Freehand thoracic pedicle screw technique using a uniform entry point and sagittal trajectory for all levels: preliminary clinical experience

Clinical article

VERNARD S. FENNELL, M.D., SHERI PALEJWALA, M.D., JESSE SKOCH, M.D.,
DAVID A. STIDD, M.D., M.S., AND ALI A. BAAJ, M.D.

Division of Neurosurgery, University of Arizona Medical Center, Tucson, Arizona

Object. Experience with freehand thoracic pedicle screw placement is well described in the literature. Published techniques rely on various starting points and trajectories for each level or segment of the thoracic spine. Furthermore, few studies provide specific guidance on sagittal and axial trajectories. The goal of this study was to propose a uniform entry point and sagittal trajectory for all thoracic levels during freehand pedicle screw placement and determine the accuracy of this technique.

Methods. The authors retrospectively reviewed postoperative CT scans of 33 consecutive patients who underwent open, freehand thoracic pedicle-screw fixation using a uniform entry point and sagittal trajectory for all levels. The same entry point for each level was defined as a point 3 mm caudal to the junction of the transverse process and the lateral margin of the superior articulating process, and the sagittal trajectory was always orthogonal to the dorsal curvature of the spine at that level. The medial angulation (axial trajectory) was approximately 30° at T-1 and T-2, and 20° from T-3 to T-12. Breach was defined as greater than 25% of the screw diameter residing outside of the pedicle or vertebral body.

Results. A total of 219 thoracic pedicle screws were placed with a 96% accuracy rate. There were no medial breaches and 9 minor lateral breaches (4.1%). None of the screws had to be repositioned postoperatively, and there were no neurovascular complications associated with the breaches.

Conclusions. It is feasible to place freehand thoracic pedicle screws using a uniform entry point and sagittal trajectory for all levels. The entry point does not have to be adjusted for each level as reported in existing studies, although this technique was not tested in severe scoliotic spines. While other techniques are effective and widely used, this particular method provides more specific parameters and may be easier to learn, teach, and adopt.

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KEY WORDS • thoracic pedicle screw • thoracic fusion • freehand technique

PEDICLE screw fixation has become the prevailing modality for thoracic spinal stabilization.^{18,23,24,26,30,32,36,37} Several techniques have been used to increase the ease and accuracy of pedicle screw placement, including the use of intraoperative fluoroscopy, intraoperative CT, and image-assisted navigation.^{1,3,5,8,39} Radiation exposure and its deleterious effects, however, is a growing concern.^{28,37,39} A safe, reproducible, and reliable practice of freehand thoracic screw placement is ideal for reducing intraoperative radiation exposure, reducing the overall operative time, and streamlining the teaching process for surgical trainees.^{4,10,16,19,28,37}

Existing techniques of freehand pedicle screw place-

ment in the thoracic spine primarily focus on various entry points and medial angulation.^{10,16,20,22} Furthermore, no consistent methods to determine cranial-caudal trajectories are described. We believe that existing published techniques and “thoracic pedicle screw charts” may be cumbersome to adopt and teach given the variability of starting points and angulations. To the best of our knowledge, this preliminary study represents one of the few single-surgeon clinical experiences of thoracic pedicle screw placement using a freehand technique that employs a uniform entry point and sagittal trajectory for all thoracic levels. In addition, very simple yet effective axial trajectories are proposed.

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Fig. 1. Illustration demonstrating the uniform entry point, which is always 3 mm caudal to the junction of the lateral margin of the superior articulating process and the transverse process.

Methods

We retrospectively reviewed the postoperative CT scans of 33 consecutive patients undergoing open thoracic pedicle screw placement. All cases were performed by the senior author (A.A.B.) and all involved neurosurgical residents assisting with pedicle screw placement under direct supervision. Pedicle screws were placed using a uniform entry point of 3 mm caudal to the junction of the lateral margin of the superior articulating process and transverse process (Fig. 1). The sagittal trajectory was orthogonal to the curvature of the dorsal spine at that level, which allows a “straight-forward” trajectory of pedicle screw insertion.

After exposure, a high-speed electric drill is used to disrupt the cortical bone at the entry point described above. A sharp, straight gearshift is used to cannulate the pedicle to the desired depth based on preoperative CT measurements. A ball-ended feeler is used to assess for breaches. The pedicle is then typically undertapped and an appropriate size screw is placed. Markers are not used, and we believe that the often-used practice of initial cannulation to 10–15 mm followed by probing and then completing the cannulation is unnecessary and increases operative time.

Intraoperative fluoroscopy is used for initial localization, and then again for a final anteroposterior and lateral radiograph. Postoperative CT scans were obtained in all patients after thoracic pedicle screw instrumentation. In this study, we retrospectively measured the average medial angulation of all screws that had an acceptable gantry. Computed tomography scans were independently reviewed for breaches by 2 resident physicians (V.S.F. and S.P.), and breach was defined as > 25% of the screw lying outside of the pedicle.

Results

Two hundred nineteen consecutive screws were evaluated and no screws were excluded. Screws were placed for a variety of spinal pathology: 61% for trauma, 12% for infection, 18% for tumor, and 9% for deformity (Fig. 2). The screw distribution was as follows: 23 screws (10.5%) at T-1, 27 (12.3%) at T-2, 11 (5%) at T-3, 13 (5.9%) at T-4, 10 (4.6%) at T-5, 8 (3.7%) at T-6, 15 (6.8%) at T-7,

23 (10.5%) at T-8, 23 at T-9 (10.5%), 25 (11.4%) at T-10, 19 (8.7%) at T-11, and 22 (10%) at T-12 (Fig. 3). There were 9 total lateral breaches (4.1%; Fig. 4) and no medial breaches. There was no evidence of suprapedicular or infrapedicular breaches. There were no neurovascular- or hardware-related complications, and no instrumentation had to be revised. Medial angulation was measured postoperatively and was, on average, 30° at T-1 and T-2 and 20° from T-3 to T-12 (Fig. 5).

Discussion

Pedicle screw stabilization is now the preferred modality of fixation for thoracolumbar pathologies such as degenerative spine disease, tumor, trauma, and deformity.^{21,25,32} Pedicle screw placement, however, can be challenging, particularly in the thoracic spine.^{17,19,21,37} In this region, the pedicles are typically smaller and have more complex morphologies, thus increasing the risk of malpositioned screws.^{17,19,21,37} The clinical consequences of

Fig. 2. Distribution of cases with freehand thoracic pedicle screw placement according to spinal pathology.

FIG. 3. Distribution of the number of screws placed at each thoracic level.

malpositioned screws can result in neurological, vascular, and visceral organ injuries.^{17,19,21,37}

To aid with successful placement of thoracic pedicle screws, intraoperative fluoroscopy and stereotactic-guided techniques have gained popularity.^{1,6,11,15,38} These modalities have been associated with increased operative time and radiation exposure to both the patient and the surgeon.^{6,28} This radiation exposure is not without risk, especially for surgeons who perform numerous surgeries over the course of a career.^{6,28} The relative accuracy rates are comparable in fluoroscopically guided versus freehand thoracic pedicle screws.^{1,6,8,13,29,33,34} In a 2012 review by Gelalis et al., the authors reviewed prospective studies comparing the accuracy rates of freehand, fluoroscopic, and image-guided techniques.¹³ The review included 26 clinical studies, 1105 patients, and 6617 screws. Freehand and fluoroscopy-aided screws had accuracy rates of 69%–94% and 28%–85%, respectively, whereas CT- and fluoroscopy-based navigation showed accuracy rates of 89%–100% and 81%–92%, respectively. It was noted that

perforated screws inserted using the freehand technique tended to be medial, as opposed to lateral with CT navigation.

Temporal limitations and increased radiation exposure associated with the use of intraoperative fluoroscopy and stereotactic navigation have placed an emphasis on the use of freehand techniques.²⁷ Technical studies on the use of freehand pedicle screw placement in the thoracic spine are few and limited.^{4,7,19,20,25} Kim and Lenke had one of the first studies to describe the use of the freehand technique for thoracic pedicle screws.¹⁸ They described a stepwise procedure for the placement of thoracic pedicle screws, starting at the base of the superior articular facet.¹⁸ Modi et al. confirmed this entry point in their study of patients with scoliosis.²⁵ These studies, however, rely almost exclusively on tactile feedback from a pedicle probe to guide both the medial-lateral and cephalad-caudad trajectories.^{4,7,18,20,25} Tactile feedback, however, can be prone to error.^{14,21} While the base of the superior articular facet is generally considered to be the best starting point for pedicle entry, the exact medial-lateral angles and cephalad-caudad trajectories remain subject to surgeon preference. Furthermore, many suggest using the transverse process as an anatomical landmark for freehand

FIG. 4. Example of a lateral breach in which more than 25% of the pedicle screw is outside the pedicle.

FIG. 5. Axial CT scans demonstrating the mean axial trajectory of a T-2 screw (left) and the mean axial trajectory of a T-12 screw (right).

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TABLE 1: Studies of freehand thoracic screw techniques

Authors & Year	Freehand Thoracic Screws	Comments	
		Strengths	Weaknesses
Fennell et al. (current study)	219	single surgeon experience, specific & uniform entry point, sagittal & axial trajectories well defined, low breach rate	small series, not tested yet in scoliosis
Parker et al., 2011	3443	large series, low breach rates	complex triangular entry point, sagittal trajectory based on suboptimally visualized endplate, no axial trajectory guidelines
Samdani et al., 2010	856	large series, specific pathology (adolescent idiopathic scoliosis)	no technique specifics provided
Cui et al., 2012	404	large series, specific pathology (scoliosis)	no technique specifics
Modi et al., 2009	482	large series, defined pathology (scoliosis), defined entry point	no guidelines for sagittal or axial trajectories
Beck et al., 2009	194	defined entry point	no guidelines for sagittal or axial trajectories
Karapinar et al., 2008	297	defined entry point	thoracic screws T10–12 only, no objective sagittal or medial trajectories provided
Upendra et al., 2008	314	compared scoliotic to nonscoliotic spines	no specifics on technique of entry point, sagittal or medial trajectories
Kim et al., 2004	3204	large series, both scoliosis & kyphosis cases	entry point varied by level, no sagittal or axial trajectories provided
Belmont et al., 2001	279	entry point & axial trajectories defined	no sagittal trajectories defined

placement, but McCormack et al. demonstrated that the transverse process is not as reliable in the thoracic spine relative to the lumbar spine.²⁴ In addition, these studies had not provided reliable methods to determine the sagittal trajectories or quantitative medial angulations (Table 1). Another difference between these original studies and our technique is that we do not use a curved probe that necessitates partial cannulation, and then recannulation after the probe is turned 180°. Although effective, this technique slightly lengthens operative time and is not necessary when a more lateral entry point is chosen.

Parker et al. recently published one of the largest series of freehand pedicle screw cases.²⁷ With an impressive number of pedicle screws placed and very low breach rates, the authors concluded that in large volume centers, the freehand technique is safe and effective.^{9,12,27,33,34} We wholeheartedly agree with that conclusion, and our current study offers a slightly different, but equally effective, approach. We have defined a specific entry point that is uniform throughout the thoracic spine and does not rely on visualization of a complex triangular relationship; it only relies on the junction of the lateral margin of the superior articulating facet and the transverse process. Furthermore, this current study offers simple but specific quantitative medial angulation parameters that complement a surgeon's preference and/or bias. Although the overall breach rate was very low, approximately one-third of all breaches were medial in the Parker et al. study, with 2 cases resulting in significant postoperative lower-extremity motor weakness.²⁷ Our entry point, which is inherently lateral, may diminish the chance of a medial breach. Our sagittal plane technique relies on pedicle

cannulation that is orthogonal to the curvature of the dorsal spine at that level, which is easier to visualize intraoperatively than the superior endplate of the corresponding vertebral body (Fig. 6); this is particularly effective with kyphotic plane deformities. Lastly, pedicle markers are not used in the presented technique, obviating the need for yet an additional lateral radiograph and a minor increase in operative time. Instead, we rely on the final anteroposterior and lateral radiographs and we have rarely had to remove or reposition a screw intraoperatively after it has been placed. More commonly, a breach or errant trajectory is detected after cannulation but before screw placement.

The present study offers our preliminary experience with a freehand thoracic pedicle-screw placement technique utilizing a uniform entry point and axial and sagittal trajectories. Some argue that, in the upper thoracic spine, the ideal entry point is typically more cranial. In our experience, the proposed entry point (3 mm caudal to the junction of the transverse process and lateral margin of the superior articulating process) is still effective in this region as long as a cranial-caudal orthogonal cannulation trajectory is used (Fig. 7). Choosing this seemingly caudal entry point obviates the need to adjust entry points in the lower thoracic spine (Fig. 8). There are certainly larger series in the literature and many of the existing techniques are effective and time tested. Our goal was to simplify and minimize variables while maintaining safety and effectiveness. Less variability can potentially make freehand thoracic pedicle screw placement techniques easier to teach and adopt. We have had initial success with this technique, but the efficacy of this ap-

FIG. 6. Freehand thoracic pedicle screw placement chart using a uniform entry point and sagittal trajectory with the appropriate axial trajectory angles. Copyright Ali A Baaj, M.D. Published with permission.

FIG. 7. Parasagittal CT scan of the upper thoracic spine region (T-4) demonstrating a traditional entry point and anatomical trajectory (dashed arrow) and a more caudal entry point with straightforward trajectory (solid arrow). Note that effective cannulation of the pedicle is possible, even at this level, with an inferior entry point.

proach in scoliotic spines and revision cases has yet to be determined.

As neurosurgeons play a bigger role in complex thoracic instrumentation and deformity cases, the need to acquire an effective and expeditious practice of freehand thoracic pedicle screw placement is imperative to completing these surgeries in a timely fashion. Furthermore, as our exposure to ionizing radiation has increased due to minimally invasive techniques, it is essential that we minimize the use of fluoroscopy in open cases.^{6,7,29,37}

Conclusions

It is feasible to place freehand thoracic pedicle screws using a uniform entry point and sagittal trajectory for all levels. The entry point does not have to be adjusted for each level as reported in existing studies, although this technique was not tested in severe scoliotic spines. While other techniques are effective and widely employed, this particular method may be easier to learn, teach, and adopt.

Disclosure

Dr. Baaj has received honoraria from Depuy Synthes, Inc., and Ulrich, Inc., as well as royalties from Thieme Medical Publishers. Author contributions to the study and manuscript preparation

Fig. 8. Multiple CT scans and radiographs demonstrating the feasibility of using our proposed entry point and trajectory at various segments of the thoracic spine; note only thoracic screws from the constructs are highlighted. **A:** Lateral cervicothoracic radiograph (T-1 and T-2). **B:** Lateral cervicothoracic radiograph (T1–4). **C:** Lateral thoracic radiograph (T4–12). **D:** Sagittal thoracic CT scan (T8–10). **E:** Lateral thoracolumbar radiograph (T-9, T-10, and T-12). **F:** Sagittal 3D reconstructed cervicothoracic CT scan showing pedicle screws from T-1 to T-8.

include the following. Conception and design: Baaj. Acquisition of data: Baaj, Fennell, Palejwala. Analysis and interpretation of data: Baaj, Palejwala, Skoch, Stidd. 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: Baaj. Administrative/technical/material support: Stidd. Study supervision: Baaj.

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Address correspondence to: Ali A. Baaj, M.D., Division of Neurosurgery, University of Arizona Medical Center, 1501 N. Campbell Ave., P.O. Box 245070, Tucson, AZ 85724. email: abaaj@surgery.arizona.edu.