicle screw placement. They can be placed based on anatomic landmarks, under direct visualization following a laminotomy, or image guided. The use of image guidance in pedicle screw placement has advanced with new technology, including C-arm fluoroscopy, 3-dimensional fluoroscopy, and computed tomography (CT) guidance.

In a retrospective review of 488 percutaneously placed pedicle screws using traditional C-arm guidance, Kim et al2 investigated the accuracy of pedicle screw placement. A cortical breach was identified in 54 (11.1%) screws, and cortical encroachment was found in 61 (12.5%) screws. Only 2 (0.4%) screws developed symptomatic medial penetration requiring revision surgery.2

It is generally believed that more advanced image guidance will increase the accuracy of pedicle screw placement. Nakashima et al3 performed a retrospective review of 300 percutaneously placed pedicle screws using postoperative CT scans to determine accuracy. Half of the screws were placed with conventional fluoroscopy, and the others were placed with isocentric 3-D fluoroscopy. Screws were classified as a perforation if more than 50% of the screw was outside of the cortical boundaries of the pedicle and as exposed if less than 50% of the screw was outside of the pedicle. Of the 150 screws placed with traditional fluoroscopy, 18 (12%) were found to be exposed and 5 (3.3%) were perforated. Of the 150 screws placed with 3-D fluoroscopy, 11 (7%) were exposed, and 0 were perforated. This difference was found to be statistically significant (P<.05).

Computer-based systems couple imaging (either CT or fluoroscopy) with intraoperative navigation probes referenced off of fixed anatomic points on the patient. First-generation CT-based navigation systems matched preoperative CT imaging to the patient’s anatomy after a registration step. Intraoperative cone beam CT scanners now have the capability to take an intraoperative set of images and register the anatomy directly to the navigation system. This technology is used by the O-arm (Medtronic, Memphis, Tennessee) and Stealth (Medtronic) navigation systems. The systems work together as a combined imaging and navigation platform for spinal surgery. Best et al4 performed a retrospective review of 672 lumbar screws placed percutaneously using computer-assisted navigation by a single surgeon. Based on postoperative plain radiographs, none of the screws were misplaced; however, postoperative CT scans were not obtained.

The use of postoperative CT scans has become the gold standard for assessment of pedicle screw placement. However, previous studies have reported the accuracy of postoperative CT scans to range from 68% to 84% compared with open dissection and visualization.5–7 The major disadvantage of using postoperative CT for assessment of pedicle screw placement is that it does not allow the surgeon to revise the pedicle screw without a return to the operating room.

The use of an intraoperative CT scanner allows the surgeon to assess the position of all pedicle screws prior to leaving the operating room so any breeched pedicle screws can be revised during the index procedure. This new technology may reduce the need to return the patient to the operating room for revision of pedicle screws. The purpose of the current retrospective study was to compare the rates of returning to the operating room for revision of pedicle screw placement when using C-arm vs O-arm fluoroscopic assessment of the screws.

Materials and Methods
A control group comprised all patients who underwent a posterior instrumented lumbar fusion between March 1, 2008, and March 1, 2009. Patients were identified through a search of a clinical database using ICD-9 codes. During this period, all lumbar pedicle screws were placed based on anatomic landmarks and were evaluated for potential pedicle breach by stimulating the screws with a neurophysiologic probe. Intraoperative C-arm fluoroscopy was used at the end of surgery to evaluate for proper placement of pedicle screws.

The study group comprised all patients who underwent a posterior instrumented lumbar fusion between March 2, 2009, and March 1, 2010. During this period, all pedicle screws were placed using CT-based navigation, and intraoperative CT scans were obtained using the O-arm prior to leaving the operating room to assess for pedicle screw placement.

Any patients who developed new radicular complaints postoperatively underwent a CT scan to evaluate for the presence of a breeched pedicle screw with nerve root compression. All patients were identified who required a return to the operating room within 6 weeks of the index procedure for revision of a symptomatic pedicle screw. Rates of returning to the operating room for revision were compared to determine whether the use of the O-arm affected the need for revision surgery compared with the use of the C-arm.

An economic analysis was also performed based on estimated cost of return to the operating room for revision of the pedicle screws and published national rates of instrumented lumbar fusions performed.

Results
Four (1%) of 386 control group patients required a return to the operating room.
room for pedicle screw revision for a breeched pedicle screw not identified with intraoperative C-arm fluoroscopy. In the study group, none of the 331 patients returned to the operating room when using the O-arm to assess pedicle screw placement (Table). Vankessel and Lee\textsuperscript{8} reported that 229,150 instrumented lumbar spine surgeries were performed in the United States in 2010. The mean additional expense at Memorial Hospital, Chattanooga, Tennessee, for returning a patient to the operating room for pedicle screw revision was $17,650. Based on the 1\% rate of returning to the operating room for pedicle screw revision in the control group, the annual rate of cases nationwide requiring pedicle screw revision would be approximately 2300, with a cost of approximately $40,595,000.

**Discussion**

This study investigated the rates of returning patients to the operating room for revision of a breeched pedicle screw based on the type of intraoperative imaging used. For patients in the control group, pedicle screws were assessed using traditional C-arm fluoroscopy and neurophysiologic stimulation of the screws prior to leaving the operating room. A 1\% rate of symptomatic breeched pedicle screws that required a revision surgery occurred in this group. After the hospital acquired an O-arm, all patients receiving pedicle screws were placed in the study group with CT-based navigation, and an intraoperative CT scan was obtained to assess the position of pedicle screws prior to leaving the operating room. In the study group, no patient required revision of a breeched pedicle screw.

These results suggest that the use of intraoperative CT can reduce the need to return to the operating room for revision of a breeched pedicle screw. Based on the 1\% revision rate in the control group, the use of intraoperative CT could lead to a nationwide cost savings of more than $40 million by avoiding the need for breeched pedicle screw revision. This study had some limitations. The intraoperative C-arm images were not routinely saved, so it is not possible to have these images independently reviewed to evaluate whether a pedicle breech was missed intraoperatively. In addition, greater attention may be paid to pedicle screw placement with more advanced technology rather than with traditional techniques. It is not possible to quantify this potential effect or to distinguish it from the benefit of the technology itself.

All technology has limitations. Santos et al\textsuperscript{9} performed a cadaveric study to assess the accuracy of intraoperative O-arm for pedicle screw positioning. They used 9 cadavers and placed 416 screws. The position of the pedicle screws assessed by the O-arm was compared with direct visualization after dissection. The accuracy, specificity, sensitivity, positive predictive value, and negative predictive value of the O-arm were reported to be 73\%, 76\%, 71\%, 74\%, and 72\%, respectively. These results are similar to the accuracy rates of traditional postoperative CT (range, 68\%–84\%).\textsuperscript{5,7} Despite these results, the current study had no cases of symptomatic breeched pedicle screws requiring a return to the operating room in the 331 study patients.

Cadaveric studies that have compared the accuracy of CT with dissection and visualization of pedicle screw breech do not allow for a determination of clinical symptoms. It is likely that a portion of the breeched pedicle screws identified on surgical dissection but missed on CT would have remained asymptomatic and not required revision surgery.

A major limitation to the routine use of new technology is the associated cost. The capital expense of a surgical navigation system and intraoperative CT scanner are beyond the resources of many hospitals. The specific cost of these systems varies widely based on geographic location, surgical volume, and contract negotiation, but can exceed $1 million. When the expense of returning patients to the operating room for pedicle screw revision is considered, the cost diminishes somewhat, but it remains out of reach for many institutions. Even if all cases requiring a return to the operating room for a breeched pedicle screw were eliminated by this new technology, the cost savings from this alone could not justify the cost of the technology.

Other potential benefits exist of using navigation and intraoperative CT that are beyond the scope of the current study. These include less radiation exposure to the surgeon and operating room staff, reduced risk of infection associated with minimally invasive techniques, and improved anatomic visualization in complex deformity to tumor cases. These potential benefits are still being actively investigated. With limited financial resources, the surgeons and hospital administration must determine the most

### Table

**Rates of Return to the Operating Room for Pedicle Screw Revision**

<table>
<thead>
<tr>
<th>Group</th>
<th>Study Period</th>
<th>Total Surgeries Performed, No.</th>
<th>Patients Returned to OR, No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C-arm)</td>
<td>March 1, 2008–March 1, 2009</td>
<td>386</td>
<td>4 (1)</td>
</tr>
<tr>
<td>Study (O-arm\textsuperscript{8})</td>
<td>March 2, 2009–March 1, 2010</td>
<td>331</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

*Abbreviation: OR, operating room.\textsuperscript{8} Medtronic, Memphis, Tennessee.*
appropriate use of these funds. Data from the current study may help with these difficult decisions.

REFERENCES


