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ORIGINAL ARTICLE

Clinical Outcome and Radiological Accuracy of the Free Hand Surgical Technique for Screw Placement in Cervical and Dorsolumbr Spine

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ABSTRACT

Introduction: Pedicle screw fixation is a commonly accepted method for attaining stable posterior spinal stabilization; however, concerns about accuracy, neurovascular safety, and radiation exposure associated with image-guided techniques remain to highlight the importance of reliable freehand screw placement on the basis of anatomical landmarks.

Objective: To assess the clinical effectiveness and outcomes of freehand pedicle screw fixation for treating dorsal, lumbar and sacral fractures at a tertiary care center in Pakistan.

Methods: Retrospective reviews were conducted for 150 consecutive patients who underwent freehand pedicle screw fixation for thoracic, lumbar, and sacral spinal fractures at a tertiary care center between January 2021 and December 2022 in Pakistan. In total, 911 pedicle screws were inserted via anatomical landmarks alone, and the accuracy of screw placement and degree of cortical breach were assessed intraoperatively and on postoperative radiographs and/or computed tomography (CT) scans.

Results: Overall, 887 screws (97.4%) were classified as acceptable. Acceptable placement was achieved for 69 of 70 cervical screws (98.6%), 169 of 174 thoracic screws (97.1%), and 630 of 637 lumbar screws (98.9%). In contrast, sacral screw placement demonstrated lower accuracy, with 19 of the 30 screws (63.3%) deemed acceptable. No neurological or vascular complications were observed.

Conclusion: Freehand pedicle screw placement based on anatomical landmarks demonstrated high accuracy and a low complication rate across the thoracic, lumbar, and sacral spinal levels. With meticulous surgical techniques and appropriate preoperative planning, freehand fixation remains a safe and effective method, particularly in settings where advanced navigation technologies are not readily available.

Keywords: Freehand technique, Pedicle screw fixation, Spinal fracture.

INTRODUCTION

The use of a pedicle screw, also known as a rod construct, is the fundamental concept of modern spinal stabilization and is widely acknowledged as a reliable method for achieving rigid fixation in a variety of spinal pathologies, including trauma, degenerative disease, deformity, infection, and tumors[1]. The evolution of pedicle screw instrumentation has been complemented by the development of multiple insertion techniques intended to improve placement accuracy and reduce procedure-related complications among patients. Among these techniques, the freehand pedicle screw technique, which is based solely on anatomical landmarks, continues to hold specific importance, especially in developing countries across the globe where access to advanced intraoperative imaging and navigation technologies remains limited[2].

Freehand pedicle screw placement, with positive clinical outcomes, relies mainly on surgeons' understanding of the spinal anatomy and ability to accurately identify pedicle entry points via surface and osseous landmarks. This technique has gained vast acceptance in lumbar spine procedures because of its larger pedicle dimensions relative to those of other spinal areas, providing more forgiving anatomical corridors; hence, the application of the technique for thoracic spine procedures remains more technically challenging[3]. Thoracic pedicles are narrower and exhibit greater anatomical variability and greater proximity to critical neurovascular structures, including the spinal cord, nerve roots, and major vascular elements, which necessitates a greater degree of accuracy and precision during screw insertion. As a result, thoracic pedicle screw placement is traditionally considered the most challenging segment of posterior spinal fixation among patients requiring spinal surgical procedures.

To address these challenges, modern spine surgery has increasingly incorporated adjunctive technologies such as intraoperative C-arm fluoroscopy, intraoperative computed tomography (CT), and computer-assisted navigation systems[4]. These modalities have been shown to increase pedicle screw accuracy; however, their routine use is not without drawbacks. Limitations include increased operative time, substantial financial cost, and cumulative radiation exposure to both patients and operating room personnel[5]. Given growing concerns regarding occupational radiation exposure and its long-term health implications, the ability to safely and accurately place pedicle screws using anatomical landmarks alone remains highly valuable.

Consequently, freehand pedicle screw placement, especially in the thoracic spine, remains extensively practiced and has been reported to be both safe and effective in the hands of experienced surgeons for better clinical outcomes[6]. Despite the widespread use of this technique, there is no single standardized freehand technique, and variations in surgical training, individual surgeon preference, and differences in pedicle morphology across spinal levels have resulted in considerable heterogeneity in the clinical outcomes of different reported techniques[7]. Many described methods advocate different entry points and trajectories depending on the thoracic level, which may limit reproducibility and pose challenges for surgeons in training or those adopting new techniques.

Given the variations and technical considerations, simplified, reproducible freehand pedicle screw techniques that can be consistently applied across spinal levels while maintaining high accuracy and safety among patients are needed. The present study aimed to assess the accuracy and safety of freehand pedicle screw fixation for thoracic, lumbar, and sacral spinal fractures among patients requiring spinal procedures at a tertiary care center in Pakistan.

METHODS

Study Design, Study Setting and Ethical Approval: This was a retrospective descriptive study conducted at the Department of Orthopedic and Spine Surgery, DHMC, Lahore, Pakistan, for a period of two years, from 1 January 2021 to 31 December 2022.

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Ethical approval for the study was obtained from the Institutional Review Board prior to the commencement of the study.

Patient Selection: A retrospective review of 150 consecutive patients who underwent posterior pedicle screw fixation for spinal fractures during the study period was performed and included patients of either sex aged 15 years to 70 years. However, patients aged over 70 years, those presenting with polytrauma, those with a history of prior spinal surgery, and those in which pedicle screw insertion was performed via fluoroscopic guidance or other navigational adjuncts were not included in the study.

Preoperative evaluation: All patients underwent a comprehensive preoperative assessment, including a detailed clinical history and physical examination by expert healthcare professionals in the healthcare facility. The radiological evaluation of all patients included plain radiographs of the spine in anteroposterior and lateral views, magnetic resonance imaging (MRI), and computed tomography (CT) scans with three-dimensional reconstruction of the lumbosacral spine to evaluate fracture morphology, pedicle anatomy, and surgical planning among the patients.

Surgical technique: All the pedicle screws were placed via the freehand technique by a reliable healthcare professional, relying exclusively on anatomical landmarks to establish the entry point and trajectory for the surgical procedure, and 911 pedicle screws were inserted across the thoracic, lumbar, and sacral spinal levels. The entry points and trajectories were standardized as follows:

Thoracic spine: The entry point is approximately 3 mm caudal to the junction of the transverse process and the lateral margin of the superior articulating process, and the sagittal trajectory is directed orthogonally to the dorsal curvature of the spine at the corresponding level[2].

Lumbar spine: The entry point was determined at the junction of the par interarticularis, which is the midpoint of the transverse process, and the inferior aspect of the superior articular facet among patients.

Sacral spine: The entry point was established at the inferolateral margin of the base of the superior articular process of the sacrum among patients. Pedicle probing, tapping, and screw insertion were performed in a stepwise manner, with tactile feedback used to confirm an intact pedicle tract prior to screw placement.

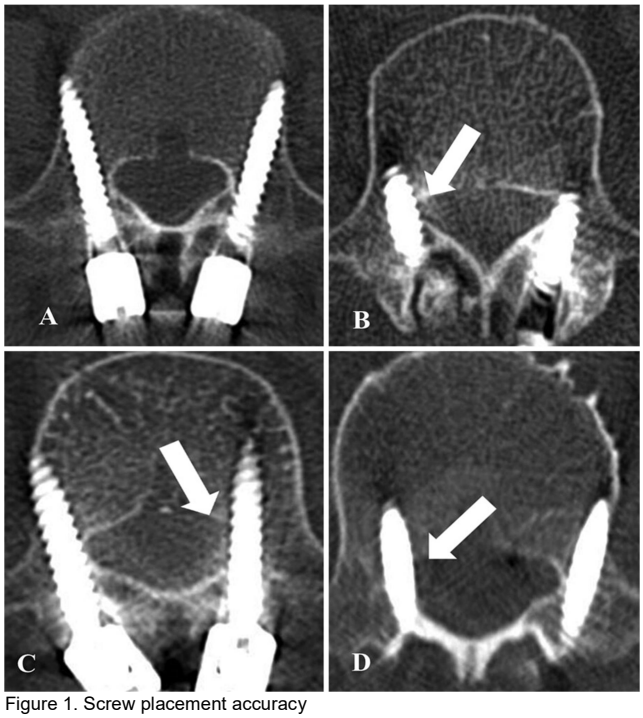

Figure 1. Screw placement accuracy

Assessment of Screw Placement Accuracy: Intraoperative evaluation of pedicle screw positioning was achieved via an image intensifier, and any screw doubted to be mispositioned intraoperatively was instantly corrected before completion of the surgical procedure. Postoperative assessment of screw placement was conducted via plain radiographs and/or axial CT scans. Furthermore, screw placement accuracy was graded on axial CT images according to the extent of cortical breach as follows: Grade 0: no cortical violation; Grade 1: cortical breach < 2 mm, Grade 2; cortical breach between 2 mm and 4 mm; and Grade 3: cortical breach > 4 mm. The direction (medial, lateral, inferior, or superior), level, and extent of screw misplacement were recorded, as reflected in Figure 1. Minor breaches that did not compromise construct stability or neurological integrity were managed conservatively without revision.

Data collection: The data collected included patient sociodemographics, medical history, number of pedicle screws inserted, spinal level of fixation, technical parameters of screw insertion (entry point and trajectory), and incidence and severity of cortical breaches. Perioperative and postoperative complications, including neurological deficits, vascular injury, cerebrospinal fluid leakage, and the need for screw revision, were documented.

Statistical analysis: The data were analyzed via Microsoft Excel 365; descriptive statistics were used to summarize the data, and continuous variables are presented as the means with standard deviations, whereas categorical variables are presented as frequencies and percentages.

RESULTS

Patient Demographics: Among the 150 patients aged 15 to 70 years, 107 (71.3%) were males, and 43 (28.7%) were females. The mean age was 34.84 ± 14.6 years.

Accuracy and Misplacement of Pedicle Screws: In the cervical spine, 70 screws were inserted, with 69 (98.57%) evaluated as acceptable and 1 (1.43%) as unacceptable. The thoracic spine included 174 screws, 169 (97.12%) of which were acceptable and 5 (2.88%) of which were unacceptable. In the lumbar region, 637 screws were placed, with 630 (98.90%) rated as acceptable and 7 (1.10%) rated as unacceptable. The sacral segment showed a comparatively lower accuracy, with 30 screws inserted, 19 (63.33%) classified as acceptable and 11 (36.67%) as unacceptable. Overall, the majority of screw placements were satisfactory, with the sacral region demonstrating the highest rate of malposition.

Table 1. Accuracy and Misplacement of Pedicle Screws

Level	Total Screws	Accurate	Misplaced
Cervical	70	69 (98.57%)	1 (1.43%)
Thoracic	174	169 (97.12%)	5 (2.88%)
Lumbar	637	630 (98.90%)	7 (1.10%)
Sacral	30	19 (63.33%)	11 (36.67%)

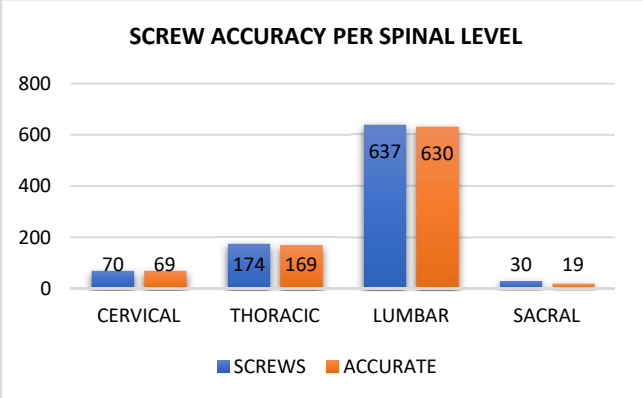

Figure 1. Screw accuracy per spinal level

DISCUSSION

The placement of freehand pedicle screws, especially in the dorsal spinal segment, can be challenging because of the varied and complex anatomy of the thoracic vertebrae, with the potential for screw malposition and neurovascular injury[2,6,8,9]. Even though modern spinal surgeons have various intraoperative navigational tools in their arsenal, sustained radiation exposure during one's career is concerning[10]. To avoid the harmful effects of radiation, freehand pedicle screw placement is becoming the preferred fixation modality for a diverse number of pathologies ranging from trauma to tumors[11]. The command-over freehand techniques in spinal surgical procedures, which are based on basic anatomy, are not only fundamental for increasing surgeons' skills but also valuable in settings where the availability of navigation is limited. Scientific evidence reveals that 8,000 screws have been placed in different studies, with a placement accuracy of 93.3% for thoracic screws[12]. Furthermore, the accuracy of pedicle screw placement was 93.34%, and the lowest reported accuracy was 87.4% for screws placed only at the T1 level. However, the highest placement accuracy was 98.3% in their series of 964 patients[13,14]. Modi et al. determined the difference in the accuracy of this method for spine pathologies and reported that the accuracy for patients with adolescent idiopathic scoliosis was 86.1%; the accuracy was 91.7% in patients with cerebral palsy, 95.9% in patients with Duchenne muscular dystrophy, 90.2% in patients with spinal muscular atrophy, and 84.4% in Polio patients[15]. In studies in which multiple surgeons performed the procedure, the placement accuracy for five surgeons was 93.8% among patients, and that for eight surgeons was 98.3% among patients[16,17].

Among the total 751 free hand-placed pedicle screws in another study, 12 screws were identified to have caused minor breaches, of which 9 had lateral breaches and three had inferior breaches[18]. Minor breaches do not need to be repositioned and are recognized only by postoperative imaging. In another study with a total of 720 screws inserted, 623 screws were placed correctly, and 97 were misplaced[19,20]. Another study highlighted that 39 screws (40.2%) were medial and that 58 (59.8%) were laterally placed among patients, highlighting the greater prevalence of lateral misplacement than of medial misplacement, with reported deviation of the screw less than 2 mm as a "definitely safe zone", a breach of 2–4 mm as a "probably safe zone", and a breach of 4–8 mm as a "questionably safe zone"[21].

In a study by Karapinar L et al., the majority of the breaches were labeled as minor (< 2 mm) in the thoracic spine[22]. Lateral breaches were more common than medial breaches of the vertebral bodies, with 2.5% to 21.6% of the screws used for lateral breaches and 1.7% to 13.2% of the screws used for medial breaches, with the majority falling below 5% of the total screws placed[23,24]. Robotic-assisted surgical procedures have gained popularity over time because of their increased accuracy, and a meta-analysis including five scientific studies with a total of 257 patients and more than 1105 screws placed in total revealed that there was no statistically significant difference in the accuracy of screw placement between the robot-assisted and conventional freehand pedicle screw placement techniques[25,26].

The current study was conducted at one of the largest healthcare facilities offering surgical care and included a wide range of patients from different age groups and backgrounds. Furthermore, the accuracy of screw placement at different anatomical spinal sites was compared. However, the study did not consider factors related to healthcare professionals, including experience, number of surgical hours and advanced qualifications. Additionally, the study did not compare the different surgical procedures in terms of the accuracy of screw placement. Therefore, further studies are needed to conclusively recommend one surgical technique over another for accuracy and effective clinical outcomes.

CONCLUSION

Freehand pedicle screw placement via anatomical landmarks demonstrated high accuracy and a low complication rate in the fixation of thoracic, lumbar, and sacral spinal fractures. When performed with careful preoperative planning and strict adherence to surgical techniques, freehand pedicle screw placement remains a safe, effective, and reproducible method, particularly in settings where advanced navigational technologies are not readily available.

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