Minimally invasive guidewireless, navigated pedicle screw placement: a technical report and case series

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OBJECTIVE Percutaneous pedicle screw insertion (PPSI) is a mainstay of minimally invasive spinal surgery. Traditionally, PPSI is a fluoroscopy-guided, multistep process involving traversing the pedicle with a Jamshidi needle, placement of a Kirschner wire (K-wire), placement of a soft-tissue dilator, pedicle tract tapping, and screw insertion over the K-wire. This study evaluates the accuracy and safety of PPSI with a simplified 2-step process using a navigated awl-tap followed by navigated screw insertion without use of a K-wire or fluoroscopy.

METHODS Patients undergoing PPSI utilizing the K-wire-less technique were identified. Data were extracted from the electronic medical record. Complications associated with screw placement were recorded. Postoperative radiographs as well as CT were evaluated for accuracy of pedicle screw placement.

RESULTS Thirty-six patients (18 male and 18 female) were included. The patients' mean age was 60.4 years (range 23.8–78.4 years), and their mean body mass index was 28.5 kg/m² (range 20.8–40.1 kg/m²). A total of 238 pedicle screws were placed. A mean of 6.6 pedicle screws (range 4–14) were placed over a mean of 2.61 levels (range 1–7). No pedicle breaches were identified on review of postoperative radiographs. In a subgroup analysis of the 25 cases (69%) in which CT scans were performed, 173 screws were assessed; 170 (98.3%) were found to be completely within the pedicle, and 3 (1.7%) demonstrated medial breaches of less than 2 mm (Grade B). There were no complications related to PPSI in this cohort.

CONCLUSIONS This streamlined 2-step K-wire-less, navigated PPSI appears safe and accurate and avoids the need for radiation exposure to surgeon and staff.

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KEY WORDS minimally invasive; spine; pedicle screw; navigation; K-wire; fusion; image guided

THE indications for percutaneous pedicle screw insertion (PPSI) have continued to broaden and can be seen in all aspects of minimally invasive spine surgery, including treatment of degenerative spondylosis, spondylolisthesis, scoliosis, deformity, and trauma as well as spinal oncology.^{3,9,15,24,26} Percutaneous instrumentation has many advantages over traditional open placement of posterior spinal hardware. One advantage is a decrease in the damage inflicted on the paraspinal musculature in comparison with open spinal exposure surgery.² Additionally, there is the benefit of decreased blood loss and length of hospitalization when minimally invasive surgical techniques are used in place of traditional open surgery.^{1,12,17,19,27} Traditionally, PPSI is a fluoroscopy-guided,

multistep process that involves traversing the pedicle with a Jamshidi needle, placement of a Kirschner wire (K-wire), placement of soft-tissue dilator, pedicle tract tapping, and screw insertion over the K-wire.⁶ This process can be time consuming, and the use of K-wires has been linked to multiple complications.^{4,11,16,20} These include K-wire fracture with subsequent inability to remove the fragmented K-wire, spinal hematomas causing neurological injury, dural injury resulting in CSF leak, and anterior breaches of the vertebral body causing retroperitoneal hematomas.^{4,11,16,20} Furthermore, the traditional approach with fluoroscopy and the K-wire process is associated with increased radiation exposure to the surgical team and is potentially less accurate than placement using spinal navigation.^{14,22} This

ABBREVIATIONS AP = anteroposterior; ASA = American Society of Anesthesiologists; BMI = body mass index; GRS = Gertzbein and Robbins system; iCBCT = intraoperative cone-beam CT; K-wire = Kirschner wire; LLIF = lateral lumbar interbody fusion; PPSI = percutaneous pedicle screw insertion; TLIF = transforaminal lumbar interbody fusion.

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study evaluates a simplified 2-step process for minimally invasive navigated pedicle screw placement without the use of a Jamshidi needle, K-wire, or fluoroscopy.

Methods

With institutional review board approval, a retrospective analysis of the electronic medical records was performed for cases in which navigated K-wire–less percutaneous pedicle screw insertion (PPSI) was performed between May 2014 and March 2017. Data consisting of age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status classification, procedure type, levels fused, and complications related to screw placement were extracted from each patient's electronic medical record. Postoperative radiographs were reviewed for accuracy of placement as described by Hari-maya et al.¹⁰ A subgroup analysis was performed for cases in which postoperative CT scans were available. The previously described Gertzbein and Robbins system (GRS) was used to evaluate accuracy of pedicle screw placement on CT.⁸ In this system, screws completely within the pedicle are Grade A; a breach of less than 2 mm is Grade B; a breach of 2 mm or more and less than 4 mm is Grade C; a breach of 4 mm or more and less than 6 mm is Grade D; and a breach greater than 6 mm is Grade E.⁸ Simple descriptive statistics were used to analyze and describe the patient data sets.

Operative Technique

Depending on the condition being treated and the specific procedure used, PPSI was performed in isolation or in conjunction with other aspects of surgery. For minimally invasive TLIF (transforaminal lumbar interbody fusion), the fusion procedure (including interbody cage placement) was performed initially, followed by navigated guidewireless PPSI.³ Conversely, PPSI was the sole procedure in cases of posterior supplemental fixation after LLIF (lateral lumbar interbody fusion) or for percutaneous treatment of vertebral body fractures. The following operative technique describes the steps involved when the navigated, guidewireless PPSI was performed as the sole procedure.

After induction of general anesthesia with an endotracheal tube, the patient is positioned prone on a Jackson frame. All pressure points are assessed and padded as necessary. The patient is prepared and draped in the usual sterile fashion. The location of the posterior superior iliac spine (PSIS) is identified, and a stab incision is made. An iliac pin is impacted into the PSIS. An image guidance reference frame is attached to the pin. Alternatively, for thoracic or upper lumbar fixation, a spinous process clamp can be used to attach a reference frame. Additional drapes are placed over the surgical field, and the intraoperative cone-beam CT (iCBCT) unit is brought into the field (Fig. 1). A 3D image of the targeted levels is obtained and auto-registered to the navigation system. Although body habitus is a factor, typically 4 spinal segments can be registered with one 3D image acquisition by the iCBCT. If more than 4 spinal segments need to be instrumented, than another 3D image acquisition is performed and saved

FIG. 1. Photograph showing 3D image acquisition of the target spinal segments. Note that there is a second layer of sterile draping applied during image acquisition, as the 3D image acquisition unit is not sterily draped.

to the navigation system. Using image guidance, an entry point is determined for the first pedicle to be instrumented (Fig. 2). A small skin incision (~ 12 mm) is made at the entry point with a No. 15 blade. The subcutaneous fat is dissected with monopolar cautery to the level of the fascia. The fascia is then incised with monopolar cautery. An image-guided awl-tap is advanced through the subcutaneous tissue and muscle to the appropriate bony entry point (Fig. 3). The sharp tip of the awl-tap allows for firm anchoring into the bone. After adjusting the trajectory based on navigation, a hammer is used to advance the tip a few millimeters into the pedicle. Of note, if the bone is very sclerotic, tapping the awl-tap further into the pedicle with the hammer can be helpful. The awl-tap is then advanced through the pedicle by navigation to an appropriate depth (Fig. 4). If bicortical fixation is desired, as in the case with S-1 screw placement, the awl-tap is advanced to the anterior margin of the vertebral body (sacral promontory) at which point the length is measured for appropriate screw size. Screw diameter can be assessed using the navigation software. The final awl-tap position within the pedicle and vertebral body is then saved as a reference. The awl-tap is removed. Next, an appropriately sized pedicle screw connected to a screw extender is attached to an image-guided driver (Fig. 5). The previously used entry site is identified with the aid of the navigation and confirmed by

FIG. 2. **Left:** Intraoperative photograph showing the navigated pointer that is used to determine entry sites on the skin for PPSI. **Right:** Photograph of navigation screen showing the trajectory from the skin (*yellow projection*) to the pedicle, which is used to determine incision site.

palpation with the screw tip. The pedicle screw is then inserted through the previously created pedicle tract. This process is repeated at all planned levels (Figs. 6 and 7). It is important to note that with any image-guided procedure periodically confirming navigation accuracy is essential. If there is any concern for loss of accuracy, fluoroscopy should be used for confirmation.

Results

Thirty-six patients who underwent navigated guidewireless PPSI were identified. The group included 18 men and 18 women. The patients' mean age was 60.4 years (range 23.8–78.4 years). The mean BMI was 28.5 kg/m² (range 20.8–40.1 kg/m²). Of the 36 patients, 16 had spondylolisthesis, 14 had deformity, 5 had traumatic fractures, and 1 patient needed posterior instrumentation for treatment of instability due to a tumor. Twenty-eight (77.8%) of the patients had posterior instrumentation placed to augment an interbody fusion and in 8 cases (22.2%), instrumentation was placed only for posterior stabilization. Of the 28 patients who underwent interbody fusion procedures, 25 (89.3%) had lateral lumbar interbody fusion (LLIF) and 3 (10.7%) had transforaminal lumbar interbody fusion (TLIF). A total of 238 pedicle screws were placed using the navigated, K-wire-less technique. A mean of 6.6 pedicle screws (range 4–14) were placed over a mean of 2.61 levels (range 1–7). Table 1 lists a summary of the surgical characteristics. Postoperative anteroposterior (AP) and lateral radiographs were available in each case. The radiographs were individually reviewed, and no gross misplacement or pedicle breach was identified. Of the 36 patients, 25 patients (69%) underwent postoperative CT. In this subgroup, 173 screw placements were evaluated. Of these, 170 (98.3%) were GRS Grade A. Three (1.7%) of these screw placements were GRS Grade B, with

medial breaches, but none caused neurological symptoms or required reoperation for repositioning. There were no complications directly associated with placement of the pedicle screws, and no patient required an additional operation for repositioning of a misplaced screw.

Discussion

As spinal fusion procedures continue to increase in frequency, the technology and approaches to posterior fixation continue to develop at a rapid pace. Throughout this development, the pedicle screw continues to be the mainstay for posterior fixation.^{5,7,23,25} A properly placed pedicle screw spans all 3 columns of the spine.^{5,25} The purchase

FIG. 3. Photograph showing the navigated awl-tap.

FIG. 4. Left: Intraoperative photograph showing advancement of navigated awl-tap through the skin incision into the pedicle. Right: Photograph of navigation screen showing awl-tap (yellow) within the pedicle.

afforded by 3-column fixation is reflected in the common use of pedicle screws for all applications of spinal surgery requiring fixation, including degenerative disease, deformity, trauma, and cancer.

Traditional pedicle screw placement is performed using anatomical landmarks and intraoperative fluoroscopy.^{23,25} In this technique, visual landmarks and manual palpation combined with 2D intraoperative fluoroscopic

guidance are used to insert pedicle screws. This process requires extensive dissection of the paravertebral musculature to visualize the appropriate entry point. The dissection not only disrupts the paraspinal musculature but also puts the facet capsule at the proximal end of the construct at risk.

The development of minimally invasive placement of pedicle screws has been a major advancement in pedicle screw technology.¹⁸ The advantages of PPSI include decreased blood loss, decreased damage to and atrophy of the paraspinal musculature, decreased length of hospital stay, and decreased trauma to the joint capsules and liga-

FIG. 5. Intraoperative photograph showing a pedicle screw connected to the screw extender attached to the navigated screw driver.

FIG. 6. Intraoperative photograph showing placement of multiple percutaneous pedicles screws via the navigated, guidewireless technique.

FIG. 7. AP (left) and lateral (right) scoliosis radiographs showing screw placement.

ments.^{2,13,15,19} The standard placement of PPSI includes the utilization of a Jamshidi needle and a K-wire, soft-tissue dilator placement, pedicle tapping, and finally insertion of the pedicle screw via fluoroscopic guidance. Typically, insertion of the Jamshidi needle through the pedicle requires AP and lateral views. This can be achieved with a single C-arm alternating from AP to lateral with each image, which can be time consuming. Alternatively, dual C-arms can be used, though this can crowd the surgical field, making the surgeon operate in nonergonomic positions. Regardless, the surgeon and staff are exposed to significant amounts of radiation during the process.²² More recently, image guidance has been used for placement of the Jamshidi needle.²¹ However, the K-wire is flexible and cannot be navigated. The only currently available method for evaluating placement of the K-wire is fluoroscopy. The placement of a K-wire has been shown to be associated with injury, including dural violation, retroperitoneal hematoma, psoas hematoma, direct neural injury, K-wire fracture, and K-wire kinking resulting in inability to pass a cannulated screw.^{4,11,16,20}

The technique described in this article utilizes a simplified 2-step process for PPSI. By using a navigated awl-tap along with a navigated pedicle screw, this technique eliminates the need for a Jamshidi needle, soft-tissue dilator placement, or K-wire. Fluoroscopy was not used with this technique, eliminating radiation exposure to surgeon and staff. In addition, without the fluoroscopy unit in the surgical field, there is unobstructed access to the patient, which is a benefit for workflow.

Based on our results, navigated and K-wire-less PPSI

TABLE 1. Summary of surgical indications, characteristics, and complications

Variable	No. of Patients
Indication category	
Spondylolisthesis	16
Deformity	14
Trauma	5
Tumor	1
No. of levels instrumented	
1	9
2	14
3	2
4	7
5	2
6	1
7	1
Interbody placement approach	
LLIF	25
TLIF	3
None	8
Immediate revision	
For screw misplacement	0
For other reason	0

was found to be safe and accurate. Radiographs were obtained in all patients and did not show any misplaced screws in this study. Furthermore, the subgroup analysis of the majority of patients who underwent postoperative CT imaging demonstrated that 98.3% of the screws were completely within the pedicle. This is consistent with other reports of navigated pedicle screw placement using K-wires. None of the 36 patients in this study required a reoperation for repositioning of the pedicle screw, and none had a complication related to PPSI.

Conclusions

This report describes a novel 2-step technique for navigated PPSI without use of a K-wire. Our results show a high accuracy and no complications related to screw placement.

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Disclosures

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Author Contributions

Conception and design: Park, BW Smith, Joseph, Kirsch. Acquisition of data: BW Smith, Joseph, Kirsch, Strasser, J Smith. Analysis and interpretation of data: BW Smith, Joseph, Kirsch, J Smith. Drafting the article: Park, BW Smith, Joseph, Kirsch, Strasser. Critically revising the article: Park, BW Smith, Joseph, Strasser, J Smith. Reviewed submitted version of manuscript: Park, BW Smith, Kirsch, Strasser, J Smith. Approved the final version of the manuscript on behalf of all authors: Park. Statistical analysis: BW Smith. Study supervision: Park.

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