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The Use of a Robotic Arm for Fixation of Pelvic Fractures

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Objectives: The objective of this study was to evaluate unplanned cortical or neuroforaminal violation of iliosacral and transsacral screw placement using fluoroscopy versus screw placement using a robotic arm.

Design: This is a prospective cohort study.

Setting: Single surgeon, single North American level 1 trauma center.

Patients: Radiographic and clinical data for 21 consecutive adult trauma patients with pelvic ring fractures undergoing surgical treatment were prospectively collected. Treatment consisted of iliosacral and/or transsacral screws with or without anterior fixation.

Intervention: Ten patients were treated with the assistance of a robotic arm. Eleven patients were treated with standard fluoroscopic techniques.

Main Outcome Measurements: Thirty-two screws were placed and evaluated with postoperative computed tomography or O-arm spins to assess unplanned cortical or neuroforaminal violation. Violations were graded according to the Gertzbein and Robbins system for pedicle screw violation, categorizing screw violation in 2-mm increments. The postoperative images were blindly reviewed by 5 fellowship-trained orthopaedic traumatologists. The treating surgeon was excluded from review.

Results: The Mann–Whitney *U* test on the Gertzbein and Robbins system results demonstrated significantly ($P = 0.02$) fewer violations with robotic assistance. χ^2 analysis of whether there was a cortical violation of any distance demonstrated significantly ($P = 0.003$) fewer cortical violations with robotic assistance. There were no neurovascular injuries in either group.

Conclusion: Robotic assistance demonstrated significantly fewer unplanned cortical or neuroforaminal violations. Further research is needed with additional surgeons and sites to evaluate the accuracy of iliosacral and transsacral screw placement with robotic assistance.

Key Words: robotic, pelvis fracture, sacroiliac, iliosacral, percutaneous, transsacral

Level of Evidence: Therapeutic, level II.

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INTRODUCTION

The surgical treatment of pelvic ring injuries requires the surgeon to correlate the complex three-dimensional (3D) anatomy of the pelvis with the two-dimensional (2D) fluoroscopic imaging. Errant placement of a screw or guidewire can result in serious neurovascular injury. Posterior ring injuries can render the pelvis unstable and necessitate operative intervention to allow for transmission of body weight to the lower extremities.[1] Closed reduction and percutaneous screw placement have become more common than open reduction in the treatment of posterior pelvic ring injuries because familiarity with percutaneous techniques has increased.[2] Percutaneous techniques offer decreased morbidity, decreased blood loss, and less pain.[3] These techniques are also advantageous in cases with soft-tissue injury because they allow early treatment and early mobilization.[4]

Percutaneous techniques depend heavily on high-quality fluoroscopic imaging. The quality of C-arm images can be reduced by bowel gas, stool burden, contrast material, obesity, and other patient characteristics, making percutaneous fixation unsafe.[5,6] Lack of understanding of complex pelvic bony anatomy, especially in patients with sacral dysmorphism, can lead to malposition of screws with resulting damage to the L5 nerve or sacral nerves.[7–9] Sacral dysmorphism has been reported to be present in 40%–44% patients.[10,11]

Three-dimensional navigation with or without the assistance of a robotic arm has been used extensively in spine surgery[12] and arthroplasty;[13] however, their use remains limited in orthopaedic trauma. There is a paucity of Western literature on robot-assisted percutaneous fixation of the posterior pelvis. A single, nonclinical feasibility study has been published demonstrating the use of a robotic arm to place lateral compression type II (LC-II) and transsacral (TS) screws into a pelvis bone model.[14] A single center in China reported successful use of TiRobot to place iliosacral (IS) screws in clinical practice.[15] After evaluating the use of a robotic arm (ExcelsiusGPS, Globus Medical, Philadelphia, PA) to place screws into various osseous fixation pathways in a cadaveric model (unpublished data), the corresponding author (J.B.C.) began using the same robotic arm in clinical

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practice, monitoring instrument and implant placement using fluoroscopy. Our study evaluates unplanned cortical or neuroforaminal violations (hereafter called violations) during screw placement with fluoroscopy versus screws placed with the assistance of a robotic arm available throughout the Americas, Europe, and Asia.

Our hypothesis is that percutaneous IS and TS screw placement with robotic assistance will lead to no more violations than screws placed with fluoroscopy and may lead to fewer violations. To the best of our knowledge, this is the first series conducted outside of the aforementioned center in China, although the use of freehand 3D navigation without robot assistance has been previously reported.[16,17]

METHODS

After institutional review board approval, 21 consecutive patients with pelvic ring injuries who underwent treatment with IS or TS screws were included. Data were gathered prospectively. No randomization was performed. Patients underwent treatment with standard fluoroscopic techniques versus robotic arm assistance at the discretion of the treating surgeon.

Thirty-two screws were placed, and postoperative CT scans or postimplantation O-arm spins were performed. One patient initially selected for robotic-assisted surgery was too obese to allow successful robotic registration. A second patient was reassigned to the fluoroscopic group because of the lack of equipment availability. One patient who was undergoing robotic-assisted surgery was noted to have lost robotic registration and treated with fluoroscopic techniques. These 3 patients were included in this study in the conventional surgery group.

Once 10 robotic cases had been completed, screw position for all 21 cases was evaluated using the previously performed CT scans or O-arm spins. Five fellowship-trained orthopaedic trauma surgeons, not including the treating surgeon, evaluated the images, blinded to the method of treatment, robotic versus traditional fluoroscopy. Any penetration of the anterior cortex or intrusion into a neural foramen was considered a violation. Violations were classified in 2-mm increments from 0 to 8+ as grade A to grade E in a manner similar to the Gertzbein and Robbins[18] system for pedicle screw violations.

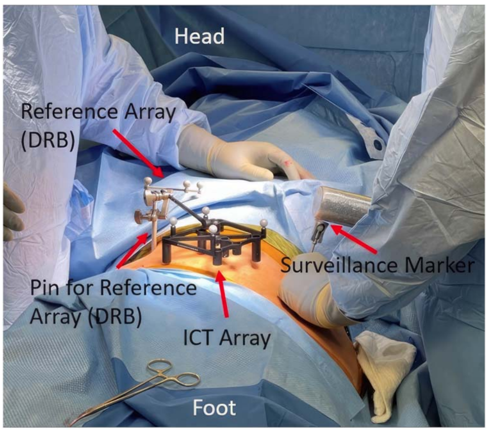

FIGURE 1. Clinical setup for robotic screw placement. Reference array (DRB and pin for DRB) on the operative hemipelvis. ICT attached to that array. Surveillance marker on the contralateral hemipelvis.

Surgical Technique

The patients are placed supine on a flattop Jackson table with a folded blanket under the sacrum and with the arms at 90 degrees to the torso. The camera for the robot comes from the head of the bed, and the robot comes from the foot of the bed—both on the operative side. With the patient draped, the robotic reference array (called the dynamic reference base [DRB]) was anchored to the operative hemipelvis in the gluteus medius pillar as perpendicular to the floor as possible. A surveillance marker was anchored similarly in the contralateral hemipelvis. Any change of position between the DRB and the surveillance marker indicates a potential loss of registration and generates an alert to the surgeon. Finally, an intraoperative CT array (called the ICT) is placed over the relevant bony anatomy in preparation for the O-arm spin (Fig. 1).

Additional sterile drapes are placed over the field taking care to ensure that no pressure is placed on the arrays. Anteroposterior and lateral fluoroscopic views are obtained using the O-arm to ensure the bony anatomy of interest, the DRB, and the ICT will be contained within the spin. Once the spin is obtained, it is transferred to the robot, and the screws are planned using the robotic software (Fig. 2).

The robotic registration is confirmed using the tip of the navigated probe placed on bony anatomic landmarks. The first screw trajectory is selected, and the arm is brought in line with the trajectory. All robotic instruments pass through a tube at the end of the robotic arm called the end effector. The skin is opened with a scalpel placed through the end effector. Blunt dissection is performed to bone. Screw trajectory is established using robotic drills, and the 2.8-mm guidewire for the cannulated screw is placed. The robotic arm is then moved to the next trajectory, and the steps are repeated until all wires are placed (see **Video**, **Supplemental Digital Content 1**, http://links.lww.com/JOT/C79). The wires are advanced, and screws are measured and placed in the usual fashion using fluoroscopy. The postoperative CT for the screw plan is illustrated in Figure 2 and is presented in Figure 3.

Supplemental videos are available from a robotic case demonstrating placement of the guidewire (see **Video**, **Supplemental Digital Content 1**, http://links.lww.com/JOT/C79), placement of an IS screw (see **Video**, **Supplemental Digital Content 2**, http://links.lww.com/JOT/C80), placement of a TS screw (see **Video**, **Supplemental Digital Content 3**, http://links.lww.com/JOT/C81), and a postprocedure O-arm spin (see **Video**, **Supplemental Video Content 4**, http://links.lww.com/JOT/C82).

Statistical Methods

The measurement data were calculated by using minimum and maximum ranges mean, median, and SD. The independent *t* test was used for continuous variables, such as age and body mass index (BMI). The Mann–Whitney *U* test was used to compare Gertzbein and Robbins grade of screw

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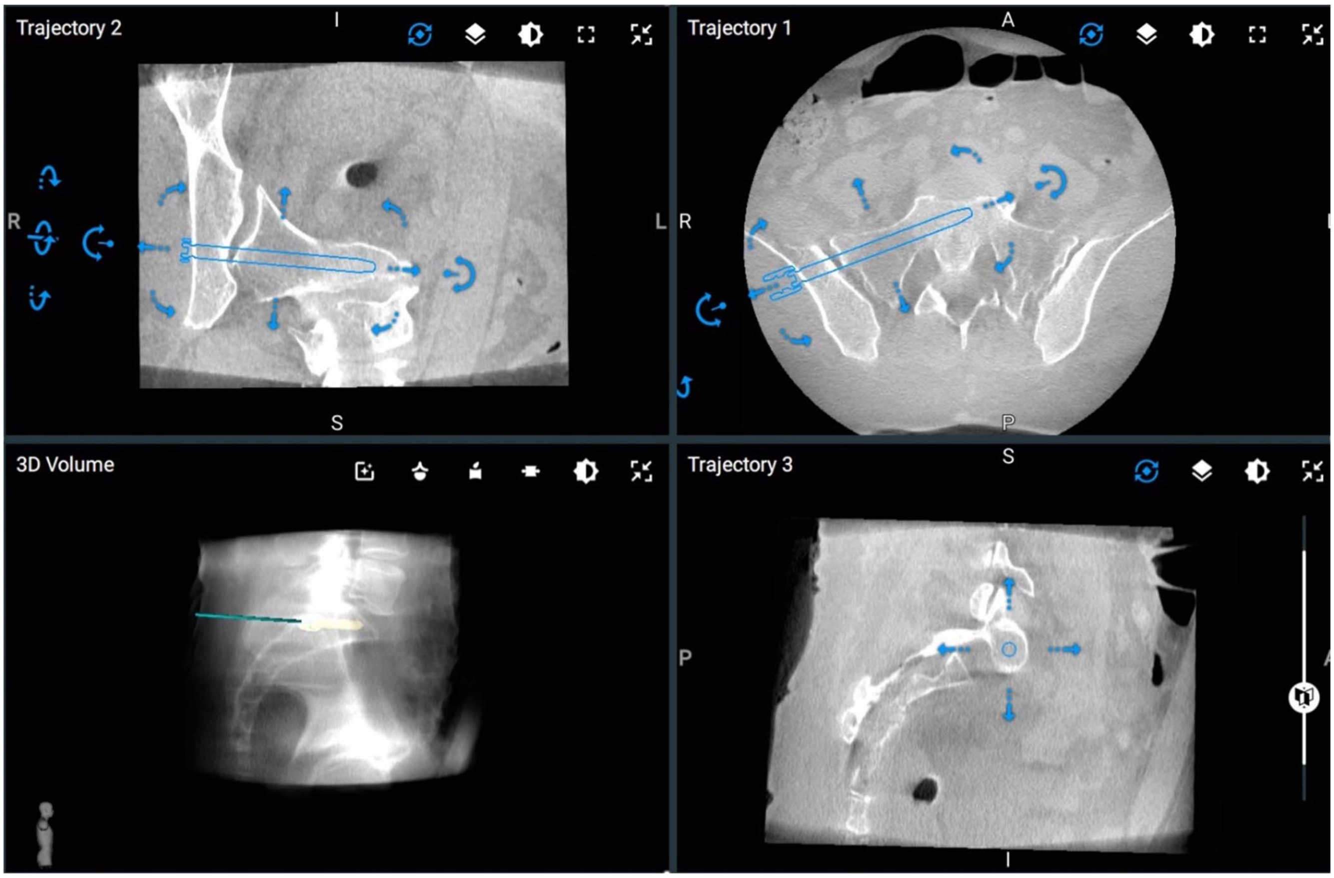

FIGURE 2. Example robotic plan for an iliosacral screw.

violation. χ^2 analysis was performed to compare patients with no violation to patients with any amount of violation. For χ^2 analysis, screws were determined to have a violation if 3/5 reviewers noted a violation. A value of $\alpha = 0.05$ was defined as statistical significance. Overall statistical analysis was analyzed using SPSS software version 25 (IBM, Armonk, NY).

RESULTS

A total of 21 patients were treated between 2021 and 2022, of which 15 were female patients and 6 were male patients. Eleven patients were treated with traditional fluoroscopic techniques, and 10 patients were treated with robotic assistance. The implants placed included 24 IS and 9 TS screws (33 total). Of these patients, the robotic group included 13 sacroiliac and 4 TS screws (17 in total). The nonrobotic group consisted of 11 sacroiliac and 5 TS screws (16 in total).

A total of 24 violations were noted across all cases by all reviewers. There were 4 violations noted in the robotic group (8%) and 17 violations noted in the fluoroscopic group (31%).

The Mann–Whitney U test for Gertzbein and Robbins grade of screw violation demonstrated that the use of robotic assistance for screw placement led to significantly fewer unplanned violations ($P = 0.02$ $U = 21.5$) compared with screw placement guided solely by intraoperative fluoroscopy (Table 1). The calculated U value of 21.5 was found to be significant with a critical U (U_c) value of 26 at $P < 0.05$. χ^2 analysis of any amount of screw violation versus no violation also demonstrated significantly fewer violations for screws placed with robotic assistance ($P = 0.003$).

The patient characteristics are presented in Table 2. There were no significant differences between the 2 groups in age ($P = 0.079$), gender distributions ($P = 0.890$), and BMI ($P = 0.594$).

DISCUSSION

Screw placement without the use of navigation has a reported malposition rate that varies widely depending upon utilization of postoperative CT scans for the evaluation of screw position. Zwingmann et al[19] performed a meta-analysis of screw malposition and reported a 2.6% malposition rate. Rommens et al[20] found screw malposition in 20 of 56 screws placed in 28 patients using postoperative CT scans. Krappinger et al[21] found only 2 cortical violations in 34 patients; however, they only performed CT scans if patients developed neurological deficits postoperatively.

Although the only reports of robotic-assisted pelvic screws come from a single center, multiple reports exist in

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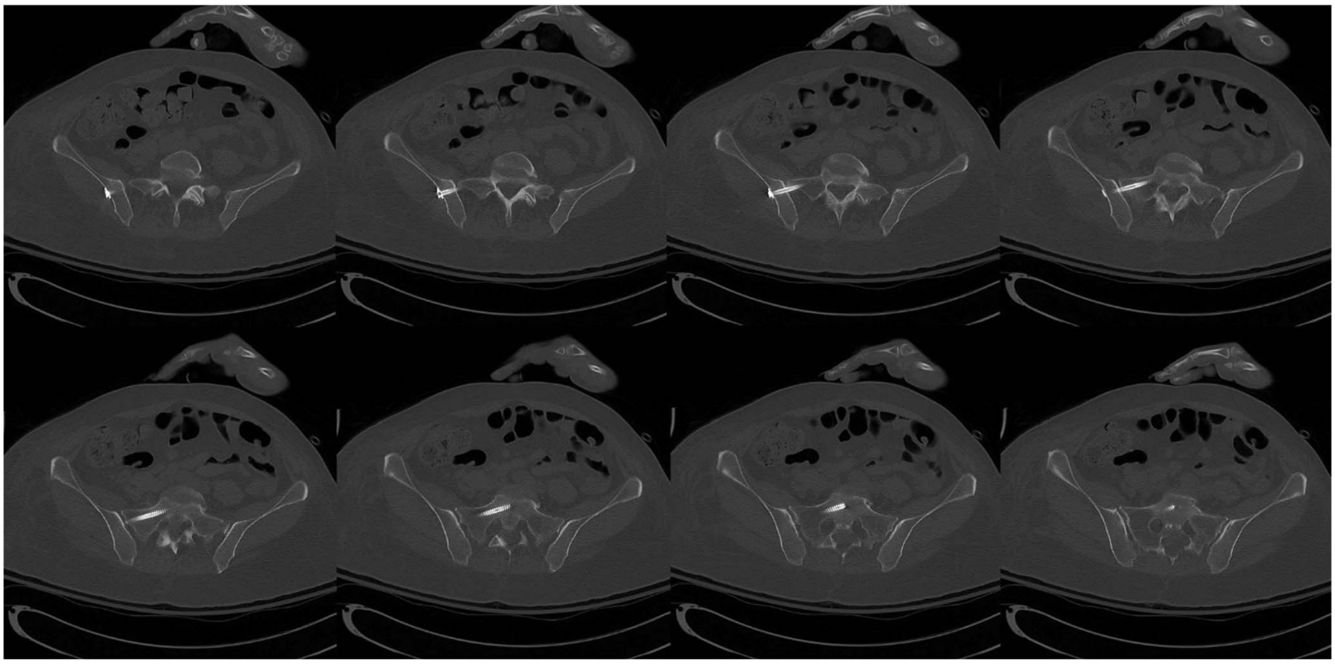

FIGURE 3. Postoperative computed tomography of the screw planned in Fig. 2.

the literature using freehand navigation techniques. Zwingmann et al[16] used navigation without a robotic arm. They found fewer malpositioned screws in the navigation group, similar to our findings. Li et al[15] used Siemens' ARCADISOrbic 3D system for navigation and TiRobot to perform placement of screws. Their results also mimic ours in that significantly less screw malposition was found in the robot-assisted group. Shaw et al,[6] on the other hand, found a higher number of unplanned cortical violations with the use of 3D imaging versus screw placement without navigation. Boudissa et al[17] noted no significant difference in accuracy of screw placement with or without navigation.

Although use of navigation alone allows more accurate screw placement, it does not assist the surgeon in following a planned trajectory. The robotic arm assists the surgeon in accurately following the trajectory planned on 3D imaging, potentially making correct screw placement more reproducible.

TABLE 1. Analysis of 2 Groups

Group	Patient No.		Total Cortical Violations/5 Observers	
Robotic	1	0/5		
	2	0/5		
	3	3/5		
	4	0/5		
	5	0/5		
	6	0/5		
	7	1/5		
	8	0/5		
	9	0/5		
	10	0/5		
Total		4/50		
Conventional fluoroscopy	1	2/5		
	2	3/5		
	3	1/5		
	4	1/5		
	5	1/5		
	6	1/5		
	7	3/5		
	8	4/5		
	9	0/5		
	10	0/5		
	11	1/5		
Total		17/55		
Statistics		$P = 0.02$	U = 21.5	$U_c = 26$
Interquartile range		Q1	Q2	Q3
Robotic		0	0	0.25
Conventional fluoroscopy		1	0.75	3

Number of reviewers for each case noting an unplanned cortical violation. Statistically significantly fewer cortical violations noted for screws placed with robotic assistance.

Table 2. Subject Characteristics

Variable	Robotic (n = 10)	Nonrobotic (n = 11)	*P*
Age			0.08
Mean ± SD	50.80 ± 14.77	38.36 ± 15.79	
Range	21.00–69.00	19.00–68.00	
Sex			0.89
Male	7 (70.00%)	8 (72.73%)	
Female	3 (30.00%)	3 (27.27%)	
BMI (kg/m^2)			0.59
Weight (kg)	28.60 ± 9.325	26.65 ± 4.608	
± SD	85.65 ± 27.30	79.22 ± 16.61	

No statistically significant differences between groups in age, sex, or BMI index.

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In our study, there were a total of 17 violations noted from all reviewers in the fluoroscopic group, demonstrating a 31% rate of unplanned cortical violation. The robotic group demonstrated only 4 unplanned violations across all reviewers for a rate of 8%. A 31% incidence of unplanned violation seems high, but the incidence of violation varied widely among reviewers, with most violations (11/17) noted by a single reviewer. One limitation of the study is that we were unable to evaluate clinically significant violations because no patients experienced neurovascular insult. In addition, most (15/17) of the violations observed were classified as grade B, meaning less than 2 mm of violation. The 2 violations classified as grade D, meaning 4 to less than 6 mm of violation, were classified by the same reviewer who noted 11 total violations; both cases were in the fluoroscopic group. In addition, our study looked at violations on a per-case basis rather than a per-screw basis. Several cases had more than 1 screw placed. As such, the reported rates of screw violation are likely lower on a per-screw basis than the rates reflected in our results. If the rate of screw malposition is normalized on a per-screw basis, the fluoroscopic group had a violation rate of 21% with the robotic group demonstrating a 4.7% rate of violation. We believe our results remain relevant as they represent a "worst case" scenario, in which every case with 1 violation assumes that every screw in that case also has a violation.

Our study has several other limitations. No randomization was performed, and the treating surgeon determined which cases were suitable to robotic versus fluoroscopic techniques. Cases requiring more extensive reduction techniques could influence the number of cortical violations. However, once reduction was obtained, risk of cortical violation should be similar regardless of robotic versus fluoroscopic screw placement.

Another limitation of the robotic technique is that any change in bony anatomy between placements of screws, such as using a screw as a reduction device, could lead to a loss of registration because the position of the bony anatomy is altered. To overcome that limitation, our workflow involves placing all wires before placing any screws. If the bony anatomy changes after placement of the first screw, subsequent screws should follow the previously placed guidewires. In addition, postprocedure CT and O-arm imaging were performed without metal artifact reduction sequences; therefore, accuracy of observations regarding violations could be reduced.

Our study was also limited in that surgeries were performed by a single surgeon. We found a significantly higher risk of violation when screws are placed without robotic assistance. Although these results are similar to other reports in the literature for cortical perforations,[20] our results may not be generalizable to other surgeons.

In summary, this study demonstrates that there were significantly fewer unplanned cortical and neuroforaminal violations using robotic assistance versus conventional fluoroscopy. Robotic screw placement may be a useful tool for placing IS and TS screws in the treatment of pelvic ring injuries. Further research with additional surgeons is needed to examine the accuracy of iliosacral and transsacral screws placed with robotic arm assistance.

REFERENCES

1. Kim W-Y. Treatment of unstable pelvic ring injuries. *Hip Pelvis*. 2014;26:79–83.
2. Kim C-H, Kim JW. Plate versus sacroiliac screw fixation for treating posterior pelvic ring fracture: a Systematic review and meta-analysis. *Injury*. 2020;51:2259–2266.
3. Gardner MJ, Chip Routt ML. The antishock iliosacral screw. *J Orthop Trauma*. 2010;24:e86–e89.
4. Routt ML, Kregor PJ, Simonian PT, et al. Early results of percutaneous iliosacral screws placed with the patient in the supine position. *J Orthop Trauma*. 1995;9:207–214.
5. Hilgert RE, Finn J, Egbers H-J. Technique for percutaneous iliosacral screw insertion with conventional C-arm radiography. *Unfallchirurg*. 2005;108:956–960.
6. Shaw JC, Chip Routt ML, Gary JL. Intra-operative multi-dimensional fluoroscopy of guidepin placement prior to iliosacral screw fixation for posterior pelvic ring injuries and sacroiliac dislocation: an early case series. *Int Orthop*. 2017;41:2171–2177.
7. Chip Routt ML, Simonian PT, Mills WJ. Iliosacral screw fixation: early complications of the percutaneous technique. *J Orthop Trauma*. 1997;11:584–589.
8. Miller AN, Chip Routt ML. Variations in sacral morphology and implications for iliosacral screw fixation. *J Am Acad Orthop Surg*. 2012;20:8–16.
9. Laux CJ, Weigelt L, Osterhoff G, et al. Feasibility of iliosacral screw placement in patients with upper sacral dysplasia. *J Orthop Surg*. 2019;14:418.
10. Barei DP, Bellabarba C, Mills WJ, et al. Percutaneous management of unstable pelvic ring disruptions. *Injury*. 2001;32(suppl 1):SA33–44.
11. Gardner MJ, Morshed S, Nork SE, et al. Quantification of the upper and second sacral segment safe zones in normal and dysmorphic sacra. *J Orthop Trauma*. 2010;24:622–629.
12. Perfetti DC, Kisinde S, Rogers-LaVanne MP, et al. Robotic spine surgery: past, present, and future. *Spine (Phila Pa 1976)*. 2022;47:909–921.
13. Ng N, Gaston P, Simpson PM, et al. Robotic arm-assisted versus manual total hip arthroplasty: a systematic review and meta-analysis. *Bone Joint J*. 2021;103-B:1009–1020.
14. Carlson JB, Zou J, Hartley B. Placement of LC-II and trans-sacral screws using a robotic arm in a simulated bone model in the supine position—a feasibility study. *J Exp Orthop*. 2022;9:36.
15. Li N, Zhu Z, Xiao C, et al. The efficacy of "TiRobot"orthopaedic robot-assisted VS conventional fluoroscopic percutaneous screw fixation of the sacroiliac joint. *Int Orthop*. 2023;47:351–358.
16. Zwingmann J, Konrad G, Kotter E, et al. Computer-navigated iliosacral screw insertion reduces malposition rate and radiation exposure. *Clin Orthop*. 2009;467:1833–1838.
17. Boudissa M, Carmagnac D, Kerschbaumer G, et al. Screw misplacement in percutaneous posterior pelvic iliosacral screwing with and without navigation: a prospective clinical study of 174 screws in 127 patients. *Orthop Traumatol Surg Res*. 2022;108:103213.
18. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. *Spine (Phila Pa 1976)*. 1990;15:11–14.
19. 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. *Arch Orthop Trauma Surg*. 2013;133:1257–1265.
20. Rommens PM, Nolte EM, Hopf J, et al. Safety and efficacy of 2D-fluoroscopy-based iliosacral screw osteosynthesis: results of a retrospective monocentric study. *Eur J Trauma Emerg Surg*. 2021;47:1687–1698.
21. Krappinger D, Lindtner RA, Benedikt S. Preoperative planning and safe intraoperative placement of iliosacral screws under fluoroscopic control. *Oper Orthop Traumatol*. 2019;31:465–473.

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