Percutaneous pedicle screw placement with computer-navigated mapping in place of Kirschner wires

Clinical article

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Object. Percutaneous pedicle screw insertion techniques are commonly used to treat a variety of spinal disorders. Typically, Kirschner (K)-wires are used to guide the insertion of taps and screws during placement since the normal anatomical landmarks are not visualized. The use of K-wires adds risks, such as vascular and nerve injuries as well as increased radiation exposure given the use of fluoroscopy. The authors describe a series of patients who had percutaneous pedicle screws placed using a new computer-assisted navigation technique without the need for K-wires.

Methods. Minimally invasive percutaneous pedicle screw placement in the thoracic and lumbar spine was performed in a consecutive series of 15 patients for a variety of spinal pathologies. Intraoperative 3D CT images were obtained and used with a computer-assisted navigation system to insert an awl-tap into each pedicle. The tap location in the pedicle was marked with the navigation software, and the awl-tap was then removed. The navigation system was used to identify each landmark to insert the pedicle screw. Connecting rods were then inserted percutaneously under fluoroscopic guidance. Postoperative CT scans were obtained in each patient to evaluate screw placement.

Results. On postprocedure scanning, only 1 screw had a minor lateral and superior breach that was asymptomatic. To date, there have been no hardware failures.

Conclusions. Percutaneous pedicle screws can be placed effectively and safely without the use of K-wires.

Key Words • bone screw • neurosurgical procedure • surgical equipment • surgical fixation device • technique

Image guidance has dramatically changed the way modern neurosurgery is practiced by simultaneously providing more precise and less invasive means of assessing operative position in the body. Perioperative CT scanning has grown in popularity over the last several years and is beginning to take the place of traditional fluoroscopy given CT’s greater resolution and real-time feedback for instrument placement.1,2,3,6,8,13–15,20 This trend is particularly true in spinal surgery, in which the need for precise placement of hardware, often extending across multiple vertebral levels, is paramount.

Currently, CT guidance is being used in minimally invasive procedures, as well as in the traditional open cases.3,4,8,13 Since there is a lack of visual anatomical landmarks in these percutaneous procedures, Kirschner (K)-wires have typically been used adjunctively in minimally invasive spine surgeries to ensure proper hardware placement.7,12,22,23 Although K-wires help to ensure the accuracy of screw placement, they also increase the risk for certain perioperative vascular and neurological complications, including K-wire migration into the spinal canal itself.10,17,25

In the present study we describe the peroperative results of a recent technique of placing percutaneous spinal hardware utilizing intraoperative CT scanning coupled with computer navigation and mapping without the need for K-wires.

Methods

Study Design and Rationale

We undertook a retrospective review of consecutive patients treated with percutaneous pedicle screw fixation using computer-assisted navigation but no K-wires. Starting in December 2011, all minimally invasive spine surgery pedicle screws were placed by the surgeons at our institution via perioperative CT guidance without the aid of K-wires. Patient demographics, indications for surgery, spinal levels treated, and perioperative complications were obtained from our review. This study was approved by the institutional review board at Indiana University.

Surgical Technique

In each case, the patient was prone on a radiolucent spinal operating table. For short-segment lumbar fixation, a reference pin was placed in the iliac crest for image guid-
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ance. For thoracic and thoracolumbar fixation, the levels were confirmed using intraoperative fluoroscopy, and a small incision was made over the most superior or inferior level of the construct. A bone clamp was then attached to the spinous process of this level and used as a reference point for image guidance. Three-dimensional CT images were obtained using an O-arm (Medtronic Inc.) and were transferred to the computer-assisted StealthStation surgical navigation workstation (Medtronic Inc.). Trajectories for screw placement were then planned, and small incisions were made through the skin overlying these locations. An awl-tap was navigated into each pedicle using image guidance, and the location was saved in 3D space using the StealthStation software (Fig. 1). The largest screws possible for a given pedicle size were determined during surgery and inserted into the appropriate pedicle using the saved location as a guide (Fig. 2). The screws were 1–2 mm smaller than the pedicle itself. Potential toggle of the images displayed on the image guidance workstation caused by possible reference point movement was accounted for by tactile feedback of the screw within the pedicle, and postoperative imaging confirmed that this strategy was effective. Image-guided screwdrivers were used to verify the final position of the screws (Fig. 3). In each case, either a postinsertion O-arm image or a postoperative CT scan was obtained, depending on which surgeon performed the surgery, to verify the position of the screws and determine accuracy. No additional operative time was required for these surgeries in comparison with traditional fluoroscopic techniques.

Clinical Course and Follow-Up

Postplacement O-arm or CT scans were analyzed for evidence of screw breach through the pedicle wall. Some patients were placed in rigid braces after surgery given the severity of their traumatic injuries. All patients were followed up with serial radiographs to determine long-term stability of the hardware and evidence of fracture healing or spinal fusion.

Results

Fifteen patients treated between December 2011 and August 2012 were included in this study (Table 1). In these patients, 88 screws were placed and there were no instances of screw revisions. In 1 patient, a suboptimally placed screw slightly breached the superolateral portion of the pedicle. This error was discovered on the postplacement O-arm image, but screw placement was not revised since no nerve roots were compromised and the screw was well inserted into the vertebral body and appeared biomechanically sound.

Illustrative Cases

Case 4

This 57-year-old man suffered an unstable fracture dislocation at T6–7 after a fall (Fig. 4). He had no evidence of a spinal cord injury or significant spinal canal compression; thus, we decided to perform percutaneous screw insertion and minimally invasive facet fusion. The patient underwent the surgery with no complications, and his postoperative CT scan demonstrated excellent screw position and spinal alignment (Fig. 5). Subsequently, he had a prolonged hospital course because of the pulmonary contusions resulting from his fall. He has had no post-
operative complications, and radiographic evidence of a stable spinal construct was demonstrated at the short-term follow-up of 3 months.

Case 7

This 79-year-old woman had progressively worsening leg numbness and weakness. Imaging demonstrated significant spondylosis at the L3–4 and L4–5 levels, as well as a lateral listhesis at the L3–4 level causing significant compression of the thecal sac and neural foramen. Extensive conservative treatment had failed; therefore, she underwent L3–5 lateral interbody fusion and minimally invasive posterior pedicle screw instrumentation.

Fig. 2. Case 7. An O-arm image capture from the StealthStation navigation software demonstrating the trajectory for screw insertion in the pedicle of L-5.

Fig. 3. Case 7. An O-arm image capture from the StealthStation navigation software demonstrating the final screw position in the pedicle of L-5.
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**TABLE 1: Summary of procedures and results in 15 patients who underwent percutaneous pedicle screw fixation using computer-assisted navigation but no K-wires**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age at Surgery (yrs)</th>
<th>Diagnosis</th>
<th>Construct</th>
<th>Postop Orthotic</th>
<th>Instrumentation Type</th>
<th>No. of Pedicle Screws Inserted</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>71</td>
<td>T10–11 fracture dislocation</td>
<td>T9–12</td>
<td>TLSO</td>
<td>Medtronic Longitude</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>L1–2 discitis &amp; osteomyelitis</td>
<td>L1–2</td>
<td>TLSO</td>
<td>Medtronic Sextant</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>61</td>
<td>T9–10 fracture dislocation</td>
<td>T8–11</td>
<td>TLSO</td>
<td>Medtronic Longitude</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>57</td>
<td>T6–7 fracture dislocation</td>
<td>T5–8</td>
<td>TLSO</td>
<td>Medtronic Longitude</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>T10–11 osteomyelitis</td>
<td>T9–L1</td>
<td>TLSO</td>
<td>Medtronic Longitude</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>L4 osteomyelitis</td>
<td>L3–5</td>
<td>TLSO</td>
<td>Medtronic Longitude</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>79</td>
<td>lumbar spondylosis &amp; scoliosis</td>
<td>L3–5</td>
<td>LSO</td>
<td>Medtronic Sextant</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>61</td>
<td>L-5 pars defects</td>
<td>L5–S1 TLIF</td>
<td>none</td>
<td>Medtronic Sextant</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>59</td>
<td>L-1 burst fracture</td>
<td>T11–L3</td>
<td>TLSO</td>
<td>Medtronic Legacy Longitude</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>77</td>
<td>T-8 fracture, ankylosing spondylitis</td>
<td>T6–10</td>
<td>TLSO</td>
<td>Medtronic Legacy Longitude</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>59</td>
<td>L4–5 spondylolisthesis, L5–S1 spondylosis</td>
<td>L4–S1</td>
<td>none</td>
<td>Medtronic Legacy Sextant</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>59</td>
<td>L4–5 spondylolisthesis</td>
<td>L4–5</td>
<td>none</td>
<td>Medtronic Legacy Sextant</td>
<td>4</td>
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<tr>
<td>13</td>
<td>58</td>
<td>L5–S1 spondylosis</td>
<td>L5–S1</td>
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<td>14</td>
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<td>15</td>
<td>52</td>
<td>L5–S1 spondylosis</td>
<td>L5–S1</td>
<td>none</td>
<td>Medtronic Legacy Longitude</td>
<td>4</td>
</tr>
</tbody>
</table>

* A CT study was obtained in every patient after pedicle screw placement. A postoperative complication occurred in only 1 patient (Case 12, an L-4 pedicle breach). Abbreviations: LSO = lumbosacral orthosis; TLIF = transforaminal lumbar interbody fusion; TLSO = thoracolumbosacral orthosis.

invasive posterior decompression and pedicle screw fixation. She had no perioperative complications, and her postoperative CT scan demonstrated excellent screw position (Fig. 6). She has had an uneventful postoperative course, and her spinal hardware remained stable at the short-term follow-up of 3 months.

**Discussion**

In this case series, we examined the efficacy of the StealthStation system in placing pedicle screws percutaneously without the aid of K-wires. Minimally invasive techniques for percutaneous screw placement provide a number of advantages over the more traditional open techniques, ranging from decreased blood loss and hospital stay to reduced cosmetic deformity and postoperative pain. Dhall et al. found a reduction in the mean hospital stay from 5.5 to 3 days with minimally invasive techniques, as well as significantly decreased blood loss, leading to reduced morbidity and hospital costs. When combined with advanced imaging modalities, such as perioperative CT guidance, pedicle screw placement becomes more accurate with fewer breaches than fluoroscopic methods. Since there is a steep learning curve with percutaneous screw placement, the use of intraoperative navigation can be very helpful in enhancing the accuracy of and reducing patient risks with such spine surgeries. In a 2009 study Nakashima et al. found that rates of screw exposure and pedicle perforation were 7.3% and 0%, respectively, when isosentric C-arm (Iso-C) 3D fluoroscopy was used, as compared with 12% and 3% when traditional fluoroscopy was used. Thus, neuronavigation can lead to significantly improved accuracy of pedicle screw placement.

Typically, percutaneous pedicle screw placement requires K-wires to maintain the position of the pedicle during tapping and screw insertion. However, the use of K-wires introduces additional risk to the patient and the operating surgeon and staff. One of these risks is associated with the increased use of fluoroscopy, which means additional radiation exposure. One of the most significant advantages of the currently featured technique is a reduction in radiation exposure. For percutaneous pedicle screw placement, the fluoroscopy time to insert each pedicle screw ranges from 3.4 to 66.0 seconds. Inserting screws at multiple spine levels can mean significant radiation exposure. In contrast, the current technique utilizes no fluoroscopy for screw insertion outside of the initial low-dose CT for image guidance. Since this CT is used for neuronavigation independent of the need for K-wires, there is a statistically significant decrease in mean radiation exposure for the patient, surgeon, and operating room staff when K-wires are not used. Given the liberal application of advanced radiology techniques in spinal sur-
surgery, efforts to minimize radiation exposure must be pursued in surgeries in which image guidance is indicated.24

As well as reducing radiation risk, the current technique decreases the perforation risks to spinal cord, vasculature, and abdominal viscerata that are inherent in the placement of K-wires.10 Moreover, these K-wires may break or bend during the procedure, reducing the accuracy of cannulated screw placement and possibly damaging equipment.21 None of the patients in our study, who were treated without K-wires, suffered intraoperative or postoperative vascular or neurological complications. Only one screw was malpositioned in this series, as a result of a suboptimal trajectory during placement, and there was no need for repositioning. The remainder of the screws had excellent placement and were not associated with any perioperative complications.

Limitations of the present study include its retrospective nature and relatively small sample size and follow-up. Additional studies are needed to assess the potential risks associated with the absence of K-wires, ideally with a greater number of patients and a more direct comparison of image-guided surgery with versus without K-wires. If the low level of complications experienced in this case series remains accurate as the technique is further expanded, the need for K-wires in percutaneous pedicle screw placement will be greatly reduced.

Conclusions

The current study details the technique of percutaneous pedicle screw insertion using computer-assisted navigation without K-wires. This technique has several advantages over those that use K-wires, including reductions in both fluoroscopy exposure and intraabdominal or vascular complications.

Fig. 4. Case 4. Sagittal T2-weighted MR image of the thoracic spine demonstrating a T6–7 unstable fracture and ligament disruption.

Fig. 5. Case 4. Sagittally reconstructed CT scan of the thoracic spine demonstrating postoperative spinal alignment.

Fig. 6. Case 7. Axial CT scan of the lumbar spine demonstrating excellent pedicle screw placement.
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perforations. Our findings indicate that this technique can be done safely and efficiently in a wide variety of spinal disorders.

Disclosure

Dr. Helbig has received an honorarium from Medtronic for teaching the surgical technique described in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Horn, Helbig. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Horn. Study supervision: Horn.

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