TRANSPEDICULAR SCREW PLACEMENT ACCURACY USING THE O-ARM VERSUS FLUOROSCOPY-ASSISTED FREEHAND TECHNIQUE IN THORACOLUMBAR SPINE SCOLIOSIS SURGERY: A COMPARATIVE STUDY

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Abstract

Objective: *to compare the accuracy and safety of screw placement using O-arm navigation versus fluoroscopy-assisted freehand methods in a tertiary spine center setting.*
Study design: *Comparative cross-sectional*
Place and duration of study: *Study was conducted at the Department of Spine Surgery, CMH Rawalpindi, Pakistan, from November 2024 to June 2025.*
Methodology: *Seventy-six patients undergoing posterior spinal fusion for scoliosis were included and divided into two groups: Group A (O-arm navigation, n = 30) and Group B (fluoroscopy-assisted freehand, n = 46). Pedicle screws were inserted from T10 to L4, and placement accuracy was evaluated postoperatively using the Gertzbein-Robbins classification. Grades A and B were considered acceptable. Independent radiologists, blinded to the surgical technique, assessed CT scans. Data were analyzed using SPSS v26.0.*
Results: *A total of 984 screws were analyzed, 376 in the O-arm group and 608 in the freehand group. The O-arm group demonstrated significantly higher Grade A placements (83.8% vs. 62.8%, p < 0.001) and overall acceptable accuracy (95.7% vs. 86.0%, p < 0.01). Breach rates, particularly medial breaches were notably lower in the O-arm group (1.9% vs. 6.7%, p < 0.01). Although operative time was longer with O-arm navigation, it was associated with less blood loss and fewer postoperative complications.*
Conclusion: *O-arm navigation significantly improves the accuracy and safety of pedicle screw placement in thoracolumbar scoliosis surgery offering a valuable advantage over conventional fluoroscopy-assisted techniques*

INTRODUCTION

Spinal deformities, predominantly scoliosis, signify a major public health concern with both functional and psychosocial implications. Worldwide, scoliosis affects between 0.5% and 4% of children, with a rising prevalence among older adults, especially those over 60 years, in whom rates may surpass 60% [1]. Adolescent Idiopathic Scoliosis (AIS) is most common with a substantial number of cases advancing to require surgical correction as the spinal curvature progresses [2]. The standard surgical threshold is usually a Cobb angle greater than 50 degrees, beyond which conservative management remains inadequate and spinal fusion becomes the most common intervention [3]. Concurrently with this rising disease burden, the frequency of spinal deformity surgeries has notably increased. Between 2005 and 2018, the incidence of scoliosis surgery in children climbed from 9.6 to 17.9 per 100,000 largely driven by AIS-related procedures [1,4]. Nevertheless, these operations are not without considerable risks postoperative complications occur in approximately 33.4% of cases, the most frequent being pulmonary issues and surgical site infections [5]. Central to successful surgical correction is the accuracy of transpedicular screw placement, which provides rigid three-column fixation essential for spinal stabilization, deformity correction, and long-term alignment [6]. Yet, pedicle screw misplacement remains a major concern, especially in scoliotic spines, where vertebral rotation, pedicle dysplasia, and altered landmarks pose a challenge. Misplacement can lead to neurovascular injuries, loss of fixation, and reoperation, with reported rates of screw malposition ranging from 5% to 41%, depending on the technique used, patient anatomy, and surgeon experience [7]. Conventionally, the fluoroscopy-assisted freehand technique has been widely adopted owing to its real-time guidance and cost-effectiveness. However, it is associated with higher radiation exposure, a steep learning curve, and suboptimal accuracy in anatomically distorted spines [8]. In contrast, the O-arm navigation system, an advanced intraoperative imaging modality combining cone-beam CT with neuronavigation, enables real-time three-dimensional visualization of spinal anatomy, promising enhanced screw placement precision. Reported accuracy rates with O-arm navigation range from 94% to 98%, significantly outperforming the 74% to 88% observed with freehand or 2D fluoroscopy techniques [9]. Literature emphasizes the superior accuracy of O-arm navigation in pedicle screw placement, particularly in complex spinal deformities. A systematic review and meta-analysis of over 4,000 screws by Feng et al. reported a 65% reduction in misplacement risk with O-arm use (RR: 0.35; 95% CI: 0.25–0.49) [10]. In spite of its advantages, O-arm adoption remains limited in developing countries due to cost and infrastructure barriers. The challenge of achieving precise pedicle screw placement in scoliosis surgery persists, particularly in complex deformities where fluoroscopic guidance alone may be insufficient, leading to increased rates of misplacement and surgical complications. The objective of the study to compare the accuracy of transpedicular screw placement using O-arm navigation versus fluoroscopy-assisted freehand technique in thoracolumbar scoliosis surgery at a tertiary care spine center.

Materials and Methods

The current comparative cross-sectional study was conducted at the Department of Spine Surgery, Combined Military hospital, located in Rawalpindi, Pakistan. The study spanned over eight months, from November 2024 to June 2025. The study involved patients undergoing posterior spinal fusion procedures at the respective hospital. The patients were mainly drawn from both urban and semi-urban catchments, referred for elective deformity correction surgeries.

The study population comprised scoliotic patients of any age and gender. The Patients were scheduled for posterior instrumented correction using pedicle screw systems. The sample size for the present study was estimated using the known prevalence of adolescent idiopathic scoliosis, which ranges from 0.47% to 5.2% in the general population [11]. For sample calculation purposes, the upper limit of this range 5.2% was used to ensure a conservative est on a 95% co ror, assuming an the wide

$$n = \frac{Z^2 \cdot P(1-P)}{d^2}$$

applicability of the condition. Applying the standard formula for prevalence studies:

The required sample size was estimated to be 76 individuals.

Participants were divided into two groups based on the surgical technique employed. Group A underwent screw placement using the O-arm navigation system ((Loop X by Brain Lab) Model O arm 2 Munich Germany. Group B underwent screw placement via the conventional fluoroscopy-assisted freehand method using a C-arm unit (GE OEC 9900 Elite, General Electric, Salt Lake City, USA). All surgeries were performed by experienced orthopedic spine surgeons trained in both techniques to mitigate operator variability.

The surgical procedure for both groups followed standard steps: patients were positioned prone under general anesthesia, followed by midline incision, subperiosteal dissection, and exposure of the posterior spine. Intraoperative planning and screw trajectory determination were done using the navigation system in Group A, while Group B relied on anatomical landmarks supplemented by two-dimensional fluoroscopic views. Screws were placed from T10 to L4 levels, followed by correction maneuvers, rod fixation, and wound closure. Postoperative computed tomography (CT) was used to evaluate screw placement accuracy. Screw accuracy was assessed using the Gertzbein and Robbins classification system, which grades screw placement from A to E based on cortical breach. Grades A and B were considered accurate placements, while Grades C, D, and E were categorized as misplacements or breach.

Table 1: Gertzbein and Robbins Classification of Screw Placement

Grade	Description	Classification
A	Completely within pedicle	Accurate
B	<2 mm breach	Accurate
C	2–4 mm breach	Misplaced
D	4–6 mm breach	Misplaced
E	>6 mm breach	Misplaced

Radiological assessment was independently performed by senior radiologists who were blinded with no prior knowledge of the group assignment, to minimize assessment bias. Data was collected using perioperative observation and postoperative imaging. Clinical variables such as age, gender, diagnosis, spinal level operated, and technique used were recorded on a standardized data collection form. Accuracy grades were recorded for each screw inserted. The primary outcome was the proportion of accurately placed screws in each group.

Before initiating the study, ethical approval was obtained from the Institutional Research Board (IRB), and ethical clearance was secured from the Institutional Ethical Review Committee under approval number 868/ERB/CMH Dated 06 May 2024. All participants or their legal guardians provided informed written consent, ensuring voluntary participation, data confidentiality.

The variables assessed included demographic, clinical characteristics and procedural outcomes. Independent variables were the screw placement technique (O-arm vs. fluoroscopy), while the dependent variable was screw placement accuracy. Confounders such as the number of levels operated, severity of deformity, and the spinal levels were noted. Data types included continuous and categorical variables. Statistical analysis was performed using SPSS version 26.0. Descriptive statistics were used to summarize the data. Continuous variables were presented as mean and standard deviation if normally distributed, or median and interquartile range for skewed data. Categorical variables were reported as frequencies and percentages. The Kolmogorov-Smirnov test was used to test for normality. For inferential statistics, the Chi-square test was applied to compare the frequency of accurate screw placements between the two groups. Independent samples t-test was used to compare continuous variables. A p-value less than 0.05 was considered statistically significant.

Results

A total of **76 patients** were enrolled in the study, with **46** undergoing **fluoroscopy-assisted freehand screw placement** and **30** undergoing **O-arm navigated surgery**. Age distribution showed the majority of patients were adolescents and young adults, particularly between **15–19 years**. A small proportion of patients were either younger than 10 or older than 30. The **BMI, scoliosis type,** surgical indications and other clinical characteristics are shown in Table 2.

Table 2: Demographic and Clinical characteristics of study groups

Variable	Freehand Group (n = 46)	O-arm Group (n = 30)	p-value
Age (years) (%)			
<10	4 (8.7%)	2 (6.7%)	0.79
10–14	8 (17.4%)	5 (16.7%)	0.93
15–19	20 (43.5%)	12 (40%)	0.77
20–24	9 (19.6%)	6 (20%)	0.97
25–30	3 (6.5%)	3 (10%)	0.57
>30	2 (4.3%)	2 (6.7%)	0.65
Gender (%)			
Male	17 (37%)	9 (30%)	0.53
Female	29 (63%)	21 (70%)	
BMI (kg/m²)	21.8 ± 2.9	22.1 ± 3.1	0.68
Scoliosis Type (%)			
Idiopathic	39 (84.8%)	26 (86.7%)	0.81
Congenital	5 (10.9%)	3 (10%)	0.91
Neuromuscular	2 (4.3%)	1 (3.3%)	0.79
Cobb Angle (°)			
Mean ± SD	58.7 ± 9.4	60.1 ± 8.6	0.48
Instrumented Levels			
Median (range)	8 (range 6–12)	9 (range 7–12)	0.22
Surgical Indication (%)			
Curve progression	23 (50%)	14 (46.7%)	0.76
Cosmetic deformity	11 (23.9%)	8 (26.7%)	0.79
Persistent pain	8 (17.4%)	5 (16.7%)	0.94
Neurological symptoms	4 (8.7%)	3 (10%)	0.84
Total Screws Placed	608	376	
Screw Location Distribution (%)			
Thoracic spine (T4–T12)	385 (63.3%)	247 (65.7%)	0.64
Lumbar spine (L1–L5)	223 (36.7%)	129 (34.3%)	0.64

Key intraoperative variables are shown in Table 2. The mean operative time was significantly longer in the O-arm group compared to the freehand group ($p < 0.001$). This increase is likely attributable to the additional time required for intraoperative imaging setup and registration. Conversely, estimated blood loss was significantly lower in the O-arm group compared to the freehand group ($p = 0.02$).

Table 3: Comparison of Intraoperative Parameters Between Study Groups

Variable	Freehand Group (n = 46)	O-arm Group (n = 30)	p-value
Operative time (minutes)	224.5 ± 38.6	256.3 ± 41.2	<0.001

Estimated blood loss (ml)	610 ± 120	520 ± 105	0.02

A total of 984 pedicle screws were assessed for placement accuracy using the Gertzbein-Robbins classification, with 608 screws placed in the freehand fluoroscopy group and 376 screws in the O-arm navigation group. The O-arm group demonstrated significantly superior placement accuracy, with 83.8% (315) of screws graded as Grade A (completely within the pedicle), compared to 62.8% (382) in the freehand group ($p < 0.001$). Grade B placements (minor breaches <2 mm) were also less frequent in the O-arm group (12.0%) than in the freehand group (23.2%). Higher-grade breaches were notably more common in the freehand group, with 8.1% of screws rated as Grade C (2–4 mm breach) and 5.9% as Grade D (>4 mm breach), compared to only 2.9% and 1.3%, respectively, in the O-arm group. When combining Grades A and B as acceptable placements, the O-arm group achieved an overall accuracy of 95.7%, significantly higher than the 86.0% in the freehand group ($p < 0.01$). (Figure 1)

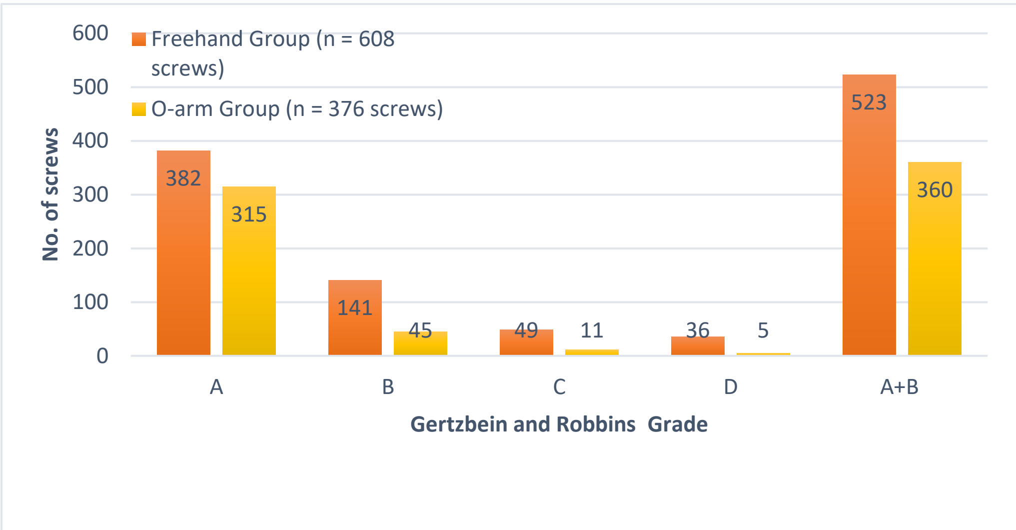

Figure 1: Comparison of Pedicle Screw Placement Accuracy between study groups

In terms of breach location, the freehand group exhibited a higher incidence of breaches overall (14.0%) compared to the O-arm group which was 4.3% ($p < 0.001$). Specifically, medial breaches, which carry the greatest risk of neurological damage, were observed in 6.7% of screws in the freehand group versus only 1.9% in the O-arm group ($p < 0.01$). Lateral breaches were also more frequent in the freehand group ($p = 0.02$), while superior and inferior breaches occurred at much lower rates in both groups without statistically significant differences. (Figure 2)

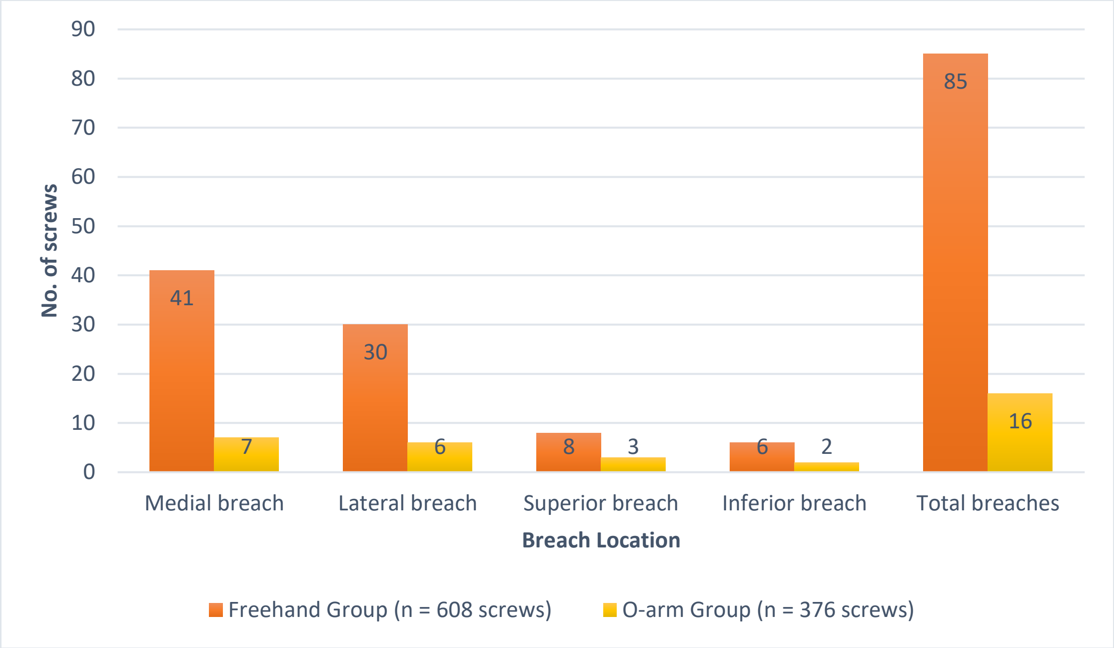

Figure 2: Comparison of breach locations between study groups

Post-operative complications were observed more frequently in the freehand fluoroscopy group compared to the O-arm navigation group. In the freehand group (n = 46), 23.9% (11 patients) experienced complications, whereas only 10% (3 patients) in the O-arm group (n = 30) had post-operative issues (p = 0.08). Neurological deficits occurred in 2 patients (4.3%) in the freehand group, while none were reported in O-arm group (p = 0.21). Wound infections were noted in 3 patients (6.5%) in the freehand group and 1 patient (3.3%) in the O-arm group (p = 0.47). Screw revision was required in 4 cases (8.7%) in the freehand group versus 1 case (3.3%) in the O-arm group (p = 0.26). Pulmonary complications were reported in 2 patients (4.3%) in the freehand group and 1 patient (3.3%) in the O-arm group (p = 0.79).

Table 4: Post-operative Complications Rate Among Study Groups

Complication Type	Freehand Group (n = 46)	O-arm Group (n = 30)	p-value
Neurological deficit	2 (4.3%)	0 (0%)	0.21
Wound infection	3 (6.5%)	1 (3.3%)	0.47
Screw revision required	4 (8.7%)	1 (3.3%)	0.26
Pulmonary complication	2 (4.3%)	1 (3.3%)	0.79
Total complication rate	11 (23.9%)	3 (10%)	0.08

Discussions

This study aimed to evaluate the precision and safety of pedicle screw placement using two distinct techniques fluoroscopy-assisted freehand versus O-arm navigation among patients undergoing thoracolumbar scoliosis surgery. With a total of 984 screws analyzed, the data analysis revealed a clear advantage of image-guided navigation over the traditional freehand method. The overall acceptable placement rate (Grades A and B) was significantly higher in the O-arm group, reaching 95.7%, whereas the freehand technique achieved 86.0%. Such a marked difference underscores the clinical relevance of navigation technologies in enhancing surgical accuracy.

Our findings resonate with those of Liu et al. (2016), who demonstrated that O-arm-assisted screw placement significantly improves accuracy, particularly in complex anatomies where pedicles are narrow or distorted [12]. Similarly, Lu et al. (2020) documented comparable improvements in screw trajectory precision when using O-arm imaging among patients with thoracolumbar fractures in percutaneous Surgery [13]. Reinforcing these observations, a retrospective analysis conducted by Akgun et al. (2024) concluded that O-arm navigation is associated with a 99% of screws were successfully implanted, a statistic that further validates the technology's clinical impact [14]. Anatomical breach analysis in our dataset revealed that both medial and lateral violations were substantially more frequent in the freehand group. Specifically, medial breaches were observed in 6.7% of cases in the freehand cohort versus just 1.9% in the O-arm group. These results are in agreement with Kothari et al. (2023), who emphasized that navigation significantly mitigates the risk of critical breaches, especially those compromising medial or inferior walls, which are in close proximity to vital neural structures [15]. A study by Noshchenko et al. (2018) further reinforces our findings, demonstrating that pedicle screw placement using O-arm navigation significantly reduces cortical breach risk compared to the freehand technique, particularly in the thoracic spine. In their series of 70 patients and 597 screws, the navigated group had an odds ratio of 0.36 ($p = 0.002$) for any breach, with medial and lateral violations notably lower. These results align with our data, which showed fewer critical breaches and higher accuracy (95.7%) in the O-arm group versus the freehand group (86%). Additionally, they observed a lower, though not statistically significant, complication rate with navigation echoing our finding of reduced postoperative complications in the O-arm cohort [16].

Remarkably, while the O-arm group demonstrated superior placement accuracy, this was accompanied by an increase in operative duration. The average surgery time extended to 256.3 minutes, compared to 224.5 minutes in the freehand group. However, this longer duration may reflect the time invested in achieving optimal positioning and conducting intraoperative imaging checks. Inconsistently, this group also experienced less intraoperative blood loss, possibly due to fewer cortical violations and a reduced need for screw repositioning. These findings are consistent with those of Houten et al. (2012) and Jing et al. (2019) who also reported a trade-off between surgical time and accuracy in favor of improved outcomes [17,18]. When scrutinizing postoperative complications, although the difference was not statistically significant, a lower complication rate was seen in the navigation group (10%) compared to the freehand group (23.9%). Wound infections, neurological deficits, screw revisions, and pulmonary issues were all numerically more common in the freehand group. These trends echo the conclusions drawn by González-Vargas, who emphasized that navigation substantially lowers the likelihood of complications arising from dispositioned screws predominantly in cases involving spinal deformities or anatomical complexity [19]. Nevertheless, it would be reductive to dismiss the efficacy of the freehand method entirely. In high-volume centers or under the hands of experienced surgeons, freehand screw placement continues to yield respectable outcomes, particularly when supported by refined tactile feedback and intraoperative anatomical landmarks. Irianto et al. acknowledged this perspective, suggesting that surgical expertise remains a critical determinant of success, regardless of the imaging modality employed [20].

Conclusions

The results demonstrated that pedicle screw placement using O-arm navigation offers significantly higher accuracy and fewer complications compared to the conventional fluoroscopy assisted freehand technique. The O-arm group achieved a markedly higher proportion of Grade A screw placements (83.8%) and an overall acceptable accuracy (Grades A + B) of 95.7%, compared to 62.8% and 86.0%, respectively, in the freehand group. Furthermore, postoperative complications and rate of breaches were considerably lower in the navigated group, reinforcing its safety advantage.

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