OPERATIVE TECHNIQUE

Navigation Template Design and the Anatomic Measurement for Anterograde Transpubic Screws

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Objective: For pelvic ring fractures, screw fixation became a popular technique for its good biomechanical performance. The safe insertion of anterograde the transpubic screw is important for patients with anterior pelvic ring fractures. This paper is to research the anatomical parameters of the anterograde transpubic screw corridor and evaluate the safety of anterograde transpubic screw placement assisted by the assembled navigation template.

Methods: Fifty subjects with normal pelvic, 25 men and 25 women, age from 20 to 60 were enrolled, and their ilium were 3D reconstructed. The ilium was divided into zone I, zone II and zone III. Zone I and zone III was defined as medial and lateral to the obturator foramen, respectively. Zone II is located between zones I and III. The corridor A is formed by zone I and zone II and corridor B is formed by zone I, zone II and zone III. The diameter and length of the inner circle, the distance from the center of the inner circle to the posterior superior and to the inferior iliac spine of corridor A and corridor B were measured, respectively. Nine patients with pelvic fractures underwent anterograde transpubic screw and transverse sacroiliac screw placement assisted by the assembled navigation template and were retrospectively analyzed. Operation time, blood loss, incision length and fluoroscopy times were recorded. Grading score and Matta score were evaluated after surgery.

Results: In the 50 subjects, the diameter of corridor A was 11.16 ± 2.13 mm, and that of corridor B was 8.54 ± 1.52 mm. The length of corridor A was 86.39 ± 9.35 mm, and that of corridor B was 117.05 ± 5.91 mm. The surface distance from the screw entry point to the posterior superior iliac spine in corridor A was 109.31 ± 11.06 mm, and that in corridor B was 127.86 ± 8.23 mm. The surface distance from the screw entry point to the posterior inferior iliac spine in corridor A was 91.16 ± 10.34 mm, and that in corridor B was 106.92 ± 7.91 mm. A total of 18 sacroiliac transverse screws and 11 anterograde transpubic screws were inserted assisted by assembled navigation templates for nine patients. The average operation time was 108.75 ± 25.71 min, the blood loss was 141.11 ± 50.21 ml, the incision length was 14 ± 4.62 cm, and the intraoperative fluoroscopy was 17.89 ± 4.01 times.

Conclusion: Transpubic screw corridor can be obtained by 3D reconstruction. For the majority of patients, the anterograde pubic ramus corridor accommodated a 6.5 mm diameter screw. It is safe to use anterograde transpubic screw placement assisted by an assembled navigation template.

Key words: 3D printing; Anatomy; Anterograde transpubic screw; Minimally invasive; Pelvic fracture

Introduction

Pelvic fractures often result in instability of the anterior or posterior ring.[1–4] To maintain the stability of the pelvis, the current treatment methods mostly involve simultaneous internal fixation.[5] For pelvic ring fractures, screws have become a popular technique for many orthopedic surgeons because of their good biomechanical performance.[6] However, there are few anatomical and biomechanical studies on anterior ring instability, especially for pubic ramus fractures. Common anterior ring fixation techniques include plate

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fixation, anterior ring percutaneous fixation (Infix) and transpubic screw fixation.[7] Through mechanical experiments, researchers have confirmed that transpubic screws can maintain the stability of the anterior ring of the pelvis.[8] Based on its advantages of good mechanical stability and low trauma, transpubic screws are considered to be the best surgical method for pubic fracture.[9] An anatomic study of 260 transpubic screw corridors found that all males were able to accommodate the insertion of screws with a diameter of 6.5 mm, while 15% of females were unable to accommodate the insertion of screws with a diameter of 6.5 mm.[10,11] Most men could even accommodate the insertion of a 7.3 mm diameter screw.[12] However, most of these studies were based on two-dimensional images of patients, which are not intuitive and accurate, and lack analysis of Asian populations and clinical application. At present, the clinical application is mostly seen in retrograde transpubic screws. In this technique, the patient is in the standard supine position and the insertion site for the screw is the distal, anterior slope of the pubic tubercle, intraoperative fluoroscopy is required to determine screw orientation.[13,14] If the patient has posterior ring instability, the patient's position is often required to change during surgery, which increases the risk of infection and operation time.

In this study, a method of rapid transpubic screw corridor extraction was developed; the cancellous corridor of transpubic screws was analyzed and measured through digital 3D modeling, and the anatomical conditions of transpubic screws in a population in Southwest China were determined. During surgery, the patient was placed in the standard prone position, assisted by an assembled navigation template, while the sacroiliac and transpubic screws were inserted. After surgery, the safety of the screws was evaluated based on cortex penetration.

This study aimed to: (i) explore a rapid method to obtain a transpubic screw corridor; (ii) evaluate the feasibility of transpubic screw placement; and (iii) assess the safety of the assembled navigation template for screw placement.

Methods

Measures of Anatomical Conditions

For the study, pelvic CT datasets with a slice thickness of 0.625 mm were collected from our hospital between December 2019 and October 2020, and residual trauma and tumorous, inflammatory or high-grade degenerative alterations were excluded. Ultimately, 50 adults (including 25 males and 25 females) with an average BMI of 24.61 ± 1.62, were included in the study. Informed patient consent for further research applications of image data was obtained.

The CT data were imported into Mimics 22.0 (Materialise, Leuven, Belgium). Based on the CT values of the bones, a pelvic mask was obtained (covering cancellous and cortical bones). The bilateral iliac crests were separated from the bone mask, and 3D models were constructed. The pubis was divided into zone I, zone II and zone III according to the Nakatani classification.[15] Based on the high CT value of bone, the mask of ilium was quickly acquired and 3D modeling was reconstructed (about 10 s); In transparent mode, by rotating the ilium and maximizing the corridor, corridor A (approximately an oval) was formed by pubis zone I and zone II (Fig. 1A,B), and corridor B (a quadrilateral) was formed by pubis zone I, zone II and zone III (Fig. 1D,E). The diameter of the tangent circle and the length of the two corridors were measured. The distance along the iliac crest surface from the center of the tangent circle of the two corridors to the posterior superior iliac spine and to the posterior inferior iliac spine was also measured (Fig. 1C,F).

Corridor A means that the screw passes through zone I and II completely, and corridor B means that the screw passes through zone I, II and III completely. The tangent circle diameter for corridor A or B was measured to evaluate whether a 6.5-mm-diameter screw could be inserted into the pubic ramus. The length of corridor A or B was measured to evaluate the length of the transpubic screw. The surface distance from the screw entry point to the posterior superior iliac spine and to the posterior inferior iliac spine was measured as a reference for the covering area of the navigation template base.

Patients

The inclusion criteria were as follows: (i) definite reducible public fracture with zone I and zone II are associated with sacral fractures (Denis type I/II) or reducible sacroiliac dislocation; the superior ramus pubis screw corridor can accommodate screws of at least 6.5 mm diameter; and (ii) tile classification B/C. The exclusion criteria were as follows: (i) patients with severe systemic diseases and open pelvic fractures; and (ii) fracture and sacroiliac dislocation cannot be closed reduction.

This study was approved by the ethics committee of Zigong Fourth People's Hospital (No. 02, 2013). All patients signed the informed consents to participate in the study. A total of nine patients with fractures in the pubis in our hospital from January 2020 to September 2020 were enrolled in this research, including five males and four females. Their ages ranged from 21 to 65 years, and their average age was 47 years. Six of the patients were injured from traffic accidents, three of them were injured from falling, and the others were injured for other reasons. CT scans were performed on the pelvises of all patients before surgery (Table 1).

Design of an assembled navigation template

The 3D model of the patient's pelvis was constructed in mimics 22.0. First, corridor A or B was determined according to the location of the fracture in the superior ramus of the pubis, and then a virtual screw with a diameter of 6.5 mm was inserted along corridor A or B (Fig. 2A); At the same time, sacroiliac screw diameters of 7.3 mm *via* S1 and S2 were inserted simultaneously according to Wu *et al.*'s

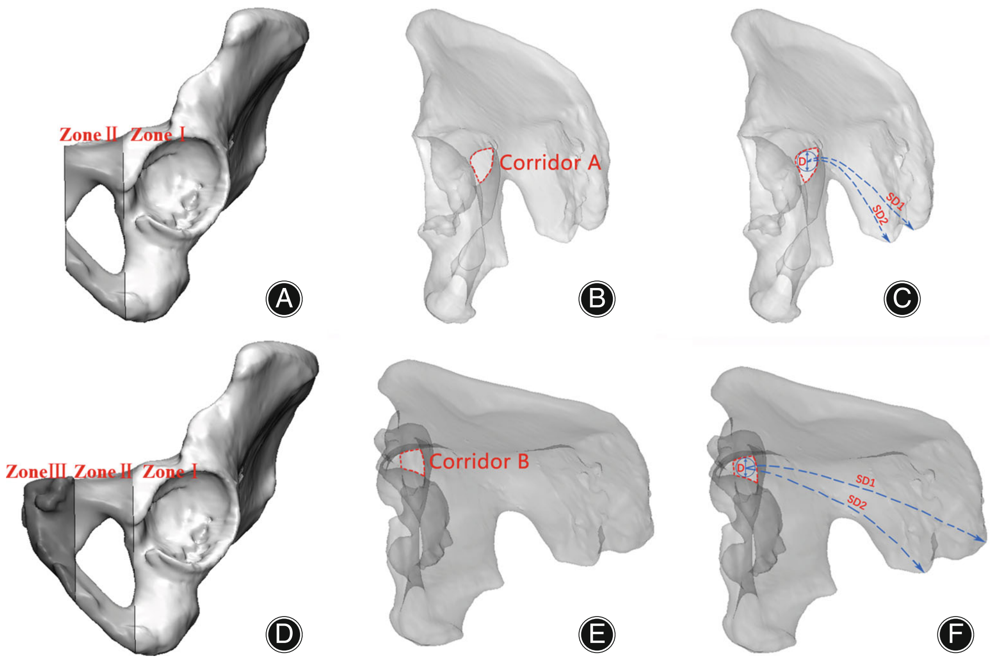

Fig. 1 The pubic was divided into zone I, zone II and zone III according to the Nakatani classification and the corridor for transpubic screw in formed. (A, B). the corridor A (an oval) was formed by the pubis of the zone I and zone II. (C). The diameter (D) of the tangent circle, length of the two corridors, distance along the Iliac crest surface from the center of the tangent circle of the two corridors to the posterior superior iliac spine (SD1) and to the posterior inferior iliac spine (SD2) was measured. (D, E). the corridor B (a quadrilateral) was formed by the pubis of zones I, II and III. (F). The diameter (D) of the tangent circle, length of the two corridors, distance along the Iliac crest surface from the center of the tangent circle of the two corridors to the posterior superior iliac spine (SD1) and to the posterior inferior iliac spine (SD2) was measured

TABLE 1 General information of patients

					Area of public fracture		
No.	Gender	Age (years)	BMI (body mass index)	Tile classification	Left	Right	Type of posterior ring damage
P1	Female	38	21.1	B2	-	I	Sacroiliac dislocation
P2	Male	42	21.2	B2	II	-	Sacral fractures
P3	Male	38	25.7	B2	II	-	Sacral fractures
P4	Male	59	23.8	B2	-	I	Sacral fractures
P5	Male	51	22.8	C1	II	II	Sacral fractures
P6	Female	61	23.3	C1	I	-	Sacroiliac dislocation
P7	Female	65	23.8	B2	II	-	Sacral fractures
P8	Female	48	25.7	B2	I	I	Sacral fractures
P9	Male	21	20.8	B2	-	I	Sacral fractures
Mean		47	23.13				
SD		13.1	1.75				
Min		21	20.8				
Max		65	25.7				

method.[16] Second, the pelvis and virtual screw were imported into 3-matic 14.0 (Materialise, Leuven, Belgium). The projection of the virtual screw to the surface of the iliac crest is used as the entry position, with the surface of the iliac bone covering the entry point. The posterior superior iliac spine and the posterior inferior iliac spine were then extracted and stretched outward 4 mm as the base of the navigation template. The base is designed with internal threaded holes in the direction of the virtual screw for assembly with the navigation pipe. Third, the navigation pipe with thread at the bottom is designed along the direction of the virtual screw (Fig. 2B,C). The navigation pipe is designed with a hole along the virtual screw that can accommodate the diameter of 2.6-mm K-wires. Fourth, the navigation pipe

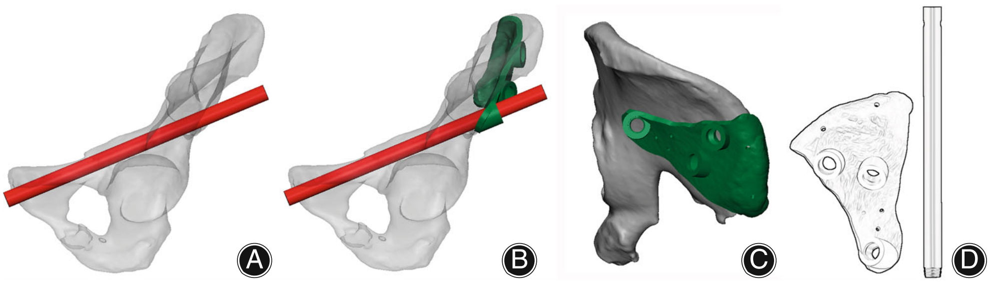

Fig. 2 The design of assembled navigation template. (A) A virtual screw with diameter of 6.5 mm was inserted along corridor. (B) The navigation base is designed with internal threaded holes in the direction of the virtual screw for assembly with the navigation pipe. (C) The navigation base is designed with 5 holes of 2.7 mm for 2.5 screws to reinforce the attachment of the base to the iliac crest. (D) Sketch of the assembled navigation template

was assembled with the base through a threaded structure (Fig. 2D). Finally, an assembled navigation template to assist simultaneous transpubic screw, S1 and S2 screw placement was formed.

Preoperative Preparation

Supracondylar femoral traction was performed and the corrected reduction of the sacral and pubic fractures was confirmed before surgery. The navigation template base, navigation pipes and pelvis were saved in STL format and imported into 3D printers (3DS, Projet 3600, United States), photosensitive resin and (3D talk, FDM 460, China), PLA+ (Fig. 3A,B). The operative procedure was simulated based on the 3D-printed object, K-wires were inserted under the assistance of a navigation template, and the consistency with the preoperative design was evaluated (Fig. 3C,D). The navigation template and pelvic model were disinfected before surgery.

Surgical Technique

The operations were performed by the same surgeon with more than 10 years experience. All patients were informed of the experimental design before the surgery and signed an informed consent form.

Under general anesthesia, the patient was placed in the standard prone position on a radiolucent operation table. First, traction reduction was performed for some patients, Reduction of fracture or dislocation was confirmed by intraoperative C-arm fluoroscopy. Second, posterior superior iliac spine and screw insertion points were located on the body surface. Third, the soft tissue of the posterior superior iliac spine was stripped, and the template base was inserted through the above incision and completely attached to the corresponding target spot (Fig. 4A). Fourth, threaded navigation pipes were inserted through a small incision and assembled and fixed with the navigation template base in the wound (Fig. 4B). Fifth, several K-wires 2.5 cm in diameter

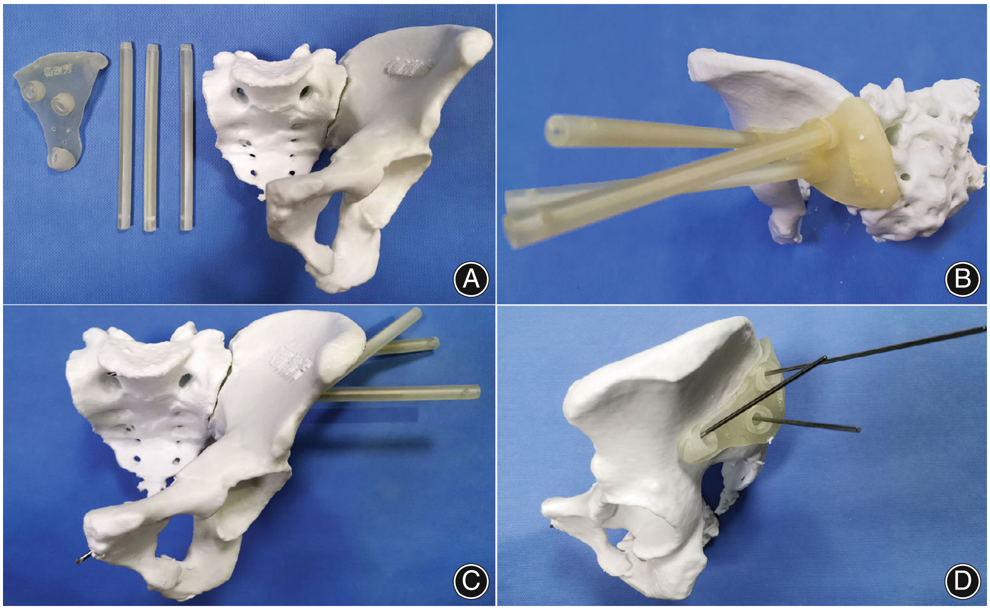

Fig. 3 The transpubic screw placement simulation based on 3D printing. (A) The 3D printed assembled navigation template and pelvic. (B) The assembled navigation template was assembled and attached to the surface of the iliac crest. (C, D). K wires were inserted under the assistant of a navigation template

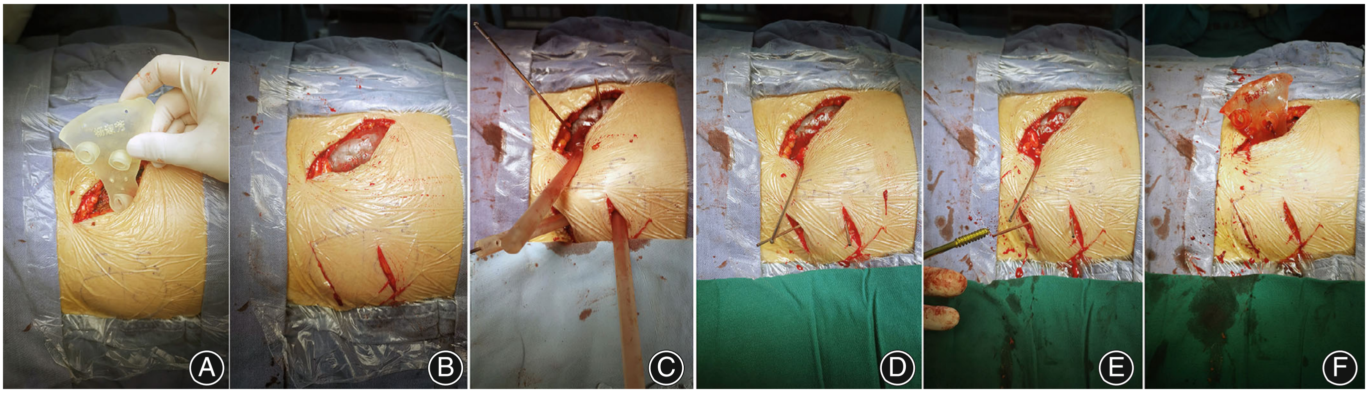

Fig. 4 The operation procedure (A) The template base was inserted through the incision on posterior superior iliac spine. (B) The template base was completely attached to the corresponding target spot. (C) Navigation pipes were inserted and assembled with the navigation template base, and K wires were inserted along the navigation pipes. (D) The K wires were inserted along the navigation pipes and navigation pipes were removed. (E) The cannulated screws were inserted along the K wires. (F) The K-wires and template base were removed

were drilled through navigation pipes (Fig. 4C). Pelvic inlet, outlet and lateral sacral fluoroscopy images were obtained to confirm the positions of the K-wires (Fig. 5A–C). Sixth, the navigation pipes were removed after the K-wire positions were confirmed (Fig. 4D), and cannulated screws with diameters of 7.3 mm and 6.5 mm were screwed into the sacrum and pubis along the K-wires, respectively (Fig. 4E). Finally, the K-wires and template base were removed (Fig. 4F).

Evaluation Criteria

Screw safety was assessed using the grading score.[17] The quality of the reduction was assessed by the Matta score.[18] A displacement of less than or equal to 4 mm was considered excellent, between 5 and 10 mm was regarded as good, between 10 and 20 mm was acceptable, and a displacement of more than 20 mm was regarded as poor.

Statistical Analysis

All statistical analyses were performed in SPSS 19.0 (SPSS Inc.; Chicago, IL, USA). Student's t-test was performed for the diameter of the corridors, the length of the corridor, and the surface distance from the screw entry point to the posterior superior iliac spine and inferior iliac spine. Descriptive statistics were performed on the general parameters and operative parameters of the patients. The confidence interval was set at 95%, and $P < 0.05$ was regarded as a significant difference.

Results

Anatomical Measurement

A total of 50 adults without fracture or dislocation in pelvic were enrolled in this study. The diameters were 11.16 ± 2.13 mm for corridor A and 8.54 ± 1.52 mm for corridor B, and with a significant difference between the two corridors ($P < 0.05$); The lengths were 86.39 ± 9.35 mm for corridor A and 117.05 ± 5.91 mm for corridor B, with a significant difference between the two corridors ($P < 0.05$). The surface distances from the screw entry point to the posterior superior iliac spine were 109.31 ± 11.06 mm for corridor A and 127.86 ± 8.23 mm for corridor B, with a significant difference between the two corridors ($P < 0.05$). The surface distances from the screw entry point to the posterior inferior iliac spine were 91.16 ± 10.34 mm for corridor A and 106.92 ± 7.91 mm for corridor B, with a significant difference between the two corridors ($P < 0.05$) (Table 2).

Clinical Indicators

A total of nine patients completed the surgery successfully, with 18 sacroiliac screws and 11 anterograde transpubic screws placement under the assistance of assembled navigation templates (Fig. 5D–I). The nine patients had an average surgical time of 108.75 ± 25.71 min, a blood loss of 141.11 ± 50.21 ml, an incision length of 14 ± 4.62 cm, and a radiation of 17.89 ± 4.01 times. One anterograde transpubic screw was grade 1, and 10 screws were grade 0. One S1 screw was grade 1, and eight S1 screws and nine S2 screws were grade 0 (Table 3). Five patients had excellent Matta scores, and four had good Matta scores.

There were no complications, such as vascular and nerve injury. One patient developed superficial wound infection. After wound treatment and dressing changes, the wound healed.

Discussion

Anatomical Conditions of Anterograde Transpubic Screws

Retrograde transpubic screw fixation can provide stability of the anterior pelvis with fewer surgical exposures than plate fixation.[19,20] There have been many studies on the anatomic measurement of retrograde transpubic screws, and taking

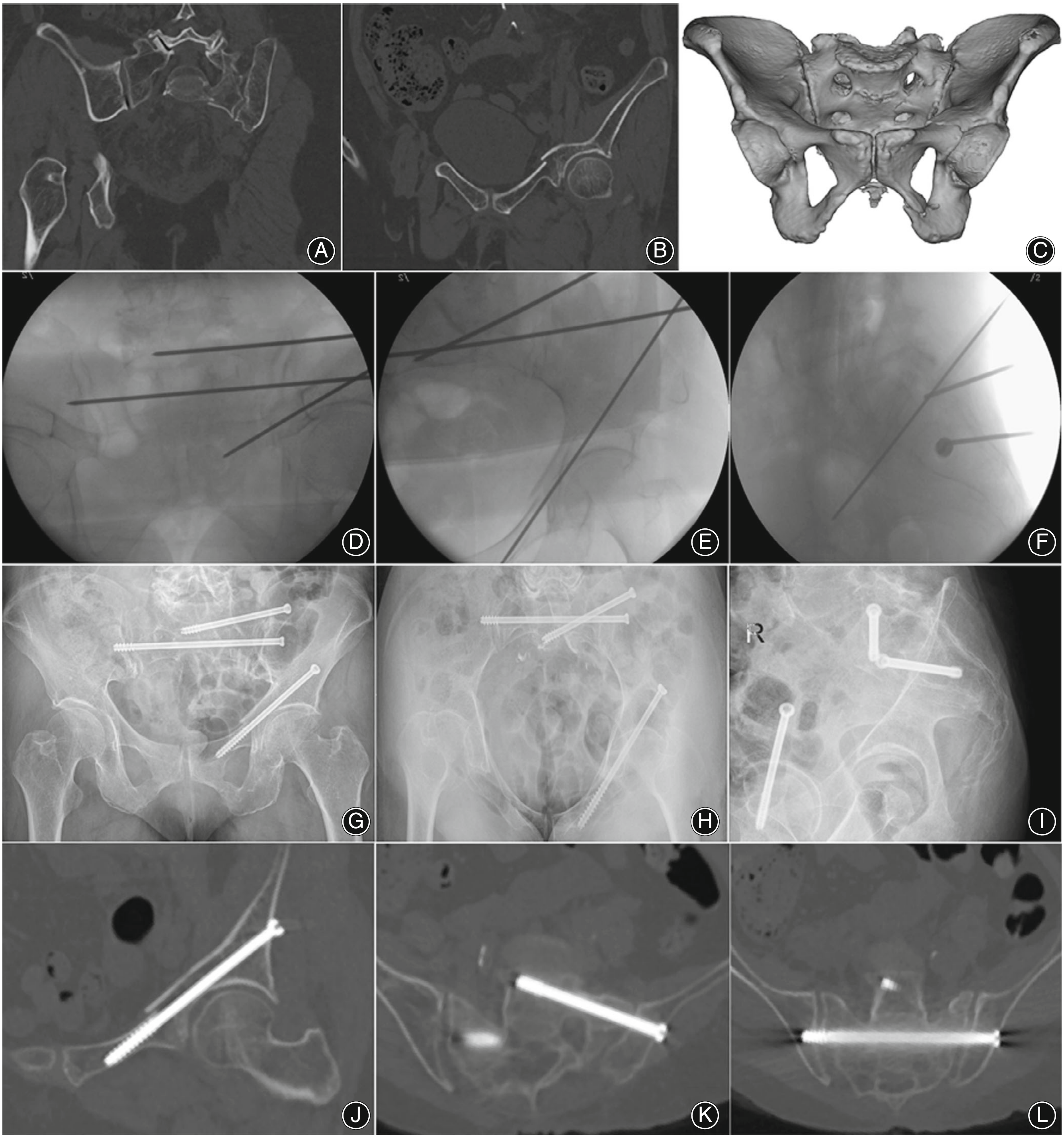

Fig. 5 A 62-year-old patient, left sacral fracture (zone II) and pubic fracture (zone I). (A) Axial CT image showing a fracture of the sacrum zone II. (B) coronal CT image showing a fracture of the pubic zone I. (C) 3D reconstruction of the pelvis. (D–F) K-wires were inserted under assistance of the navigation template during the operation and C-arm fluoroscopy confirmed none of the K wires breached the cortex. (G) post-operation X-ray of pelvic in outlet view. (H) post-operation X-ray of pelvic in inlet view. (I) post-operation X-ray of pelvic in lateral view. (J) post-operation CT image of transpubic screw. (K) post-operation CT image of S1 screw. (L) post-operation CT image of S2 screw

reproductive structures as the marking point, the entry point of retrograde transpubic screws was located, which greatly reduced the difficulty of screw placement.[10,11,14] Zhang *et al.* developed a navigation apparatus to assist with the placement of percutaneous retrograde transpubic screws to minimize trauma.[21] However, the reduction failure rate is up to

TABLE 2 Anatomical parameters of the pubic for 50 adults

	Left + right(n = 100)				Corridor A(n = 50)		Corridor B(n = 50)	
	Corridor A	Corridor B	T	*P*	Right	Left	Right	Left
Diameter (mm)	11.16 ± 2.13	8.54 ± 1.52	19.13	<0.05	11.05 ± 2.02	11.26 ± 2.08	8.36 ± 1.56	8.71 ± 1.48
Length (mm), D	86.39 ± 9.35	117.05 ± 5.91	−39.74	<0.05	86.13 ± 9.58	86.65 ± 9.22	116.78 ± 6.33	117.31 ± 5.52
Surface distance from the screw entry point to the posterior superior iliac spine (mm), SD1	109.31 ± 11.06	127.86 ± 8.23	−20.49	<0.05	108.84 ± 11.10	109.78 ± 11.12	127.86 ± 8.11	127.85 ± 8.44
Surface distance from the screw entry point to the posterior inferior iliac spine (mm), SD2	91.16 ± 10.34	106.92 ± 7.91	−19.53	<0.05	90.14 ± 10.45	92.17 ± 10.22	106.48 ± 8.07	107.36 ± 7.81

TABLE 3 Clinical results of patients

						Grading score			
No.	Surgical time(min)	Blood loss(ml)	Incision length(cm)	Radiation (times)	Matta criteria	Pubic-L	Pubic-R	S1	S2
P1	100	100	12	18	Good	-	0	0	0
P2	90	150	12	16	Excellent	0	-	0	0
P3	110	150	15	16	Good	0	-	0	0
P4	100	120	12	10	Excellent	-	0	0	0
P5	160	250	22	22	Good	0	0	1	0
P6	90	100	9	20	Excellent	0	-	0	0
P7	80	100	9	18	Excellent	0	-	0	0
P8	140	200	22	25	Good	1	0	0	0
P9	100	100	13	16	Excellent	-	0	0	0
Mean	108.75	141.11	14	17.89					
SD	25.71	50.21	4.62	4.01					
Min	80	100	9	10					
Max	160	250	22	25					

15% after percutaneous screw fixation for pubic ramus fractures, and failure is particularly common in elderly patients and females.[15] Peng *et al.* found that there are many variations between anterograde transpubic screws and retrograde transpubic screws at the entry point, and there is a larger screw insertion area for anterograde transpubic screws than for retrograde transpubic screws.[22] However, there are currently few clinical and anatomical studies on anterograde transpubic screws.

Advantages of Anterograde Transpubic Screws

Although the anterograde transpubic screw show a larger entry point area in the anatomical study,[22] the lack of significant anatomical markers makes it very difficult to accurately place the anterograde transpubic screw. Therefore, there are few clinical applications of anterograde transpubic screws. In addition, expensive computer navigation or robotic navigation increases the cost of anterograde transpubic screw placement. In this study, based on the anatomical characteristics of the pubis, we used an assembled navigation template to assist in the placement of the anterograde transpubic screw, and there were only two screws in grade 1 and 27 screws in grade 0. The advantages of assembled navigation template-assisted placement of the anterograde transpubic screw are as follows: First, the anterograde transpubic screw had more excellent fixation strength than a plate or a retrograde transpubic screw.[23,24] Second, a minimally invasive screw fixation technique for pelvic fractures can significantly reduce trauma, with equivalent clinical results for unstable pelvic fractures.[15,25] In addition, the procedure is minimally invasive and has good fracture reduction according to the Matta score in this study. Third, simultaneous placement of sacroiliac screws and anterograde transpubic screws in a prone position can avoid intraoperative position changes, reducing the operation time and the risk of infection. In this study, the average operation time of nine patients was only 108 min, and the procedures had a low infection rate.[26] Fourth, anterograde transpubic screw fixation can avoid many problems, such as large trauma due to anterior ring fixation and injury of the lateral femoral cutaneous nerve. Fifth, the assembled navigation template can significantly improve the safety of screw placement, and no screw penetrated the cortex more than 2 mm in our study.

Surgical Tips

First, in this study, the diameter of corridor A is larger than that of corridor B, while the length is shorter than that of corridor B. For fracture in zone I, both corridor A and corridor B can achieve fixation effect, but corridor A is preferred for better safety screw placement. For zone I and II fractures, only corridor B can achieve fixation. Second, The CT threshold usually defined between 600 to 3071 for cortical bone, which can be adjusted according to the patient's bone situation. Third, the base of the navigation template should cover important targets, such as the posterior superior iliac spine and the posterior inferior iliac spine; the navigation template base will be warped if it is too long; therefore, the navigation template base should be shortened as much as possible while still covering important targets. The directions of the navigation pipes should not intersect to prevent interference between screws, and K-wire holes are designed based on the navigation template to strengthen the fixation between the navigation template and the iliac crest. Fourth, the entry point of the transpubic screw should be located on the body surface under fluoroscopy before surgery to reduce the tension of skin and soft tissue. Fifth, the soft tissue around the target should be thoroughly removed during the operation to ensure the tight attachment of the navigation template base. Sixth, it is recommended to perform pelvic inlet, outlet and lateral sacral fluoroscopy. Finally, navigation K-wires for sacroiliac screws are recommended to be inserted first to enhance the stability of the navigation template base, followed by navigation K-wires for transpubic screw insertion.

Limitations

Once the intraoperative incision deviates from the screw entry point are located on the body surface, soft tissue tension will reduce the accuracy of the navigation wire; therefore, we are developing a metal mesh that can be attached to the skin for the positioning of the entry point.

Conclusion

Transpubic screw corridor can be obtained quickly by the transparent model of 3D reconstruction. Corridor A was formed by zone I and zone II, and looks like a circle; corridor B was formed by zone I, zone II and zone III, and looks like a quadrilateral; the majority patients can accommodate anterograde transpubic screws with a diameter of 6.5 mm. Anterograde transpubic screw placement assisted by assembled navigation template without nerve and blood vessel damage, and it is clinically feasible and safe.

Acknowledgments

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Author Contributions

Chao Wu was responsible for experiment design, clinical trials, paper writing and review; Danwei Shen for data preprocessing; Jiayan Deng for data analysis and paper writing; Bofang Zeng, Xiangyu Wang, Hong Li, Lian Xu and Min Luo for clinical trials.

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