Percutaneous lumbar and thoracic pedicle screws: a trauma experience [1]

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Introduction

Minimally invasive spine surgical techniques have been growing in popularity. A critical component of the armamentarium is percutaneous pedicle screw instrumentation into the spine. Regardless of technique, pedicle screw fixation has allowed for more stable constructs, earlier mobilization, and better deformity correction through the use of three column spinal fixation. However, with usage of minimal invasive percutaneous techniques, pedicle screws can be placed in the spine without the traditional large posterior skin incisions, extensive striping and retraction of the paraspinal musculature, significant postoperative pain, and long recovery times[4]. Standard exposure has also been shown to cause muscle denervation, increased intramuscular pressure, ischemia, and revascularization injury[4,20]. The end results of the collateral soft tissue damage are paraspinal muscle atrophy, scarring, and decreased strength and endurance.

Percutaneous fixation is not without its attendant disadvantages. This minimal technique requires use of fluoroscopy or various types of specialized radiological guidance. Furthermore, because percutaneous techniques do not allow gross visualization and tactile feel, the technique is very demanding and the incidence of erroneous placement of pedicle screws may be high. Even in traditional open techniques the rate of screw misplacement has been as high as 40%, but only 5.7% severe medial penetrations[2]. Erroneous placement, particularly medial and inferior, can lead to neurological deficits since the nerve root passes medial and inferior to the pedicle. Lateral malposition on the other hand can affect stability and can cause loosening of the fixation. Previous cadaveric study has reported an overall perforation rate of 10% using percutaneous techniques[21]. Using CT imaging to verify placement, the same authors found a rate of 6.6% (mainly affecting S1 level) in another study[22]. A wide range of pedicle malpositioning exists in the literature primarily due to variation in assessment methods including the definition of

misplacement. To minimize these malpositions, various surgical techniques have been developed for safe percutaneous placement of pedicle screws which require modification of implants or the need for additional or customized instruments and navigation.

Despite its wide use in traditional degenerative spine conditions, percutaneous screw fixation in trauma is novel[1,10,11,15,19,23]. Furthermore, the purported benefits of minimally invasive surgery stated previously may be even more advantageous in the trauma setting as Verlann et al found trauma patients may be more susceptible to increased operative blood loss and infection. Therefore incorporating minimally invasive techniques would ultimately, minimize morbidity in patients with multitrauma.

The first aim of the present study is to define/describe a technique of placing percutanous screw fixation with only 2D fluoroscopy in trauma patients and verify its the clinical accuracy. The second aim of the study is to validate the technique by a morphometric study of the spine in patients without spinal fracture.

Methods

Patients who underwent percutaneous pedicle screw placement by one surgeon (MB) at a Level I trauma center were included in this study for clinical review. Exclusion criteria included patients who did not have a postoperative computerized tomography (CT) scan to review the accuracy of pedicle screw placement. Inclusion criteria included patients who underwent percutaneous pedicle screw placement with at least 3 month follow-up and with pre and postoperative CT scan available for review.

Surgical Technique

Patients were placed in the prone position on the Jackson table in the standard fashion. Fluoroscopy was used to confirm and mark the midline on the skin. C-arm again was used to locate the position of the pedicles once each level's endplates were parallel to the image intensifier's beam. A Jamshidi needle was then advanced through skin at the 3 o'clock or 9 o'clock position at each pedicle to be included in the instrumentation. The Jamshidi needles were docked such that they were in the lateral halves of each pedicle. The Jamshidi needles were slightly placed into the pedicle to stabilize the position. Then using only an AP image, guidewires were placed 20 mm into the pedicle making sure that the wire tip was lateral to the medial border of the pedicle on the AP image **Figure 1a**. Once all guidewires were placed on the AP image, a lateral image was then obtained to verify the sagittal alignment **figure 1b**. Any adjustments were then made then utilizing the lateral view. The appropriate screw length was then determined **Figure 1c**. Pedicle strew instrumentation was either the Depuy Viper 2 (Depuy Orthopaedics, Warsaw, IN) or Stryker MANTIS (Stryker, Kalamazoo, MI) minimally invasive systems.

In situations requiring fusion, decortications and grafting with autologous cancellous graft chips and with bone morphogenetic protein was accomplished in the facet joints through the percutaneous pedicle screw skin incision. Postoperatively, CT scans of instrumented levels were obtained to evaluate screw placement.

Grading of CT

Accuracy of pedicle screw placement was as follows: grade I when the screw is within the pedicle, II if less than 2 mm is outside the pedicle, III if 2-4 mm is outside the pedicle, and IV > 4 mm is outside the pedicle. Screw positioning was assessed in axial, sagittal, and coronal

images to assess if breaches occurred medially, laterally, inferiorly, or superiorly. Three orthopedic surgeons assessed the grading of the screw. Final grading was assigned when at least two of the three graders had agreement. Any major postoperative complications were recorded. Reoperations were also recorded.

Morphometric Study

Forty consecutive patients who received standard CT scans of the spine (thoracic and lumbar) as part of the standard trauma protocol at a level 1 hospital were reviewed. Inclusion criteria were ages of 20-40 years old to minimize abnormal measurements due to facet arthropathy and no spinal fractures. Pedicle length was defined as the length of the pedicle at mid axis of the pedicle in both the cephalad-caudad and medial-lateral dimension. In this mid axis point, the length from the dorsal cortex to the junction of the pedicle and the posterior vertebral body was measured. Using Philips iSite PACS Suite (Koninklijke Philips Electronics; Amsterdam, Netherlands) for multiplanar reconstruction of CTs, mid-axis pedicle lengths were measured in the axial, coronal, and sagittal planes. **Figure 2** demonstrates the usage of multiplanar reconstruction for accurate measurement of pedicle lengths. Two reviewers measured the length of the pedicle. Inter-observer reliability of the values obtained for the morphometric portion of the study was determined with Pearson correlation coefficient. Least squares of the mean were applied to pedicle lengths for the morphometric portion of the study to assess if the pedicle lengths across the thoracic and lumbar spine were different.

Results

Clinical analysis

Overall, 26 patients that had undergone percutaneous spinal instrumentation were included in the clinical review portion of this study. Age distribution of this group ranged from 20 to 69 years old. Mechanisms of injury were predominately motor vehicle accidents, but also included fractures due to falls from heights and insufficiency fractures. A total of 172 pedicle screws were placed. Of these, there were 20 grade II (less than 2mm) medial perforations (11.6%). There were two grade III (2-4mm) medial perforations (1.2%), and no grade IV (>4mm) medial perforations. There were five grade II lateral perforations (2.9%), one grade III lateral perforation (0.6%) and two grade IV lateral perforations (1.2%). There was also one grade II inferior perforation (0.6%). Overall there were 31 grade II-IV perforations (18.0%), with only five (2.9%) being significant perforations (grade III or IV). (**Figures 3-5)** Levels were also subdivided into thoracic, thoracolumbar, and lower lumbar segments. The thoracic level (T1-T9) had a perforation rate about 28% (14 of 50 screws). The thoracolumbar levels (T10-L2) had a perforation rate of about 16.9% (14 of 83 screws). The lower lumbar levels (L3-L5) had a perforation rate of 10% (3 of 30 screws). The sacroiliac levels had no perforations. In terms of inter-observer reliability, the majority of screws (156 screws) had complete agreement (90.7%), and no screw had complete disagreement.

Of the 26 patients that underwent percutaneous posterior spinal fusion, there were no cases of postoperative infections. No patient reported new onset postoperative weakness, paresthesias, or any other new neurological deficits on follow up visits. Three patients required subsequent hardware removal. One patient following a L4-ilium fixation for a comminuted sacral fracture required removal of instrumentation once healed due to loosening of the rods out of the pedicle screw tulip. Another patient who underwent instrumentation at L1-S1 with a L1-3 fusion required removal of hardware once healed due to loosening of the distal L5 and S1 pedicle

screws. The third patient underwent removal of T7-12 posterior instrumentation after his thoracic level injuries showed adequate healing.

Morphometric analysis

The morphometric analysis of pedicle lengths of 40 patients from T1-L5 levels reveals a range of pedicle length from 14mm to 22mm, with the smaller values in the upper thoracic levels. The pedicles in the thoracolumbar junction were the longest as the pedicle length decreased at lower lumbar levels (**Figure 6**). There was no statistical difference between right and left pedicles at each level (**Table 1**) ($p>0.2$). The pedicle lengths were not significant for T2 compared to T3; T4 to T5; T5 to T6, 8, 9; T6 to T7, 8, 9, 10, L5; T7 to T8, 9, 10, L5; T8 to T9, 10, L5; T9 to T10, L5; T10 to L5; T12 to L3; L1 to L2; L2 to L3. The other pairings were statistically significant using the least squares of the means (**Table 2**). The inter-observer reliability was high ($r=0.96$).

Discussion

Various studies have demonstrated the feasibility of percutaneous pedicle screw instrumentation. Each study utilizes a slightly different technique or instrumentation such as fluoroscopic navigation[13], CT navigation[6], or robotics[12]. Few published reports rely solely on fluoroscopy. This study is one of the largest published studies on use of percutaneous screw fixation using only fluoroscopy especially in the setting of trauma. Furthermore, the morphometric study analyzing the length of the pedicle confirms and validates the technique.

In this study, 172 screws were placed in 26 patients. The rate of cortical breach was 18.0%, but only 2.9% were greater than grade II breach. Therefore, our rate compares favorably to the previous literature utilizing only fluoroscopy as well as to screws placed via navigation.

Furthermore, we utilized CT scans to assess cortical breaches which is much more accurate compared to conventional radiographs[7]. We also evaluated medial/lateral perforations and cephalad/caudal perforations. If one considers potential dangerous breaches as malpositions greater than grade II breaches, our success rate was 97.2%. Grade II and less is considered safe in many instances because CT has artifact from metal; 1 to 2 mm of error may occur due to artifact[13]. Furthermore, frank perforations of the cortex do not correlate with neurological damage. Lien et al showed the distance between the pedicle wall and nerve root vary, but usually 2.4 mm of space is present[9].

We believe our rate of perforation is low due to the tenet that as long as the guide-wire remains lateral to the border of the medial wall of the pedicle throughout the length of the pedicle, the trajectory should be safe. The distance necessary to trespass the pedicle is confirmed via the morphometric study, which demonstrated the pedicle length to range from 14.4 to 22.1 mm. The longest being at L1-2 and the shortest in the upper thoracic spine. Because of this fact, a short length may suffice in the upper thoracic spine. We believe this is the one of the first study analyzing the lengths of the pedicles in the general population. The only other published finding is by Li et al who found pedicle length to range from 18 to 25 mm on CT scan in 41 Chinese patients[8].

Because of our low breach rate, we did not have any patients who had to be revised due to screw malpositioning. Two complications related to hardware however did arise. In one patient, the rods had slipped out of the pedicle screw tulips at the most cephalad level postoperatively. Patient remains asymptomatic however. In another patient, there was evidence of screw loosening prior to hardware removal at the cephalad level. This patient however underwent a fusion at L3-S1 and only instrumentation at L1-3. In addition, one patient

underwent a concomitant miniopen exposure to help reduce a T11-T12 fracture dislocation. The miniopen approach was not used for screw insertion however. Overall, no neurological complications occurred.

There are previous studies in the literature that have relied solely on fluoroscopy. Schizas reported 60 screws in 15 patients using fluoroscopy only and found 80% of patients with some perforation while an overall rate of screw perforation of 23%. Only one patient needed revision due to screw placement. There was no association of breached pedicles with the specific spinal level instrumented[16]. In this technique, surgeons placed guide wires until the K wire reached the posterior vertebral wall level on the lateral fluoroscopic image. The exact distance was not measured. In another study, re-operation rate due to screw misplacement, presumably with neurological symptoms was 4%[17]. Another larger study using fluoroscopy found in 104 patients (115 pedicle screws), the postoperative CT scans demonstrated 87% good screw placement, 10% acceptable, 11 revisions necessary (9 for screw placement and 2 for loosening bolts), and 2 patients with new radicular pain because of screw placement. Screw was rated good if < 2 mm of violation, acceptable > 2 mm but still sufficient bone purchase, and unacceptable if >2 mm and poor bone purchase or new screw associated symptoms[14]. Another technique using fluoroscopic guidance found overall misplacement ranging from 8-13% depending on the traditional Magerl technique or a modified version technique. Thirty of 37 violations were less than 3.0 mm[21]. Previously, a similar technique used by the senior author has been described with good clinical outcomes however a radiological evaluation of screw placement was not reported[3].

Although technology has advanced and there is a trend toward navigation techniques, the advantages of fluoroscopic guidance only is that navigation techniques such as fluoro-navigation require lengthy set up time while CT-dependent navigation utilize pre-procedure CT which may

differ after decompression or positioning on bed. In addition, CT based navigation is surgeon–dependent; it requires the surgeon to register landmarks on preoperative CT with corresponding anatomy intraoperatively. The advantage of navigation however is potential decreased screw malpositioning. In FluoroNav (2D virtual navigation), 161 screws were placed, 83.8% where grade II or less[13]. CT navigation depends on preoperatively obtained data to provide 3-D views intraoperative. Kosmopoulos and Schizas found in a meta-analysis of 130 studies, 96.1% accuracy in navigated group compared to 79% in non navigation[5].

We believe this report differs from the others for multiple reasons. This technique relies only on the AP image for the majority of the case and utilizes the lateral image as a confirmatory image. Second, this study is a report on use in the trauma setting. Third, a morphogenetic study is included to justify the amount of guide wire that is inserted before checking a lateral image. Last, clinical data is presented for 172 screws placed in 26 patients.

Disadvantages of this study mainly reside in the follow-up. Long-term follow is incomplete in this study cohort. Because of the trauma setting, patient follow up is unpredictably difficult. It would be interesting to see whether there are other instrumentation related complications such as loosening. Notably, the major complications associated with neurologic compromise or instrumentation catastrophes are unlikely after the immediate postoperative state. Lastly, the ideal evaluation of screw accuracy may be best evaluated doing CT scans after pedicle screw removal to eliminate artifact from the instrumentation.

In summary, this paper reports a comprehensive overview of a technique utilizing only fluoroscopic guidance for the placement of pedicle screws percutaneously. The applicability in

the spinal trauma patients is viable while the rate of cortical breaches compares favorably with the published literature. Additionally, morphometric studies validate the technique.

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