Article published online: 2022-09-27

ORIGINAL ARTICLE

Percutaneous pedicle screw placement in the thoracic spine: A cadaveric study

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ABSTRACT

Study Design: A cadaveric study to determine the accuracy of percutaneous screw placement in the thoracic spine using standard fluoroscopic guidance.

Summary of Background Data: While use of percutaneous pedicle screws in the lumbar spine has increased rapidly, its acceptance in the thoracic spine has been slower. As indications for pedicle screw fixation increase in the thoracic spine so will the need to perform accurate and safe placement of percutaneous screws with or without image navigation. To date, no study has determined the accuracy of percutaneous thoracic pedicle screw placement without use of stereotactic imaging guidance.

Materials and Methods: Eighty-six thoracic pedicle screw placements were performed in four cadaveric thoracic spines from T1 to T12. At each level, Ferguson anterior–posterior fluoroscopy was used to localize the pedicle and define the entry point. Screw placement was attempted unless the borders of the pedicle could not be delineated solely using intraoperative fluoroscopic guidance. The cadavers were assessed using pre- and postprocedural computed tomography (CT) scans as well as dissected and visually inspected in order to determine the medial breach rate.

Results: Ninety pedicles were attempted and 86 screws were placed. CT analysis of screw placement accuracy revealed that only one screw (1.2%) breached the medial aspect of the pedicle by more than 2 mm. A total of four screws (4.7%) were found to have breached medially by visual inspection (three Grade 1 and one Grade 2). One (1.2%) lateral breach was greater than 2 mm and no screw violated the neural foramen. The correlation coefficient of pedicle screw violations and pedicle diameter was found to be 0.96.

Conclusions: This cadaveric study shows that percutaneous pedicle screw placement can be performed in the thoracic spine without a significant increase in the pedicle breach rate as compared with standard open techniques. A small percentage (4.4%) of pedicles, especially high in the thoracic spine, may not be safely visualized.

Key words: Minimally invasive surgery, pedicle screw, thoracic spine

Introduction

Advances in minimally invasive procedures have enabled surgeons to minimize damage to the contiguous tissues, leading to positive outcomes including shorter operating periods, faster postoperative patient mobilization, reduced blood loss as well as less muscle trauma and postoperative pain.[1-6] Various forms of image navigation have contributed to the evolution of spine surgery. Surgical guidance tools are becoming more accessible and intuitive; however, these aids cannot make up for deficiencies in a surgeon's skill, experience and knowledge of spinal anatomy. If the movement toward performing progressively more complex surgeries through minimally invasive techniques is to continue, surgeons must seek more ways to perform spinal instrumentation through percutaneous or "mini-open" procedures.

Percutaneous placement of pedicle screws in the lumbar spine has been increasing rapidly for a wide range of surgical indications,[1,3,6-8] but this method has been slower to gain acceptance in the thoracic spine. Recent studies have shown that thoracic transpedicular screw fixation is a viable

Access this article online

Quick Response Code:

Website: www.asianjns.org

DOI: 10.4103/1793-5482.121687

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surgical option for a variety of diagnoses, including kyphotic deformity,[9,10] tumor,[11,12] fracture[13,14] as well as adolescent idiopathic scoliosis.[15,16] The potential for screw placement malposition and neurological complications is higher due to the adjacent structures and the diminutive pedicle size in this region.[17-19] The evaluation of the current surgical techniques, including methods of image-navigation, is imperative to ensure that these types of procedures are not limited to the most distal aspect of the spine.

Since the origin of image-guided spinal navigation, there has been much controversy regarding the proper manner of performing pedicle screw placement. Computed tomography (CT) navigation has proven to be popular among surgeons.[20] Although CT navigation can provide an accurate depiction of spine anatomy and reduce the radiation exposure, significant preoperative planning and experience is required.[21,22] Additional arguments have been made that the complexities of spinal surgeries demand three-dimensional (3D) imaging assistance.[19,23-25] To date, no study has determined the accuracy of percutaneous thoracic pedicle screw placement using solely two-dimensional (2D) standard fluoroscopy. This study was used to test the feasibility and safety of placing thoracic pedicle screws through the entire extent of the thoracic spine using a percutaneous technique in a cadaveric model.

Materials and Methods

Surgical procedure

Pedicle screws were placed percutaneously in the thoracic spines of four cadavers with intact torsos from T1 to T12. A fluoroscopically guided technique, similar to that used for vertebroplasty, was used to localize the pedicle. The superolateral aspect of the pedicle was defined as the entry point. A transpedicular route was used in all cases, even when the cannulated screws utilized exceeded pedicle size. In these cases, we approached the pedicle tangentially, allowing for a small lateral breach while minimizing potential disruption of the medial cortex. Pedicle screws were placed at all levels accessible, with several levels skipped as they were used to test other percutaneous thoracic techniques. Two upper thoracic levels (T1 and T2) in one cadaver were skipped due to the inability to adequately visualize the anatomy radiographically.

Anterior–posterior (AP) fluoroscopy was used initially. The gantry was adjusted to align to the upper endplate of the vertebra and rotated to position the spinous process midway between the pedicles. A Jamsheedi needle was then placed bilaterally, entering the pedicle at the 3 o'clock position on the right (9 o'clock on the left). Serial AP and lateral images were taken as the Jamsheedi was advanced, with the goal being to place the tip within the midline of the pedicle as the lateral image revealed entry into the vertebral body. Once the pedicle was cannulated, a K-wire was guided through the Jamsheedi into the body. A 5.5 mm tap and 5.5 mm polyaxial screw (M-8, Medtronic Sofamor Danek, Memphis, TN, USA) followed, guided into the vertebral body by the K-wire. The screw was then removed and the path was casted with Plaster of Paris to minimize streak artifact on the postprocedural CT images. CT was the image modality of choice because the clarity of the image allows for precise measurement of pedicle diameter and screw placement within 1 mm.[26]

The cadavers were assessed using pre- and postprocedural CT scans. These images were evaluated by two independent radiographers to determine screw containment and rate of misplacement. Additionally, each cadaveric spine was also dissected and visually inspected in order to determine the medial breach rate. Gross inspection of the medial pedicle wall was performed after laminectomy and removal of the thecal sac. Transpedicular screw malposition was categorized according to the system of Mirza *et al*.[27] Essentially, there were three classes of malposition: Grade 1 (<2 mm), Grade 2 (2-4 mm) or Grade 3 (>4 mm). The effect of vertebral level on breach rate was determined and the influence of pedicle diameter was evaluated using the Pearson correlation coefficient [Table 1].

Results

Percutaneous transpedicular screw fixation was attempted on 90 pedicles and 86 (96%) screws were placed. Fixation was aborted on four pedicles (levels T1 and T2, on a single cadaver) because they were not clearly visualized by AP fluoroscopy. Postinstrumentation CT scans, followed by anatomic dissections, were used to evaluate the screw breach rates and the orientation relative to the pedicle axis [Figure 1].

On CT imaging, six (7%) screw trajectories abutted or breached the medial cortical wall (Grade 1) and one (1.2%) screw trajectory breached between 2 and 4 mm (Grade 2). In addition, only one (1.2%) lateral breach was greater than 2 mm and no screw was found to have entered the neural foramen. Under direct inspection following laminectomy and removal of the canal contents, only three of the six presumed lower grade breaches were noted. Therefore, only a total of four (4.7%) screws were found to have breached medially upon visual inspection (one Grade 2 and three Grade 1). This represents a 4.7% incidence of proven medial breach, 3.5% of which was structurally insignificant and 1.2% of which was structurally significant.

Table 1: Medial breach rates categorized by grade and evaluation method

	CT (%)	Visual inspection (%)
Grade 1	6 (7.0)	3 (3.5)
Grade 2	1 (1.2)	1 (1.2)
Grade 3	0 (0.0)	0 (0.0)

CT – Computed tomography

Figure 1: Reconstructed computed tomography scan images showing accurate placement of percutaneous thoracic pedicle screws. Axial views of characteristic low (a) and middle (b and c) thoracic vertebrae. Sagittal view (d) of all attempted levels within the thoracic spine

All the breaches occurred in the mid-thoracic spine and 100% of the breached pedicles were smaller than the screws used to instrument the spine. There were significant differences in the breach rates between the middle (T5-T8: 12.5% or 4/32) compared with the upper (T1-T4: 0% or 0/28) and lower (T9-T12, 0% or 0/26) thoracic regions, respectively ($P < 0.001$). The correlation coefficient between pedicle screw violations, as determined by two independent observers by examination of CT scans, and pedicle diameter was found to be 0.96. A significant correlation between pedicle diameter and breach rate was also found ($P < 0.0001$).

Discussion

Transpedicular screw fixation is becoming more common in spine surgery; however, this procedure is technically challenging and can be fraught with complications, particularly in the thoracic spine. Minimally invasive surgical techniques are proving to result in many benefits for the patient; however, diminished visualization of anatomy can increase intraoperative complications for the surgeon. Accordingly, it is imperative to evaluate varying surgical methods and navigation aids in order to optimize clinical outcomes.

Image navigation systems have been shown to improve the accuracy of transpedicular screw placement, but the debate continues as to whether CT navigation, 3D fluoroscopy or standard 2D fluoroscopy is best. Substantial research suggests that CT navigation improves the accuracy of pedicle screw placement.[28-36] However, fluoroscopic guidance systems minimize the pre- and intraoperative preparatory steps such as preoperative scanning, data acquisition and patient registration that have prevented the general acceptance of CT navigation.[21,22] Intraoperative CT-like devices (e.g., Seimen's Iso-C) have simplified the data acquisition steps, but many technical challenges remain in performing minimally invasive spine surgery.

Proper placement of transpedicular screws is imperative to prevent injury of the adjacent neural and vascular elements, and helps maximize the amount of bone surrounding the screw and increases screw purchase.[37] The current study sought to evaluate the accuracy of percutaneous pedicle screw placement using standard 2D fluoroscopy as the means of intraoperative guidance in a cadaveric model. A comprehensive meta-analysis of the current literature on image-guided pedicle screw insertion found that the median accuracy rate of *in vitro* thoracic transpedicular screw placement using 2D fluoroscopic guidance was 88.6% and that using CT navigation was 92.5%.[20] For this study, an "all-in" transpedicular route was used for every pedicle attempted even when the cannulated screws exceeded the pedicle diameter. Regardless of this, the overall accuracy that we have shown herein (95.3%), with approximately 99% of the screws placed without any significant medial breaches and no screw entering the neural foramen, is comparable to the results cited elsewhere for the thoracic spine.

If surgeons are going to continue the trend of minimally invasive spine fusion, it is imperative to determine the safety of the different instrumentation methods and, at a minimum, replicate the accuracy of the currently accepted techniques. In the case of the current study, a 1.2% rate of structurally significant medial breaches (greater than a 2 mm violation) is noteworthy as it compares favorably with the studies found in the literature. Thus, percutaneous thoracic pedicle screws can be placed accurately under standard fluoroscopic guidance.

The ability to achieve thoracic pedicle screw fixation percutaneously using standard fluoroscopy eliminates the need for complex imaging guidance while avoiding the invasiveness of standard open techniques. This may theoretically lead to decreased operative costs and overall surgical time as well as improved surgical outcomes. At the same time, our data confirms that breach rates, especially in the mid-thoracic spine, are influenced by pedicle diameter. Thus, preoperative CT imaging may be useful in determining the optimal screw size.

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How to cite this article: Hardin CA, Nimjee SM, Karikari IO, Agrawal A, Fessler RG, Isaacs RE. Percutaneous pedicle screw placement in the thoracic spine: A cadaveric study. Asian J Neurosurg 2013;8:153-6.

Source of Support: Internal funding from duke university medical center, **Conflict of Interest:** None declared.