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Assessment of the Accuracy of Pedicle Screw Fixation in Thoracolumbar Vertebrae using Freehand Technique in Resource-Limited Settings: Insights from a Prospective Analysis

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Abstract

Background. Thoracolumbar fractures and diseases represent a significant healthcare problem. Pedicle fixation is a cornerstone in the surgical stabilization of spinal disorders, where spinal stability is crucial for maintaining proper biomechanical function and preventing neurological compromise.

***The aims*:** 1) to reassess the accuracy of freehand pedicle screw fixation in thoracolumbar vertebrae, particularly within the context of resource-limited settings where image-guidance technologies are not feasible; 2) to explore how surgical ergonomics, particularly surgeon handedness, affects screw placement accuracy.

Methods. A prospective study was conducted, recruiting 90 patients with thoracolumbar lesions who underwent pedicle screw fixation by freehand technique in 2024. We excluded patients with congenital spine deformities and revision surgery. The accuracy and incidence of cortical breach of screws were determined by postoperative CT.

Results. Six hundred eighty-one screws were inserted in the lumbar and thoracic spine of 90 patients using a freehand approach. Out of them, 579 (85%) screws were installed within the pedicle without cortical breach, 78 (11.4%) screws — with a cortical breach less than 2 mm, and 24 (3.5%) screws — a with a cortical breach more than 2 mm. Six hundred fifty-seven (96.4%) screws were considered a safe breach, and 24 (3.6%) screws were considered a dangerous breach.

Conclusions. The use of freehand technique in pedicle screw fixation appears to be reliable and safe. It remains a valuable method, particularly in a resource-limited environment, providing a cost-effective and radiation-free alternative to navigation-assisted systems. This study reveals that surgical ergonomics, specifically surgeon handedness, do not significantly impact a breach when proper technique is maintained.

Keywords: pedicle screw fixation; freehand technique; thoracolumbar fractures; thoracolumbar diseases.

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Оценка точности транспедикулярной фиксации в грудопоясничном отделе позвоночника методом «свободной руки» в условиях ограниченных ресурсов: результаты проспективного анализа

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Реферат

Актуальность. Травмы и заболевания грудопоясничного отдела позвоночника представляют серьезную проблему для хирургов и всего здравоохранения в целом. Транспедикулярная фиксация лежит в основе хирургической стабилизации позвонков, а стабильность позвоночника имеет решающее значение для поддержания надлежащей биомеханической функции и предотвращения неврологических нарушений.

Цели исследования: 1) провести повторную оценку точности транспедикулярной фиксации в грудопоясничном отделе позвоночника методом «свободной руки», особенно в условиях ограниченных ресурсов, когда применение методов визуализации невозможно; 2) изучить, как хирургическая эргономика, в частности предпочтение хирурга работать левой или правой рукой, влияет на точность установки винтов.

Материал и методы. Было проведено проспективное исследование, в котором приняли участие 90 пациентов с поражениями грудопоясничного отдела, которым в 2024 г. была выполнена транспедикулярная фиксация методом «свободной руки». Пациенты с врожденными деформациями позвоночника и предшествующими ревизиями были исключены. Точность фиксации винтов и частота повреждений кортикального слоя определяли при помощи послеоперационной компьютерной томографии.

Результаты. У 90 пациентов в поясничный и грудной отделы позвоночника был установлен 681 винт методом «свободой руки». Из них 579 (85%) винтов были установлены интрапедикулярно без нарушения кортикального слоя, 78 (11,4%) винтов — с выходом винта из ножки менее 2 мм и 24 (3,5%) винта — с выходом винта из ножки более 2 мм. Положение 657 (96,4%) винтов было признано безопасным, а 24 (3,6%) винтов с повреждениями — опасным.

Заключение. Использование техники «свободной руки» при транспедикулярной фиксации является надежным и безопасным методом, который особенно полезен в условиях ограниченных ресурсов, являясь экономичной и безрадиационной альтернативой навигационным системам. Результаты проведенного исследования показали, что хирургическая эргономика, в частности предпочтение хирурга работать левой или правой рукой, не оказывает существенного влияния на успешность хирургического лечения при соблюдении техники.

Ключевые слова: транспедикулярная фиксация; метод «свободной руки»; травмы грудопоясничного отдела позвоночника; заболевания грудопоясничного отдела позвоночника.

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INTRODUCTION

Spinal fixation has been developed in the 20th century. Before that, immobilization of an unstable spine had been tried using traction, bed rest, bracing, and casting [1]. One of the earliest spinal fixations was introduced in 1891 by B.E. Hadra, who used a sliver wire loop around a spinous process in a figure-of-eight to stabilize spinal fractures caused by Pott's disease [2].

Nowadays, pedicle screws fixation with rod constructs has gained global acceptance in multiple reconstructive spine surgeries, spinal fusion, and spinal stabilization in traumatic, degenerative, and neoplastic spine diseases [3]. The coronal and sagittal orientations of the thoracic and lumbar facets define the thoracolumbar spine, a crucial transitional region between the more rigid thoracic spine and flexible lumbar spine [4].

Various methods, including the freehand technique, have been established for pedicle fixation; this method relies on the surgeon's experience and the ability to determine the entry point with anatomical landmarks exposure of the posterior elements. Freehand pedicle screw fixation has been widely accepted in the lumbar region. In contrast, the thoracic region is more challenging due to the narrow pedicle corridor and critical neurovascular anatomy [5]. Due to the spine's unique neurovascular anatomy, there has been a movement in favor of new techniques that enhance the accuracy of pedicle screw fixation, including intraoperative fluoroscopy, computed tomography (CT), and computer-assisted navigation [6]. Despite their advantage in the accuracy of pedicle screw positioning, they pose hazards, including radiation exposure to the medical team and the patient, prolonged operative time, blood loss, and high costs that hinder their availability in all facilities. The benefit of the freehand method is that it may be used anywhere, especially in developing areas, decreases radiation exposure, saves time and money, and prevents repeated interruption during surgery [5].

Spine surgeons are among the most exposed surgical specialists in terms of occupational radiation. Compared to other fields, their exposure ranks third after interventional cardiologists and radiologists, mainly due to the frequent use of intraoperative fluoroscopy and navigation in spinal instrumentation. Studies show that spine surgeons may receive between 1 to 5 mSv per year, significantly higher than general surgeons or neurosurgeons, whose exposure typically remains below 0.5 mSv [7]. Intraoperative fluoroscopy in spine procedures, especially minimally invasive surgeries, poses substantial radiation risks to the surgeon's hands, thyroid, and lens of the eye. Long-term cumulative exposure can lead to increased risks of cataracts, thyroid abnormalities, and even malignancies [8, 9]. This elevated risk underscores the occupational health advantage of adopting the freehand technique, particularly in routine thoracolumbar surgeries, where it eliminates intraoperative radiation. In resource-limited settings, where radiation shielding may be inadequate or inconsistently used, this benefit becomes even more critical.

Despite the advantages of pedicle fixation by the freehand technique, there is a potential risk of screw malposition in the surrounding critical neurovascular anatomy, which requires higher accuracy and precision. Screw malposition can lead to a permanent neurological deficit and necessitate reoperation [10].

The aims: 1) to reassess the accuracy of freehand pedicle screw fixation in thoracolumbar vertebrae, particularly within the context of resource-limited settings where image-guidance technologies are not feasible; 2) to explore how surgical ergonomics, particularly surgeon handedness, affects screw placement accuracy.

METHODS

Patients

A prospective study was conducted on 90 patients aged 18 to 65 years with spinal pathologies, including fractures, metastatic diseases, infection, and degenerative diseases, from January 2024 to June 2024 at the Ain Shams University. We excluded any congenital deformities, such as congenital scoliosis and malformations, or revision surgery.

Six hundred and eighty-one pedicle screws were implanted in 90 patients (54 males and 36 females) using a freehand approach. The patients were clinically and radiologically evaluated preoperatively and postoperatively. Personal history included name, age, and sex; history of trauma included mode, site, time till presentation, and severity; history of night fever; loss of weight; neurological disorders including sensory, motor, and sphincter disorders, or history of other general health problems that may hinder anesthesia.

Examination

The general examination included evaluating the patient's hemodynamic state, examining the head, chest, abdomen, and extremities for associated injuries, and palpating the spine for tenderness and deformity. Inspection for any deformity, contusion, or sinuses, evaluating any deformity and identifying any associated injuries. Neurological examination included motor, sensory, and sphincter examination. The motor examination included reflexes (superficial and deep) and motor power, assessed using the MRC muscle power scale, which grades the motor power from grade 0 (no contraction) to grade 5 (normal power) [11]. Sensory examination is a comprehensive process that encompasses both superficial and deep sensations, providing a robust foundation for diagnosis. Radiological evaluation included AP and lateral radiography, spine CT and MRI, further enhancing our understanding of the pathology and aiding in decision-making.

After admission, when all the investigations had been done, anticoagulants were administrated to non-ambulatory patients, and analgesics were used to manage other comorbidities. The surgery and postoperative management were explained to the patient and their relatives, and consent was obtained for the approach and postoperative CT.

Preoperative preparation and positioning

All patients received prophylactic antibiotics prior to the induction of anesthesia. The patients were positioned prone with a slightly flexed hip, and their knees were kept in slight flexion to avoid stretching over the sciatic nerve. Exposure of the entire back was achieved, and pressure points at the hips and chest were avoided by using proper padding. Fluoroscopy was used to confirm the level of incision.

Surgical technique

A longitudinal midline incision is done along the skin, subcutaneous fat, and fascia to reach the tips of spinous processes. Paraspinal muscles are stripped off the lamina subperiosteally to reduce blood loss with exposure to the transverse processes bilaterally, exposing the facet joints.

The entry point of the lumbar spine is at the meeting between the transverse process, pars interarticularis, and the inferior margin of the superior articular process. In the thoracic spine, the entry point is at the center of a triangle formed by the lower border of the superior articular process and the medial wall of the transverse process and the pars interarticularis. In the lower thoracic spine, the entry point tends to be more medial and cephalad when moving proximally; above T7, the entry point tends to be more lateral and caudal again.

An awl is used to create an entry point, and then a pedicle probe is inserted about 15-20 mm. Once the probe is removed, the track is checked to ensure that only blood is coming out, not pulsatile, and not cerebrospinal fluid. Then, the pedicle track is palpated with a feeler to ensure that the five osseous borders are intact. Then the screw is placed down into the body. The rod is placed and secured with set screws. Then, the surgical wound is irrigated, homeostasis is achieved, and the wound is closed in layers.

All the operations were performed by expert right-handed surgeons, and all the screws were positioned from the same side. The surgeon placed the right screws from the right side and the left screws from the left side.

To ensure accurate placement of pedicle screws during the surgery, we utilized a structured intraoperative audit tool named the Pedicle Screw Freehand Accuracy Checklist (PSFHAC) (Table 1). This checklist systematically verifies critical anatomical landmarks and procedural steps at each stage of screw insertion. It helps detect potential breaches early and guides the surgeon in maintaining the correct screw trajectory.

Postoperative protocol

The patients underwent neurological examination in the postoperative period. They were given antibiotics, and brace was prescribed for all of them. Different techniques are used to detect breaches intraoperatively, including fluoroscopy, and postoperatively by radiography, CT, or MRI. In this study, we utilize postoperative CT scans to assess the accuracy of pedicle screw placement and intraoperative fluoroscopy to detect any apparent breaches (Figure 1).

Table 1

Pedicle Screw Freehand Accuracy Checklist (PSFHAC)

Step	Anatomical landmark/technique	Checkpoint	Remarks
1	Identify the junction of the transverse process and superior articular facet	Entry point correctly marked? (Yes/No)	Align with the base of the facet
2	Use of gear shift probe	Medial wall breach during probing? (Yes/No)	Tactile loss of resistance warning
3	Palpate pedicle trajectory with a ball-tip probe	Smooth canal felt to depth? (Yes/No)	Check that all walls intact
4	Measure depth and angle with gear shift or probe	Medial/lateral angulation within the expected range?	Based on the vertebral level
5	Screw insertion	Smooth insertion without resistance? (Yes/No)	Sudden loss = possible breach
6	Record estimated trajectory angle (optional)	Matches anatomical norms for level?	For training purposes

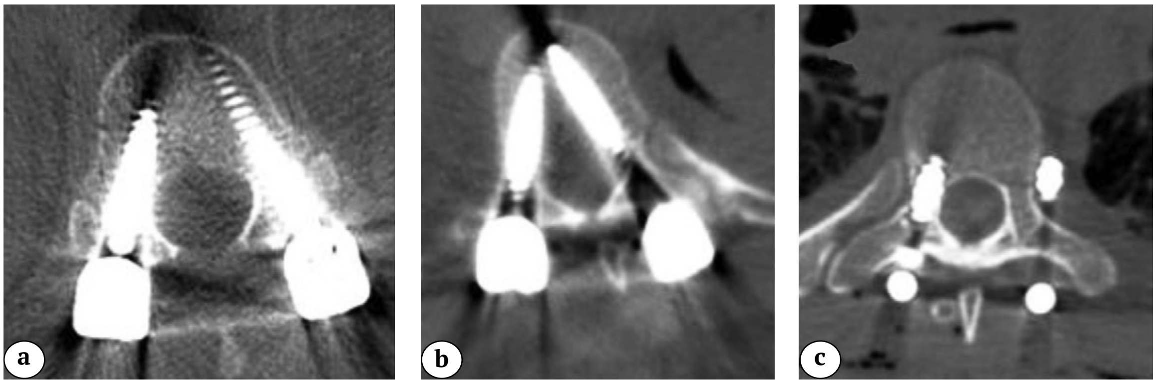

Figure 1. Postoperative CT scans assessing the accuracy of pedicle screw placement of:
a — a 35-year-old female with L1 fracture post-fixation with T12, showing screws within the pedicle;
b — a 43-year-old male with T12 fracture post-fixation with T10, showing a medial breach;
c — a 41-year-old female with T7 pathological fracture with T6, vertebra showing a lateral breach

The placement of the pedicle screw was assessed using postoperative CT scans. We analyze the axial, sagittal, and coronal views to get a comprehensive view of the screw trajectory, whether the screw is in the planned trajectory of the pedicle and the vertebral body and assess any cortical breach.

Then we use the Gertzbein-Robbins classification, which grades breaches as follows: a screw entirely within the pedicle is considered grade A; a violation of <2 mm is considered grade B; a violation of 2 to <4 mm is considered grade C; a violation of 4 to <6 mm is grade D; and a violation >6 mm is grade E [12]. According to the Gertzbein-Robbins classification, this study considers grades A and B breaches as safe, while C, D, and E are dangerous.

Statistical analysis

Data were collected, revised, coded, and entered into the Statistical Package for the Social Sciences (SPSS), version 23.0 (SPSS Inc., Chicago, IL, USA). Qualitative variables were presented as numbers and percentages. Chi-square test (χ^2) was used to assess the association between categorical variables, such as the screw breach status (safe vs dangerous) and factors like vertebral region (thoracic vs lumbar), screw side (right vs left), and underlying pathology. Logistic regression analysis was performed to identify predictors of dangerous screw breaches. The odds ratio (OR) and its corresponding 95% confidence interval (CI) were reported for each predictor to quantify the likelihood of a dangerous breach. The regression coefficient (β) represents the change in the log odds of the outcome for each unit change in the predictor variable. A p-value of < 0.05 was considered statistically significant.

RESULTS

Among 90 study participants, 54 (60%) were male, and 36 (40%) were female; all were operated on using the freehand technique. Forty-eight (53.3%) patients were diagnosed with vertebral fracture, 18 patients (20%) — with spondylodiscitis, 12 patients (13.3%) — with metastatic lesions, 9 (10%) patients — with a disk prolapse, and 3 (3.3%) patients — with spondylolisthesis.

We used 681 screws in the thoracolumbar vertebrae, 270 — in the lumbar vertebrae, and 411 — in the thoracic vertebrae, with most of the screws in the thoracolumbar transition zone. We used 375 (55%) screws in vertebral fractures, 123 (18%) screws in metastatic lesions, 135 (19.8%) screws in spondylodiscitis, 36 (5.2%) screws in a disc prolapse, and 12 (2%) screws in spondylolisthesis (Figure 2). No statistically significant difference in breach rates between pathologies ($p > 0.05$) were observed, although lateral breaches were numerically higher in infection and metastatic cases.

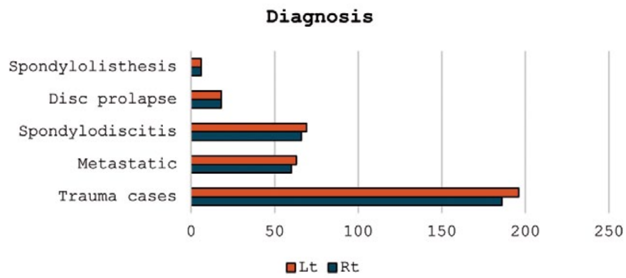

Figure 2. Number of screws in each pathology

In the thoracic vertebrae, we used 411 screws, 204 screws on the right side, and 207 screws on the left side. The percentage of screws within the pedicle was 342 (83%) screws out of 411 screws. Most of the screws outside the pedicle caused a lateral breach (8%) (Figure 3).

In the lumbar vertebrae, we used 270 screws, 132 on the right side and 138 on the left side. The percentage of screws within the pedicle was 237 (87.8%) screws out of 270 screws. Most of the screws outside the pedicle caused a lateral breach (7.8%) (Figure 4).

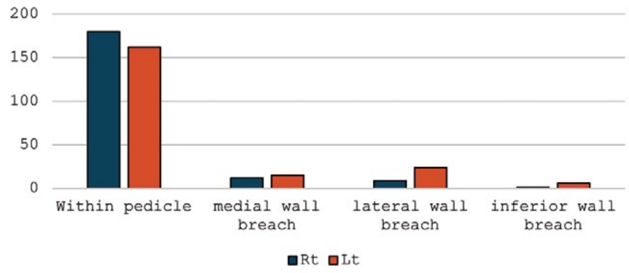

Figure 3. Position of screws in the thoracic spine

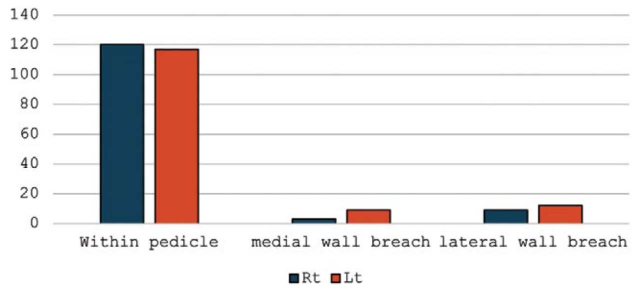

Figure 4. Position of screws in the lumbar spine

The following tables compare the thoracic and lumbar spine regarding the position of the screw (Table 2). Lateral breaches were most common, particularly in the thoracic region. Medial breaches, which pose a higher neurologic risk, were observed in only 5.7% of cases.

In this study, according to the Gertzbein-Robbins classification, 579 (85%) screws were considered grade A, 78 screws — grade B (11.4%), 18 (2.6%) screws — grade C, and 6 (0.9%) screws — grade D. Grade A and B with breaches <2 mm are considered acceptable breaches, while grades C, D, and E with breaches >2 mm are considered dangerous breaches. In this study, 657 screws out of 681 (96.4%) screws are considered safe breaches, while 24 (3.6%) screws are considered risky breaches (Table 3). Reoperation was required only in one patient due to pedicle screw malposition, which resulted in nerve root irritation. There is no significant difference in breach rates between right- and left-sided insertions, despite all surgeons being right-handed.

Side-based analysis and surgeon handedness

All screws were placed using an ipsilateral approach by right-handed surgeons (i.e., right screws inserted from the right side, left screws from the left). Among the 336 right-sided screws, 327 (97.3%) were classified as safe breaches (Grades A and B), and 9 (2.7%) were dangerous breaches (Grades C, D, and E). In comparison, among 345 left-sided screws, 330 (95.7%) were safe breaches, and 15 (4.3%)

Table 2

Thoracic versus lumbar screw placement accuracy

Spine region	Within pedicle	Medial wall breach	Lateral wall breach	Inferior wall breach	Total number of screws	Total number of breaches	χ^2	p-value
Thoracic	342 (83.2%)	27 (6.6%)	33 (8.0%)	9 (2.2%)	411	69 (16.8%)	2.07	0.59 (NS)
Lumbar	237 (87.8%)	12 (4.4%)	21 (7.8%)	0 (0.0%)	270	33 (12.2%)	0.89	0.35 (NS)

NS — non-significant.

Table 3

Combined Gertzbein-Robbins classification with breach acceptability by a screw side

Grade	Right-sided screws	Left-sided screws	Total	Classification
A	300	279	579	Safe
B	27	51	78	Safe
C	9	9	18	Dangerous
D	0	6	6	Dangerous
Total	336	345	681	
Acceptable breach (A+B)	327	330	657	96.4% of all screws
Non-acceptable breach (C+D)	9	15	24	3.6% of all screws
p-value (acceptable vs non-acceptable)				0.50 (NS)
	Right	Left	χ^2	p-value
Acceptable breach	327	330	0.47	0.50 (NS)
Non-acceptable breach	9	15		
Total	336	345		

NS — non-significant.

were dangerous breaches. The difference was not statistically significant (p = 0.50). These findings suggest consistent screw placement accuracy irrespective of screw laterality and surgeon handedness.

As illustrated in Table 4, the freehand technique significantly reduces the overall cost of surgery compared to navigation-assisted methods. This difference is mainly due to the elimination of high-cost imaging equipment, system maintenance, and extended operative time. In resource-limited settings, this reduction in cost per procedure enhances accessibility and surgical efficiency, supporting broader implementation of the freehand technique. Moreover, a comparative overview of cost and operative parameters between freehand and image-guided techniques for thoracolumbar pedicle screw fixation reveals that the freehand approach shows substantial advantages in cost, setup time, and radiation exposure, with a marginal difference in screw malposition rate.

A total of 681 pedicle screws were analyzed, of which 24 (3.5%) were classified as dangerous breaches. Logistic regression was performed to assess whether the screw region, side, or underlying pathology was associated with the occurrence of a dangerous breach. As shown in Table 5, none of the predictors demonstrated statistically significant associations. Screws placed in the lumbar region had lower odds of resulting in a dangerous breach compared to thoracic screws (OR = 0.69, p = 0.290). Similarly, screws placed on the right side had slightly higher odds than those on the left (OR = 1.16, p = 0.700). When compared to fractures, infections were associated with higher odds (OR = 1.23, p = 0.555), while metastatic lesions (OR = 0.95, p = 0.867) and other pathologies such as spondylolisthesis and disc prolapse (OR = 1.09, p = 0.854) showed no significant differences.

Table 4

Cost-effectiveness comparison between freehand and image-guided pedicle screw fixation

Parameter	Freehand technique	Image-guided (fluoroscopy/navigation)
Equipment cost (per case)	0-20 USD	300-600 USD
Setup time	5-10 minutes	20-30 minutes
Operative time (avg.)	90 minutes	120 minutes
Radiation exposure	none	moderate to high
Screw malposition rate	4%	2%
Total estimated cost per case	~500 USD	~1200-1800 USD

Table 5

Logistic regression for predictors of dangerous screw breaches

Predictor	Coefficient (β)	p-value	Odds ratio (OR)	95% CI for OR
Lumbar vs thoracic	-0.32	0.27	0.73	0.42-1.26
Right vs left	0.15	0.59	1.16	0.66-2.05
Infection vs fracture	-0.20	0.52	0.82	0.45-1.52
Metastatic vs fracture	0.10	0.77	1.11	0.58-2.13
Other vs fracture	0.25	0.58	1.29	0.53-3.15

DISCUSSION

This study confirms the high accuracy (96.4% safe placement) of freehand pedicle screw fixation in a broad cohort of thoracolumbar pathologies. It is important to note that these results stem from real-world conditions with limited resources that are underrepresented in the literature. Although image-guided techniques offer higher theoretical precision, their marginal gains may not justify the cost, operative time, and radiation exposure in all settings.

The low incidence of dangerous breaches (3.6%) and the single reoperation reflect the technique's clinical safety when performed by experienced surgeons. Moreover, our subgroup analysis offers additional insight into the anatomical and pathological patterns of screw placement challenges. This reinforces that, while navigation may benefit specific complex deformities or revision surgeries, freehand fixation remains highly effective in routine thoracolumbar surgery.

Pedicle screw fixation by freehand technique has been widely used depending on the anatomical landmark and surgeon experience; despite the availability of various intraoperative navigation tools in most centers, the freehand method is most commonly used to avoid harmful radiation exposure, prolonged time and blood loss, and the high cost of navigation tools [13]. A pedicle breach is a complication that can occur during spinal surgery. This can result in several potential issues, such as nerve damage with the medial or inferior breach, can impinge on the spinal cord or nerve roots causing numbness, pain or even motor deficits. Instability with improper placement can compromise the stability of the spinal construct. Vascular injury as a breach can damage nearby vessels, leading to bleeding or hematoma formation [14, 15].

A noteworthy component of our study is the analysis of pedicle screw accuracy with respect to the surgeon's handedness. All procedures were performed by right-handed surgeons who inserted screws from the ipsilateral side. Despite the expected ergonomic preference for the dominant side, our results did not demonstrate a significant difference in breach rates between the right- and left-sided screws. This observation reinforces the consistency and reliability of the freehand technique, regardless of the surgeon's laterality.

This study adds a novel dimension by integrating a multivariate approach to understanding predictors of screw breaches, particularly about ergonomics and laterality. While previous studies have not explicitly explored the influence of surgeon handedness on screw placement accuracy, our analysis showed a trend toward higher breach rates in left-sided screws placed by right-handed surgeons. Although not statistically significant, this observation raises important questions about ergonomic consistency, visual angles, and dominant-hand biomechanics during spine instrumentation.

This study was a prospective study on the accuracy of 681 screws positioned in 90 patients with different pathologies, including fracture, metastatic lesions, discitis, disc prolapse, and listhesis. Expert surgeons positioned all the screws; the acceptable breach was 96.4% divided into 85% — purely within the pedicle, 11.4% — with a breach of less than 2 mm, and 3.6% — with a dangerous breach of more than 2 mm, with only one patient underwent revision due to screw malposition.

L. Karapinar et al. conducted a study on the freehand technique on T10-L3 fixation that showed an accuracy of 94.2% with violated screws (5.8%) [16]. S.L. Parker et al. carried out a study on freehand pedicle screw fixation in the thoracic and lumbar spine. They defined the breach as more than 25% of the diameter of the screw is outside the pedicle or vertebral cortex. The result was 1.7% of screws were identified as breaching the pedicle [6]. In another study by V.S. Fennel et al. on the freehand thoracic pedicle screw method with the same definition of the breach (more than 25% of the screw diameter outside the pedicle), the result was 4.1% of screws violating the cortex [17].

Compared to other methods, such as navigation and image-assisted techniques, in different studies, the freehand approach has a higher accuracy rate than image-assisted techniques. T. Laine et al. reported that the accuracy of the image-assisted technique was 95.7% compared to the freehand technique, which was 85.7% [18]. L.P. Amiot et al. reported that image-assisted techniques' accuracy was 95%, with the misplaced screws found 0.1 to 2 mm from the cortex. In comparison, the freehand technique accuracy was 85%, with the misplaced screws divided into 12.5% of screws found 0.1 to 2 mm from the cortex (grade B), 1.8% of screws were 2.1 to 4 mm away from the cortex (grade C), and 0.7% of screws were found away from the cortex by more than 4 mm (grade D) [19].

In comparison with other studies, we have accepted the accuracy rate of the freehand technique with negligible complications encountered in our study, such as neurological or vascular complications following the freehand technique due to the misplaced screws.

Study limitations

This study has several limitations, as it is non-comparative, has been performed by different surgeons, and includes a small number of cases. The lack of comparison with image-guided techniques is a key limitation. However, the study's strength lies in its pragmatic design and clinical relevance the to real-world settings.

CONCLUSIONS

Pedicle screw insertion using the freehand technique, depending on the anatomical landmark, is safe, reliable, and accurate, which provides advantages such as a decrease in setup and operative time, a reduction in blood loss and radiation exposure, and less cost-effectiveness in a resource-limited environment. Additionally, the accuracy was maintained across both right and left pedicle screw insertions, regardless of the surgeon's handedness, which underscores the ergonomic reliability of the technique. A larger and comparative study is required to provide stronger evidence. This technique should be done by an expert surgeon who is well-oriented in the anatomical landmarks.

DISCLAIMERS

Author contribution

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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Consent for publication. The authors obtained written consent from patients to participate in the study and publish the results.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Заявленный вклад авторов

Все авторы сделали эквивалентный вклад в подготовку публикации.

Все авторы прочли и одобрили финальную версию рукописи статьи. Все авторы согласны нести ответственность за все аспекты работы, чтобы обеспечить надлежащее рассмотрение и решение всех возможных вопросов, связанных с корректностью и надежностью любой части работы.

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