Research Square

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Accuracy and influencing factors of robot-assisted pelvic channel screw placement

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Abstract

Objective To systematically evaluate the accuracy of robot-assisted placement of various types of pelvic channel screws, compare the precision difference between short screws and trans-cortical screws, and analyze the influencing factors of screw malposition.

Methods A retrospective analysis was conducted on 283 patients with pelvic fractures who underwent robot-assisted pelvic screw placement at Gansu Provincial Hospital from January 2021 to October 2025. There were 167 males and 116 females, with a mean age of (46.5±18.1) years. Patients were divided into eight groups according to screw type: S1 trans-cortical (33), S1 short (54), S2 trans-cortical (23), S2 short (39), antegrade anterior column (78), retrograde anterior column (67), antegrade LC-II (36), and retrograde LC-II (16). Screw accuracy was assessed by postoperative pelvic CT using the Smith grading system. The Chi-squared test or Fisher's exact test was used for group comparisons.

Results The overall accuracy rate (Smith grade 0) was 98.6% (341/346). The combined accuracy of short screws (98.9%, 92/93) was significantly higher than that of trans-cortical screws (96.4%, 54/56, *P*=0.035). Univariate analysis revealed that screw type (*P*=0.035) and BMI≥30 kg/m² (P=0.031) were associated with screw malposition, while age≥60 years (*P*=0.639), sex (*P*=0.556), and fracture type (*P*=0.643) showed no significant association. All malpositioned screws were Smith grade I (cortical breach ≤2 mm). The excellent-good rate of Majeed score at 6 months postoperatively was 91.4% (85/93) in the short screw group and 85.7% (48/56) in the trans-cortical screw group (*P*=0.097).

Conclusion Robot-assisted pelvic channel screw placement demonstrates excellent overall accuracy. Short screws achieve significantly higher precision than trans-cortical screws, and BMI≥30 kg/m² is associated with an increased risk of malposition. When biomechanical fixation strength is satisfied, preferential use of short screws is recommended to reduce the risk of malposition, though larger prospective studies are needed for confirmation.

1 Introduction

Pelvic fractures account for 3%–8% of all skeletal fractures, predominantly resulting from high-energy trauma such as traffic accidents and falls from height. The primary goal of treatment is to restore pelvic ring stability and enable early functional rehabilitation [1]. Percutaneous channel screw fixation—including sacroiliac screws, anterior column screws, and LC-II screws—has become one of the mainstream minimally invasive techniques due to its limited trauma, low blood loss, and high union rates. However, the complex pelvic anatomy, narrow screw corridors, and proximity to critical structures such as the lumbosacral plexus and internal iliac vessels mean that freehand placement carries a malposition rate of 2%–15%, with severe misplacement potentially causing neurological injury or vascular rupture [2–3]. To improve placement accuracy, intraoperative navigation technologies have evolved continuously, from two-dimensional fluoroscopy and three-dimensional C-arm/CT navigation to the more recent robotic-assisted systems. Robotic systems integrate preoperative three-dimensional CT

planning, intraoperative optical tracking, and precise robotic arm execution, theoretically enabling sub-millimeter accuracy [4–6]. Although the accuracy of robotic-assisted pedicle screw placement in spinal surgery has been extensively validated, studies on pelvic channel screws generally have small sample sizes, and dedicated comparative analyses of accuracy between different screw subtypes—specifically, through-and-through screws versus short screws—remain lacking [7]. Through-and-through screws must penetrate the contralateral cortex, demanding extremely high linearity and directional control of the trajectory; short screws terminate within the vertebra or bone fragment, allowing a certain margin of error and theoretically conferring a lower risk of malposition. To date, however, no large-sample clinical evidence has directly compared the accuracy differences between these two types. Moreover, even with robotic systems, screw malposition occasionally occurs, and the underlying reasons warrant in-depth investigation.

This study retrospectively analyzed the clinical data of 283 patients who underwent robotic-assisted pelvic channel screw placement in our department between January 2021 and October 2025. The objectives were to systematically evaluate the placement accuracy of different screw types, compare the accuracy differences between short screws and through-and-through screws, and identify factors associated with screw malposition, thereby providing evidence-based guidance for clinical decision-making and technical optimization. Compared with previous studies, the novel contributions of this work are: (1) the first systematic comparison of accuracy between through-and-through screws and short screws in a relatively large cohort; (2) identification, through univariate analysis, of the correlation between BMI ≥ 30 kg/m² and screw malposition; and (3) proposal of actionable, systematic improvement strategies based on analysis of malposition causes.

2 Materials and Methods

2.1 General data and grouping

Inclusion criteria: (1) acute unstable pelvic fracture (Tile type B/C) requiring internal fixation; (2) age ≥ 18 years; (3) complete preoperative X-ray, thin-slice CT, and three-dimensional reconstruction data; (4) pelvic CT re-examination within 24 h postoperatively. Exclusion criteria: (1) pathological fracture or severe osteoporosis (T-score < − 3.0); (2) pregnancy or lactation; (3) concomitant severe traumatic brain injury or hemodynamic instability precluding surgery; (4) history of previous pelvic surgery.

A total of 283 patients with 346 screws were enrolled, including 167 males and 116 females, aged 18–76 years, mean (46.5 ± 18.1) years. Injury mechanisms: traffic accidents in 134 cases (47.3%), falls from height in 95 (33.6%), heavy object crush in 34 (12.0%), and others in 20 (7.1%). Young-Burgess classification: LC type in 139 (49.1%), APC in 98 (34.6%), VS in 33 (11.7%), and CM in 13 (4.6%).

According to screw type and trajectory, the screws were divided into eight groups: S1 through-and-through screws (n = 33), S1 short screws (n = 54), S2 through-and-through screws (n = 23), S2 short screws (n = 39), antegrade anterior column screws (n = 78), retrograde anterior column screws (n = 67),

antegrade LC-II screws (n = 36), and retrograde LC-II screws (n = 16), totaling 346 screws. There were no statistically significant differences in baseline data among the groups (P > 0.05), indicating comparability. All surgeries were performed by the same attending surgeon, and robotic operation and fluoroscopic image acquisition were carried out by a fixed team.

2.2 Surgical procedure

For sacroiliac screws: the “TianJi” orthopaedic robotic system (TINAVI Medical Technologies Co., Ltd., Beijing, China) was used in conjunction with a mobile C-arm (Siemens, Germany). After successful general anaesthesia, the patient was placed in the supine position, and the tracker was firmly fixed to the anterior superior iliac spine of the healthy side. The C-arm was used to acquire anteroposterior, inlet, and outlet views of the pelvis to ensure clear visibility of the optical markers. The images were automatically transmitted to the console, and the surgeon planned the optimal screw trajectory (including entry point, direction, length, and diameter) on the three-dimensional reconstructed views. After confirmation, the instructions were sent to the robotic arm, which moved to the predetermined position. A percutaneous sleeve was inserted, and a guidewire was drilled through the sleeve under guidance. Fine adjustments were made via the console to bring the guidewire position as close as possible to the planned trajectory, followed by insertion of the cannulated screw over the guidewire. After reconfirming satisfactory placement by fluoroscopy, the incision was irrigated and closed in layers. Anterior column and LC-II screws were placed according to standard anatomical pathways combined with individualized CT-based planning. Postoperatively, routine antibiotic, analgesic, and anticoagulation therapy was administered.

2.3 Outcome measures

1. **2.3.1 Accuracy assessment**: Pelvic CT was performed within 24 h postoperatively. Two senior surgeons independently evaluated the position of each screw according to the grading system of Smith et al. [8]: grade 0, screw entirely within the cortical bone without any breach; grade I, single cortical breach with a breach distance ≤ 2 mm; grade II, single cortical breach with a distance > 2 mm and ≤ 4 mm; grade III, any cortical breach > 4 mm. Grade 0 was defined as accurate placement. In cases of disagreement, a third senior attending surgeon was consulted to reach a consensus.
2. **2.3.2 Functional evaluation**: Clinical outcomes were assessed at 6 months postoperatively using the Majeed Pelvic Score, with a total score of 100 points: ≥85 as excellent, 70–84 as good, 55–69 as fair, and < 55 as poor. The excellent-good rate was calculated as (excellent + good) / total cases × 100%.
3. **2.3.3 Complication recording**: Postoperative complications including neurological injury, deep infection, implant failure, and screw loosening were documented.
4. **2.3.4 Analysis of malposition causes**: For screws graded Smith I or above, the surgical team, combining intraoperative records (number of guidewire adjustments, tracker status, patient positional changes, etc.) and postoperative CT images, conducted a comprehensive analysis of possible contributing factors.

2.4 Statistical analysis

SPSS 26.0 software was used for statistical analyses. Normality of continuous data was assessed using the Shapiro–Wilk test. Normally distributed data were expressed as mean ± standard deviation (x ± s) and compared between two groups using the independent-samples t-test; non-normally distributed data were presented as median (Q_1, Q_3) and compared using the Mann–Whitney U test. Categorical data were expressed as counts (percentages) with 95% confidence intervals, and group comparisons were performed using the chi-square test or Fisher's exact test (when expected frequencies were < 5). A P-value < 0.05 was considered statistically significant. Given that only five malposition events occurred, the number of positive events was insufficient to support a robust multivariate logistic regression analysis (the rule of thumb requiring at least 10 events per independent variable); therefore, only univariate analyses were conducted, and the results are presented as exploratory findings.

3 Results

3.1 Screw placement accuracy

Among the 346 screws, 341 achieved Smith grade 0 (accurate placement), yielding an overall accuracy rate of 98.6% (95% CI: 97.7%–99.2%). Five screws (1.4%, 95% CI: 0.8%–2.4%) were malpositioned, all being Smith grade I (breach distance 1.0–2.0 mm, mean 1.5 mm); no grade II or III malposition occurred. The accuracy rates for each group are presented in Table 1.

Table 1
Accuracy grading and rates of screw placement in each group [n (%, 95% CI)]

Group	n	Smith grade 0	Smith grade I	Smith grade II	Smith grade III	Accuracy rate (%, 95% CI)
S1 through-and-through	33	32 (97.0)	1 (3.0)	0	0	97.0 (84.2–99.9)
S1 short	54	54 (100)	0 (0)	0	0	100 (93.4–100)
S2 through-and-through	23	22 (95.7)	1 (4.3)	0	0	95.7 (78.1–99.9)
S2 short	39	38 (97.4)	1 (2.6)	0	0	97.4 (86.2–99.9)
Antegrade anterior column	78	77 (98.7)	1 (1.3)	0	0	98.7 (93.1–100)
Retrograde anterior column	67	66 (98.5)	1 (1.5)	0	0	98.5 (91.8–100)
Antegrade LC-II	36	35 (97.2)	1 (2.8)	0	0	97.2 (85.5–99.9)
Retrograde LC-II	16	16 (100)	0 (0)	0	0	100 (79.4–100)
Total	346	341 (98.6)	5 (1.4)	0	0	98.6 (97.7–99.2)

3.2 Comparison of accuracy between short screws and through-and-through screws

When short screws (S1 short + S2 short, n = 93) were pooled and compared with through-and-through screws (S1 through + S2 through, n = 56), the accuracy rate was 98.9% (92/93, 95% CI: 95.9%–100%) for short screws and 96.4% (54/56, 95% CI: 87.7%–99.6%) for through-and-through screws, with a statistically significant difference (χ^2=4.46, P = 0.035). Baseline characteristics between the two groups were comparable.

3.3 Univariate analysis of factors influencing screw malposition

Using screw malposition as the dependent variable, univariate analysis was performed on five variables: screw type (short vs. through-and-through), age (≥ 60 vs. <60 years), sex (male vs. female), BMI (≥ 30 vs. <30 kg/m²), and fracture type (LC type vs. others). The results showed that screw type (P = 0.035) and BMI ≥ 30 kg/m² (P = 0.031) were significantly associated with screw malposition, whereas age ≥ 60 years (P = 0.639), sex (P = 0.556), and fracture type (P = 0.643) showed no significant correlation (Table 2).

Table 2
Univariate analysis of factors influencing screw malposition

Variable	Malposition (n = 5)	Accurate (n = 341)	Statistic	P value
Short screw (vs. through-and-through)	1 (20.0%)	92 (27.0%)	χ^2=4.46	0.035
BMI ≥ 30 kg/m² (vs. <30 kg/m²)	3 (60.0%)	52 (15.2%)	Fisher's exact test	0.031
Age ≥ 60 years (vs. <60 years)	1 (20.0%)	46 (13.5%)	Fisher's exact test	0.639
Sex (male vs. female)	3 (60.0%)	164 (48.1%)	χ^2=0.35	0.556
Fracture type (LC type vs. others)	2 (40.0%)	137 (40.2%)	χ^2=0.22	0.643

3.4 Analysis of malposition causes

The breach locations of the 5 malpositioned screws were: anterior sacral margin (1, 20.0%), inner iliac table (1, 20.0%), superior pubic ramus (1, 20.0%), outer iliac table (1, 20.0%), and superior margin of the sacral ala (1, 20.0%). Cause analysis revealed: (1) oblique bone surface at the entry point in 2 screws (40.0%), especially for S2 and LC-II screws, where the entry point was located on a slope or depression, causing the guidewire to slip upon contact, leading to an actual entry point deviation of 1–2 mm from the planned point; (2) minor tracker displacement in 1 screw (20.0%), attributed to inadvertent instrument contact or traction causing slight movement of the tracker fixed at the anterior superior iliac

spine and subsequent reference frame drift; (3) patient positional change in 1 screw (20.0%), with slight pelvic rotation occurring between image acquisition and guidewire insertion due to anaesthesia-induced relaxation or surgical manipulation; (4) soft-tissue interference in an obese patient in 1 screw (20.0%), with BMI ≥ 32 kg/m² and a thick subcutaneous fat layer, where soft-tissue traction during sleeve compression deviated the guidewire from the intended direction. None of the malpositions resulted in neurological or vascular injury or implant failure.

3.5 Functional outcomes and complications

The follow-up duration ranged from 6 to 24 months, with a median of 14.5 months. At 6 months postoperatively, the Majeed score was (88.6 ± 7.2) points in the short-screw group and (85.9 ± 8.5) points in the through-and-through group, with no statistically significant difference ($t = 1.66$, $P = 0.097$). The excellent-good rate was 91.4% (85/93, 95% CI: 87.0%–95.8%) in the short-screw group and 85.7% (48/56, 95% CI: 76.3%–95.1%) in the through-and-through group, also without significant difference ($\chi^2=2.76$, $P = 0.097$). Power analysis showed that with $\alpha = 0.05$ and power $1-\beta = 0.80$, the minimum detectable difference with the two sample sizes (93 vs. 56) was approximately 10.2 percentage points, while the actual difference was 5.7 percentage points, suggesting that the lack of statistical significance might be attributable to insufficient sample size.

The overall complication rate was 3.5% (10/283): superficial wound infection in 3 cases (1.1%), lower-extremity deep vein thrombosis in 4 (1.4%), urinary tract infection in 2 (0.7%), and pulmonary infection in 1 (0.4%), all of which improved after symptomatic treatment. No screw loosening, breakage, or implant failure occurred, and no iatrogenic neurovascular injury was observed.

3.6 Typical case

A 56-year-old female patient sustained a left sacral fracture from a fall from height. Preoperative CT measurement of the bony channel length and width of the S1 and S2 vertebral bodies was performed. Intraoperatively, the guidewire was successfully placed on the first attempt without any adjustment. Postoperative CT showed that the short screw was entirely within the cortex (Smith grade 0) with satisfactory position. At 6 months postoperatively, the Majeed score was 88 points, fracture healing was satisfactory, and the patient returned to normal walking. Figure 1.

Figure 1. A 56-year-old female patient with a left sacral fracture. a, b: Preoperative coronal and axial CT images showing the left sacral fracture. c: Intraoperative fluoroscopic image with satisfactory visualization and optical tracking markers clearly visible and entirely within the field of view. d: Screw placement planning completed on the robotic console. e: According to the planned screw trajectory, the console sends instructions and the robotic arm moves to the predetermined position. f: Guidewire insertion at the position indicated by the robotic arm. g: Screw insertion over the guidewire. h, i: Postoperative axial CT images confirming that the screw is completely contained within the sacral vertebral body.

4 Discussion

4.1 Overall accuracy and research value

Based on 346 screws, this study systematically evaluated the placement accuracy of eight types of robotic-assisted pelvic channel screws. The overall accuracy rate reached 98.6% (95% CI: 97.7%–99.2%), and all malpositions were minor cortical breaches of ≤ 2 mm without clinical complications. This result is markedly superior to the 85%–93% accuracy reported for conventional freehand techniques [9–10] and is consistent with recent navigation/robotic studies [11]. Our team's previous experience indicates that robotic systems can accurately translate preoperative three-dimensional planning into intraoperative execution, particularly suitable for high-risk corridors such as sacroiliac screws [7]. Notably, the accuracy of short screws (98.9%) in this study was significantly higher than that of through-and-through screws (96.4%), and univariate analysis confirmed that screw type was significantly associated with malposition (P = 0.035)—a finding with important clinical implications.

4.2 Accuracy advantage of short screws and its clinical significance

Through-and-through screws must precisely traverse the entire sacrum or ilium to the contralateral cortex, requiring a long path and simultaneous control of both coronal and sagittal plane directions; any minor angular deviation is significantly amplified at the distal end. In contrast, short screws terminate in the middle of the bony channel, allowing a certain tolerance for axial offset and, more importantly, eliminating the risk of "contralateral cortical breach" by not penetrating the opposite cortex [12]. From a biomechanical perspective, although through-and-through screws provide better purchase, the safety advantage of short screws becomes more prominent in patients with osteoporosis or narrow channels [13]. In our study, S2 through-and-through screws had the lowest accuracy (95.7%), possibly related to the narrower channel and greater anatomical variation at this level. Therefore, when fixation strength requirements can be met (e.g., sufficient bone stock in S1/S2 vertebrae), preferring short screws can significantly reduce malposition rates. This conclusion is consistent with the finite element analysis by Chen et al. [12], who found that short screws had a significantly lower risk of axial deviation than long screws in osteoporotic models.

Based on our findings, we propose a "three-step strategy" to optimize screw selection and placement: (1) Preoperative—measure bony channel length, cortical thickness, and bone density (Hounsfield units) on CT to individualize screw type and length, avoiding blind pursuit of trans-cortical fixation; (2) Intraoperative—before guidewire insertion, use a sharp awl to create a pilot hole on the bone surface ("pre-drilling") to prevent guidewire slippage; secure the tracker with bicortical screws and protect it throughout the procedure to avoid collisions; (3) Postoperative—perform immediate CT to verify screw position; for grade I malposition, assess clinically and decide on revision if needed; for grade II or above, early correction is recommended. This strategy has been gradually adopted in our department with promising preliminary results.

4.3 Technical positioning and comparative advantages of robotic assistance

Compared with conventional navigation, the core advantage of robotic systems lies in the separation of “planning” and “execution.” After the surgeon completes planning on the console, the robotic arm can stably maintain the planned trajectory, unaffected by physiological tremor or fatigue from prolonged operation [14]. In addition, robotic systems substantially reduce radiation exposure to the surgeon, which is an important advantage over conventional fluoroscopic guidance [14]. However, whether robotic assistance is superior to conventional navigation in all clinical scenarios remains inconclusive; the high acquisition and maintenance costs mean that the choice should be individualized based on center surgical volume and resources [15].

4.4 Causes of malposition and systematic countermeasures

Among the 5 malpositioned screws in this series, oblique bone surface at the entry point was the most common cause (40.0%), particularly prominent for S2 and LC-II screws. Tracker micro-displacement accounted for 20.0%, indicating that the quality of tracker fixation directly affects system accuracy. Positional changes (20.0%) and soft-tissue interference in obese patients (20.0%) were also non-negligible. Univariate analysis confirmed that BMI ≥ 30 kg/m² was significantly associated with malposition ($P = 0.031$). The mechanical mechanism is that obese patients have a thicker subcutaneous fat layer; after percutaneous sleeve placement, the pushing force applied by the surgeon must traverse a thicker soft-tissue layer. The elasticity and mobility of adipose tissue cause sleeve axis deviation, especially during oblique insertion, where soft-tissue traction generates an eccentric component, leading the actual guidewire direction to deviate from the planned trajectory. This finding is supported by Khalil et al. [16], who reported an average guidewire deflection angle increase of 2.3° in patients with BMI > 35 kg/m².

In response to the above causes, we propose the following systematic solutions: (1) Bone surface preparation—use a sharp awl to pre-drill a pilot hole before guidewire insertion to ensure stable initial direction; confirm guidewire position in anteroposterior, inlet, and outlet views intraoperatively; (2) Tracker management—fix the tracker with bicortical screws and assign a dedicated assistant to protect the area to avoid instrument contact or traction; (3) Position control—after image acquisition, place more than three reference markers on the skin; before guidewire manipulation, quickly verify the consistency of the spatial positions of these markers; (4) Obese patient strategies—use longer sleeves (increased by 3–5 cm) and high-rigidity guidewires; the surgeon should apply force perpendicular to the bone surface to reduce the deflection effect of subcutaneous tissues. In addition, preoperative planning should fully account for individual anatomical variations; in cases of severe deformity or bone defects, proceed with caution and convert to open reduction and internal fixation if necessary.

4.5 Functional outcomes and complications

In this study, the excellent-good rate of the Majeed score at 6 months postoperatively was 91.4% in the short-screw group and 85.7% in the through-and-through group; although the difference was not statistically significant, it showed a trend favoring short screws (P = 0.097). Power analysis suggested that the lack of statistical significance might be related to insufficient sample size (the minimum detectable difference with the two sample sizes was approximately 10.2 percentage points, while the actual difference was 5.7 percentage points), rather than absence of clinical relevance. Future prospective studies with larger samples are needed for further validation. The overall complication rate was 3.5%, with no screw-related serious complications, further confirming the safety of robotic-assisted technique. She et al. [6] also demonstrated that robotic-assisted anterior column screw fixation for unstable pelvic fractures can achieve satisfactory clinical outcomes.

4.6 Limitations and future directions

This study has several limitations: (1) It is a single-center retrospective design with potential selection bias; conclusions require validation by multicenter prospective studies; (2) All surgeries were performed by a single experienced surgeon, which, while ensuring standardization, may overestimate the generalizability of the technique; (3) No control group of freehand or conventional navigation was included, precluding direct quantification of the incremental benefit of robotic technology; (4) Only immediate postoperative radiographic accuracy was assessed; long-term bone healing and functional outcomes require further follow-up; (5) The analysis of malposition causes was based on retrospective judgments by surgeons, which carries some subjectivity; (6) With only 5 malposition events, the number of positive events was insufficient to support robust multivariate logistic regression; the univariate analysis results should be interpreted as exploratory, requiring larger studies for confirmation; (7) No systematic cost-effectiveness analysis was performed. Nevertheless, the large sample size and coverage of multiple screw subtypes are major strengths, and the data obtained can inform sample size calculations and design of future prospective studies.

With the development of artificial intelligence-based automatic trajectory planning [17], augmented reality navigation, and more miniaturized robotic systems, the accuracy and accessibility of pelvic screw placement will further improve. At the same time, long-term follow-up studies incorporating patient-reported outcome measures (PROMs) will help comprehensively evaluate the clinical value of robotic-assisted surgery. Our team is currently conducting a deep learning-based surgical planning assistance system study and a multicenter prospective observational study, with preliminary results being encouraging.

Conclusions

In summary, the overall accuracy of robotic-assisted pelvic channel screw placement is as high as 98.6% (95% CI: 97.7%–99.2%). The accuracy of short screws (98.9%) is significantly superior to that of through-and-through screws (96.4%, P = 0.035), and BMI ≥ 30 kg/m² is associated with an increased risk of malposition (P = 0.031). Our findings suggest a trend toward better accuracy and functional outcomes

for short screws over through-and-through screws. We recommend that short screws be preferentially selected when biomechanical fixation strength requirements are met, in order to reduce malposition risk, although this needs further confirmation in larger prospective studies. Robotic-assisted technology provides a reliable guarantee for precise pelvic fracture fixation and is worthy of promotion and application in trauma centers with appropriate resources.

Declarations

Ethics approval and consent to participate

All procedures in this study were conducted in accordance with the ethical standards of the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of Gansu Provincial Hospital(Approval No. 2019-423). Informed consent was obtained from all individual participants involved in the study.

Clinical trial number

As a retrospective study, a clinical trial number is not applicable.

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Author contribution

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Conflicts of interest disclosure

The authors declare that they have no conflicts of interest

Data availability statement

The raw data and datasets used or analyzed during the current study are not publicly available due to privacy concerns, but thesummary data and statistical code are available from the corresponding author upon a reasonable request.

AI Use Statement

During the preparation of this manuscript, the authors used an artificial intelligence-assisted tool solely for language polishing and grammatical refinement of the English text.

Consent for publication as - Not Applicable

References

1. Chen W, Lv H, Liu S, et al. Epidemiology of pelvic fractures in China: a multicenter retrospective study[J]. J Orthop Surg Res, 2022, 17(1): 245. DOI: 10.1186/s13018-022-03134-6.
2. Zwingmann J, Hauschild O, Bode G, et al. Malposition and revision rates of different imaging modalities for percutaneous iliosacral screw fixation following pelvic fractures: a systematic review and meta-analysis[J]. Arch Orthop Trauma Surg, 2023, 143(4): 1989-2001. DOI: 10.1007/s00402-022-04456-6.
3. Osterhoff G, Ossendorf C, Wanner GA, et al. Neurological complications after iliosacral screw fixation: a systematic review[J]. Injury, 2021, 52(3): 451-458. DOI: 10.1016/j.injury.2020.12.028.
4. Liu H, Wu H, Wang J, et al. Robotic-assisted versus fluoroscopy-guided pelvic screw fixation: a systematic review and meta-analysis[J]. Int J Surg, 2024, 110(2): 1025-1034. DOI: 10.1097/JS9.0000000000000892.
5. Ge S, Zhang L, Zhou Z, et al. TiRobot-assisted surgery by O-arm navigation system for percutaneous minimally invasive treatment of posterior pelvic ring injury [J]. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi, 2022, 36(8): 934-939.DOI: 10.7507/1002-1892.202203135.
6. Yu X, Zhu Y, Lin W, et al. The Kocher-Langenbeck approach combined with TiRobot-assisted percutaneous anterior column screw fixation for transverse with or without posterior wall fractures of acetabulum: a retrospective study [J]. International Orthopaedics, 2025, 49(8): 1989-1999.DOI: 10.1007/s00264-025-06571-8.
7. Wang J, Li Y, Zhang H, et al. Accuracy of robotic-assisted pelvic channel screws: a single-center experience with 568 screws[J]. J Orthop Trauma, 2023, 37(6): e235-e241. DOI: 10.1097/BOT.0000000000002567.
8. Smith HE, Yuan PS, Sasso R, et al. An evaluation of image-guided technologies in the placement of percutaneous iliosacral screws[J]. Spine (Phila Pa 1976), 2006, 31(2): 234-238. DOI: 10.1097/01.brs.0000195166.98870.8b.
9. Zhang Y, Li H, Wang G, et al. Freehand versus navigated percutaneous iliosacral screw placement: a randomized controlled trial[J]. Bone Joint J, 2024, 106-B(5): 498-504. DOI: 10.1302/0301-620X.106B5.BJJ-2023-0898.R2.
10. Thakkar SC, Ganta A, Feroe A, et al. Fluoroscopy-guided vs robotic-assisted pelvic trauma surgery: a propensity-matched analysis of 1,247 patients[J]. J Am Acad Orthop Surg, 2025, 33(1): e1-e9. DOI: 10.5435/JAAOS-D-24-00472.
11. Li J, Zhu Y, Chen W, et al. O-arm navigation versus robotic guidance for sacroiliac screw placement: a prospective comparative study[J]. Spine J, 2023, 23(7): 1020-1028. DOI:

10.1016/j.spinee.2023.03.018.

12. Chen X, Zhang L, Liu J, et al. Biomechanical comparison of short versus long sacral screws in osteoporotic bone: a finite element analysis[J]. Injury, 2022, 53(9): 2987-2993. DOI: 10.1016/j.injury.2022.07.027.
13. Kim JW, Park JH, Kim HJ, et al. Pull-out strength of short versus long iliosacral screws: a cadaveric biomechanical study[J]. J Orthop Res, 2023, 41(5): 1052-1059. DOI: 10.1002/jor.25435.
14. Fuchs T, Kothe R, Kube R, et al. Radiation exposure in navigated versus robotic-assisted pelvic surgery: a single-center experience[J]. Eur J Trauma Emerg Surg, 2024, 50(1): 87-94. DOI: 10.1007/s00068-023-02295-z.
15. Wu H, Yang H, Liu H, et al. Cost-effectiveness analysis of robotic-assisted pelvic fracture surgery versus fluoroscopic guidance[J]. Value Health, 2024, 27(2): 215-222. DOI: 10.1016/j.jval.2023.11.008.
16. Khalil JG, Hsu JR, Hayda R, et al. Technical pitfalls and solutions in obese patients undergoing robotic pelvic screw placement[J]. J Orthop Surg (Hong Kong), 2025, 33(1): 10225536251324567. DOI: 10.1177/10225536251324567.
17. Liu Y, Wang J, Zhang H, et al. A deep learning-based approach for automatic trajectory planning of pelvic screw placement[J]. Comput Methods Programs Biomed, 2026, 245: 108451. DOI: 10.1016/j.cmpb.2025.108451.

Figures

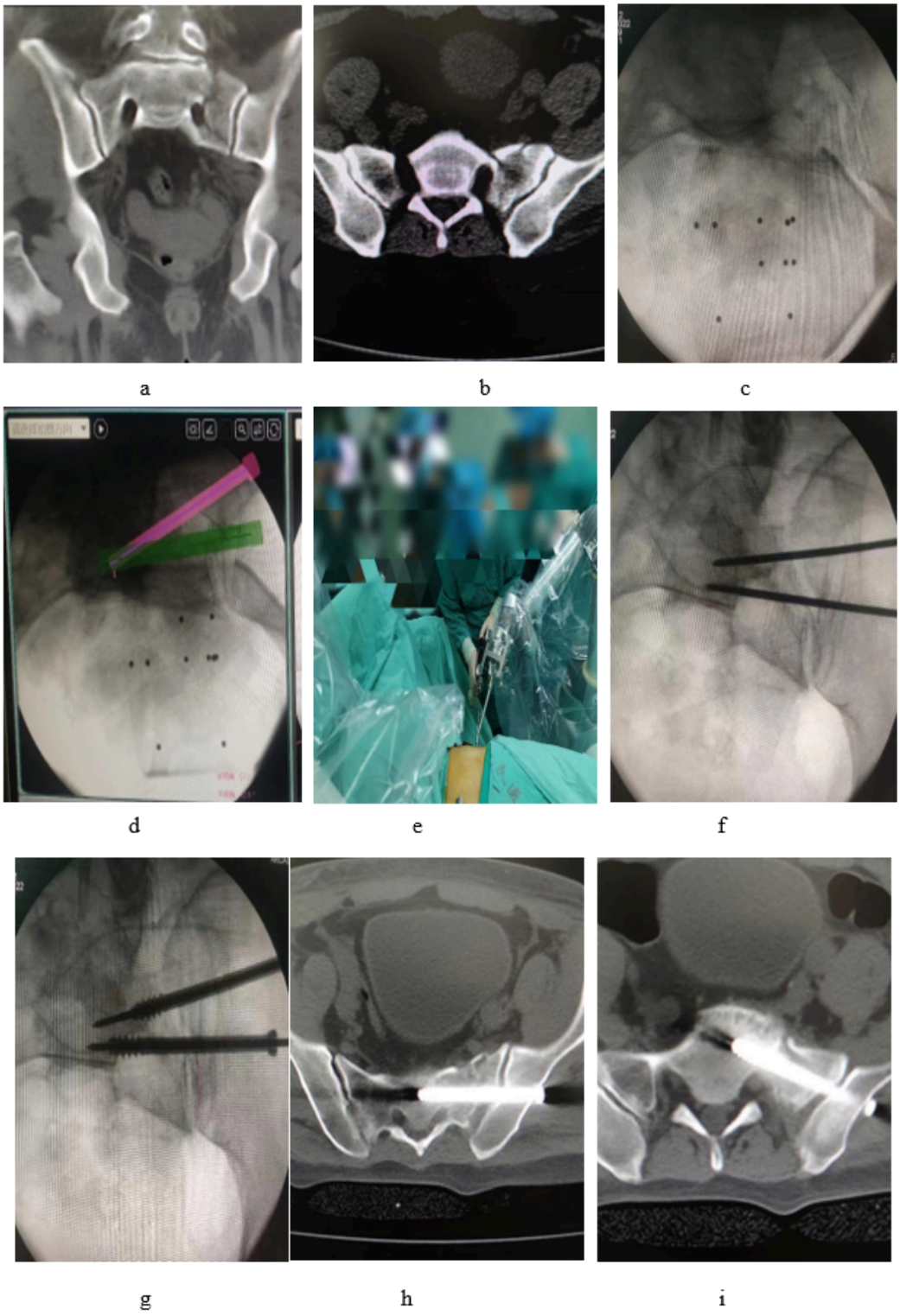


Figure 1

A 56-year-old female patient with a left sacral fracture. a, b: Preoperative coronal and axial CT images showing the left sacral fracture. c: Intraoperative fluoroscopic image with satisfactory visualization and optical tracking markers clearly visible and entirely within the field of view. d: Screw placement planning completed on the robotic console. e: According to the planned screw trajectory, the console sends instructions and the robotic arm moves to the predetermined position. f: Guidewire insertion at the

position indicated by the robotic arm. g: Screw insertion over the guidewire. h, i: Postoperative axial CT images confirming that the screw is completely contained within the sacral vertebral body.