Anatomical conditions and patient-specific locked navigation templates for TSS placement

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Abstract

Objective To analyse the anatomical conditions of transverse sacroiliac screws about the S1 and S2 segments in order to develop and validate a locked navigational template for transverse sacroiliac screw placement.

Methods The CT data of 90 normal sacra were analysed. The long axis, short axis and lengths of transverse sacroiliac screw cancellous corridors were measured through 3D modelling. A patient-specific locked navigation template based on simulated screws was designed and 3D printed and then used to assist in transverse sacroiliac screw placement. The operative time, intraoperative blood loss, incision length, and radiation times were recorded. The Matta criteria and grading score were evaluated. The entry point deviation of the actual screw placement relative to the simulated screw placement was measured, and whether the whole screw was in the cancellous corridor was observed.

Results S1 screws with a diameter of 7.3 mm could be inserted into 69 pelvises, and S2 screws could be inserted in all pelvises. The S1 cancellous corridor had a long axis of 25.44±3.32 mm in males and 22.91±2.46 mm in females, a short axis of 14.21±2.19 mm in males and 12.15±3.22 mm in females, a corridor length of 153.07±11.99 mm in males and 151.11±8.73 mm in females, and a proportional position of the optimal entry point in the long axis of the cancellous corridor of 35.96±10.31% in males and 33.28±7.2% in females. There were significant differences in the corridor long axis and corridor short axis between sexes ($p<0.05$), and there were no significant differences in corridor length and proportional position of the optimal entry point in the long axis of the cancellous corridor between sexes ($p>0.05$). The S2 cancellous corridor had a long axis of 17.58±2.36 mm in males and 16±2.64 mm in females, a short axis of 14.21±2.19 mm in males and 13.14±2.2 mm in females, a corridor length of 129.95±0.89 mm in males and 136.5±7.96 mm in females, and a proportional position of the optimal entry point in the long axis of the cancellous corridor of 46.77±9.02% in males and 42.25±11.95% in females. There were significant differences in the long axis, short axis and corridor length ($p<0.05$). There was no significant difference in the proportional position of the optimal entry point in the long axis of the cancellous corridor ($p>0.05$). A total of 20 transversal sacroiliac screws were successfully inserted into 10 patients with the assistance of locked navigation templates. Nineteen screws were grade 0, 1 screw was grade 1, and there were no postoperative complications of infection or nerve root injury. All screw entry point deviations were shorter than the short axis of the cancellous corridor, and all screws were located completely within the cancellous corridor.

Conclusion Approximately 76% of males and females can accommodate screws with diameters of 7.3 mm in S1, and all persons can accommodate the same screw in S2. From the standard lateral perspective of the sacrum, the optimal entry point of the transverse screw is in the first 1/3 of the cancellous corridor for S1 and the centre of the cancellous corridor for S2. The patient-specific locked navigation template assisted in transverse sacroiliac screw placement with little trauma and fluoroscopy radiation and secure screw placement.

Introduction

Because posterior pelvic ring disorders have a high risk of sacral nerve root injuries and high-grade biomechanical instability, the traditional surgical treatment method is internal fixation by plate, including posterior percutaneous plate fixation and anterior open reduction plate screw fixation. However, these methods are associated with poor pelvic stability, plate or screw loosening, fracture reduction failure, large trauma, wound infection and other risks [1–2]. Matta et al [3] discovered that internal sacroiliac screw fixation for unstable pelvic ring fractures can significantly reduce trauma; it has subsequently become a popular technique for a large number of orthopaedic surgeons. Compared with traditional sacroiliac screws, transverse sacroiliac screws have better pelvic stability due to the longer screw corridor [4], but transverse sacroiliac screws are not for everyone. According to the anatomical analysis of 76 normal pelvic CT cases by König MA[5] et al, it was found that in 37% of males, the S1 osseous corridor was unable to accommodate a screw with a diameter of 8 mm, compared with 34% of females. All male S2 corridors can accommodate screws with a diameter of 8 mm, while 13% of female S2 corridors cannot. A large number of studies have shown that the anatomical morphology of the sacrum has a significant effect on the placement of transverse screws [6–9], but the anatomical conditions for transverse sacroiliac screws in patients of Asian ethnicity have been less reported.

In the internal fixation of transverse sacroiliac screws, the insertion of a hollow screw guide wire is very important, and placement under traditional fluoroscopy not only increases the radiation dose for the doctor and patient but also requires the doctor's detailed knowledge, clinical experience, anatomical familiarity and X-ray interpretation ability[10–11]. Screw penetration rates have been reported to be as high as 68%, and nerve injury has been reported in as many as 7.9% of screw placements by fluoroscopy [12–14]. With the application of various navigation equipment, the safety and accuracy of screw placement have been greatly improved. However, there is a learning process required before they can be used proficiently, which adds some difficulties for the doctors [15–17]. In addition, the acquisition of navigation equipment is expensive and becomes an economic burden for most hospitals.

To solve the above problems, this study analysed and measured the cancellous corridor of transverse sacroiliac screws through digital 3D modelling and provided the anatomical conditions for the placement of transverse sacroiliac screws in a population in Southwest China. For patients with posterior pelvic ring disorders in our hospital, a personalized navigation template was then designed, 3D printed and applied for intraoperative application. After the surgery, the screws were evaluated for penetration into the cortex. The deviation of the screws from the optimal insertion point at the entrance to the sacrum was measured, thereby verifying the safety and accuracy of sacroiliac screw placement assisted by personalized navigation template.

The purpose of this study is as follows: (i) To discuss the feasibility of transverse screws about the S1 and S2 segments; (ii) to measure the optimal screw entry point and safety screw corridor of transverse screws about the S1 and S2 segments through a digital 3D model; (iii) to design a locked, patient-specific navigation template for transverse sacroiliac screw placement; and (iv) to evaluate the accuracy and safety of the locked navigation template for transverse sacroiliac screw placement.

Materials And Methods

Measures of anatomical conditions

A total of 47 adult males and 43 adult females who underwent computed tomography (CT) scans of their pelvises between January 2017 and May 2018 were included in the study. Investigations that revealed obvious traumatic, degenerate or osteolytic conditions were excluded. Investigations with a slice thickness of 0.625 mm were selected. Institutional review board approval was obtained.

The CT data were imported into Mimics 21.0 (Materialise, Leuven, Belgium). The CT threshold of bone was measured, the sacral cortex was extracted, and a 3D model of the sacrum was constructed (Fig. 1a). In the transparent view (Fig. 1b), the maximum inscribed circle of the cancellous corridor was marked (Fig. 1c). Drawing lines through the centre of the circle, the longest line was considered the long axis of the corridor (A), and the shortest line was regarded as the short axis of the corridor (B) of the cancellous corridor (Fig. 1d). The centre of the maximum inner circle (O) is considered the optimal screw entry point, and the proportional position of the optimal entry point on the long axis of the corridor was calculated (Fig. 1d). The total corridor length (L1 and L2) was the distance from the centre of the maximum inscribed circle to the projection point on the left pelvic surface and to the projection point on the right (Fig. 1e).

Patients

The inclusion criteria were as follows: definite sacral fracture with Denis type I/II; reducible sacroiliac dislocation; Tile classification B/C; age 18 to 60 years old. The exclusion criteria were as follows: patients with severe systemic diseases or open pelvic injuries.

A total of 10 patients with pelvic fractures were involved in this study from May 2018 to February 2019, including 4 males and 6 females, with an average age of 44.4 years and an average BMI of 23.73 kg/cm^2. Eight of them presented with a B2 fracture and 2 with a C1 fracture. According to the posterior pelvic ring disruption classification, five patients suffered from a Denis [illegible] fracture, 3 patients suffered from a Denis II fracture and 2 patients suffered from an SI dislocation. One patient had a sacral deformity, and the others had normal sacral morphology (Table 1).

Table 1
General information of patients treated by Locked navigation template

No.	Gender	Age (years)	BMI(Body Mass Index, kg/cm^2)	Tile classification	Type of posterior pelvic ring disruption	Sacral morphology
P1	Female	42	22.3	B2	Denis [illegible] fracture	Normal
P2	Male	47	26.5	B2	Denis [illegible] fracture	Normal
P3	Male	37	25.7	C1	SI dislocation	Normal
P4	Female	54	21.8	B2	Denis [illegible] fracture	Normal
P5	Female	51	20.5	B2	Denis [illegible] fracture	Normal
P6	Female	38	22.5	B2	Denis [illegible] fracture	Normal
P7	Female	49	23.5	B2	Denis [illegible] fracture	Normal
P8	Female	39	25.9	C1	SI dislocation	Dysmorphic
P9	Male	42	23.8	B2	Denis [illegible] fracture	Normal
P10	Male	45	24.8	B2	Denis [illegible] fracture	Normal
Mean		44.4	23.73			
SD		5.78	1.98			
Min		37	20.5			
Max		54	26.5			

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

Design Of The Locked Navigation Template

The CT images of the patients were imported into Mimics 21.0, and a 3D model of the sacrum and pelvis was built. In accordance with the above method, the virtual screw was inserted from the optimal screw entry point and then passed along the optimal screw corridor to complete the simulated screw placement (Fig. 2a). The pelvis and virtual screws were imported into 3-matic 13.0 (Materialise, Leuven, Belgium). The guide pipe and locked template were designed according to the direction of the virtual screw (Fig. 2b), and the inside of the guide pipe was designed with a diameter of 2.6 mm for passing the 2.5 mm K-wires. The base of the locked navigation template was designed according to the shape of the pelvic surface where the virtual screw on (Fig. 2c) and designed with a 9 mm diameter pipe for passing screws (Fig. 2d).

Preoperative Preparation

The pelvic model and navigation template were printed (Fig. 3a). Then, the base of the template was attached to the posterior superior iliac spine, the guide pipe was screwed into the base, and K-wires with a diameter of 2.5 mm were implanted along the guide pipe (Fig. 3b). Whether the K-wires broke through the bone cortex was observed, and the consistency of the K-wires' placements with the preoperative design was evaluated. The locked navigation template was sterilized at low temperatures before operation.

Surgical Technique

Under general anaesthesia, the patient was placed in the prone position as recommended for the surgical procedure on a radiolucent operation table. In most cases, internal fixation of the anterior pelvic ring was performed with indirect reduction.

First, the posterior superior iliac spine and the transverse sacroiliac screw insertion points were located on the body surface (Fig. 3a). The incision of the posterior superior iliac spine was performed according to the size of the navigation template base, and soft tissue was stripped from the bones. The template base was inserted through the incision and completely attached to the corresponding anatomical positions on the posterior superior iliac spine (Fig. 3b). Second, a small incision was made at the location of the transverse sacroiliac screw entry points, through which the threaded guide pipes were inserted and screwed onto the base (Fig. 3c). Third, 2 K-wires with a 2.5 cm diameter were implanted into the sacrum through the guide pipes. Fluoroscopy of the pelvic inlet and outlet and the lateral sacrum were performed to confirm the position of the K-wires (Fig. 3d). Then, the guide pipes were removed, and a hollow screw with a 7.3 mm diameter was screwed into the sacrum along the K-wires through the iliac bone (Fig. 3e). Fifth, fluoroscopy was performed again to confirm the screw positions. Finally, the K-wires and template base were removed (Fig. 3f, g).

Evaluation Criteria

Normal anatomical parameters of the sacrum

The 90 pelvises were divided into two groups by gender. The long axis, short axis and length of the cancellous corridor were measured, and the proportional position of the optimal entry point on the cancellous corridor was calculated.

Operated Information For Patients

The operation time, blood loss, incision length and radiation times were recorded to evaluate the operation quality. The following grading score was used to evaluate the safety of the transverse sacroiliac screws [18]: grade 0: safe placement, screws located in cancellous bone; grade 1: cortical bone perforation less than 2 mm; and grade 2: cortical bone perforation greater than 2 mm. Grade 0 and 1 placements are considered successful and safe, and grade 2 indicates the possibility of nerve damage.

The quality of the reduction was assessed by the Matta score[19]: excellent, $\leq$ 4 mm; good, 4–10 mm; and fair, 10–20 mm.

Deviation Of Screw Entry Point

By registering the pre- and postoperative CT images, the distance between the actual and planned screws at the point of entrance was measured based on the 3D model [20] (Fig. 5b). On the sagittal view of the sacrum (Fig. 5c), the screw was evaluated if it was completely located within the cancellous corridor.

Statistical analysis

All statistical analyses were performed in SPSS 19.0 (SPSS Inc.; Chicago, IL, USA). Independent sample T tests were performed for the long axis, short axis, and length of the cancellous corridor and for proportional position of the optimal entry point in the cancellous corridor. Descriptive statistics were obtained for general and operative patient parameters.

Results

Measurements

The CT data of 90 normal adults were measured. S1 screws with a diameter of 7.3 mm could not be inserted in 21 patients; of those that could accept the screw, 36 were male and 33 were female. S2 screws with a diameter of 7.3 mm could be inserted into all pelvises, (47 males and 43 females). The distribution of the security index was obtained according to the shape of the cancellous corridor in S1 and S2 (Fig. 5a). The cancellous corridor for S1 had a long axis of 25.44 ± 3.32 mm in males and 22.91 ± 2.46 mm in females, which was significantly different between the sexes ($p = 0.001$). For S2, the long axis was 17.58 ± 2.36 mm in males and 16 ± 2.64 mm in females, which was significantly different between the sexes ($p = 0.004$). The cancellous corridor for S1 had a short axis of 14.01 ± 3.53 mm in males and 12.15 ± 3.22 mm in females, with a significant difference between the sexes ($p = 0.025$); for S2, the short axis was 14.21 ± 2.19 mm in males and 13.14 ± 2.2 mm in females, with a significant difference between the sexes ($p = 0.023$). The cancellous corridor for S1 had a length of 153.07 ± 11.99 mm in males and 151.11 ± 8.73 mm in females, with no significant difference between the sexes ($p > 0.05$); for S2, it had a length of 129.95 ± 0.89 mm in males and 136.5 ± 7.96 mm in females, with a significant difference between the sexes ($p < 0.05$). The proportional position of the optimal entry point in the cancellous corridor was 35.96 ± 10.31% in males and 33.28 ± 7.2% in females for S1, with no significant difference between the sexes ($p > 0.05$), and 46.77 ± 9.02% in males and 33.25 ± 11.95% in females for S2, with no significant difference between the sexes ($p > 0.05$) (Table 2).

Table 2

Measurement of transverse sacroiliac screw cancellous corridor

	Parameter measured	Male(n = 36)	Female(n = 33)	P value
S1	Long axis of corridor(mm)（A）	25.44 ± 3.32	22.91 ± 2.46	0.001
	Short axis of corridor(mm)（B）	14.01 ± 3.53	12.15 ± 3.22	0.025
	Corridor length(mm)（L1）	153.07 ± 11.99	151.11 ± 8.73	0.438
	Proportional position of the optimum entry point to long axis of secure corridor width (%)	35.96 ± 10.31	33.28 ± 7.2	0.172
S2	Parameter measured	Male(n = 47)	Female(n = 43)	P value
	Long axis of corridor(mm)（A）	17.58 ± 2.36	16 ± 2.64	0.004
	Short axis of corridor(mm)（B）	14.21 ± 2.19	13.14 ± 2.2	0.023
	Corridor length(mm)（L2）	129.95 ± 0.89	136.5 ± 7.96	0.000
	Proportional position of the optimum entry point to long axis of secure corridor width (%)	46.77 ± 9.02	42.25 ± 11.95	0.065

Clinical Outcome

Twenty transverse sacroiliac screws were successfully inserted into 10 patients with the assistance of locked navigation templates, with a surgical time of 88 ± 14.76 min, blood loss of 110 ± 24.94 ml, an incision length of 10.1 ± 1.37 cm, radiation times of 11.5 ± 1.78 seconds, and a screw entry point deviation of 1.95 ± 0.39 mm for S1 and 1.34 ± 0.65 mm for S2. There were no postoperative complications of infection or nerve root injury. One screw had a grade score of 1, and the rest had a grade score of 0 (Table 3). Eight patients had excellent Matta scores, and two had good Matta scores. All screw entry point deviations were shorter than the short axis of the cancellous corridor, and all screws were located within the cancellous corridor (Fig. 6).

Table 3
Clinical outcome of patients

No.	Surgical time(min)	Blood loss(ml)	Incision length(cm)	Radiation times	Matta criteria	Grading score		Deviation of screw entry point(mm)		Screw located in the safe corridor	
						S1	S2	S1	S2	S1	S2
P1	90	100	9	11	Excellent	0	0	2.54	0.50	Yes	Yes
P2	80	100	12	12	Excellent	0	0	2.1	1.61	Yes	Yes
P3	110	150	11	15	Good	0	0	1.9	1.28	Yes	Yes
P4	90	120	10	10	Excellent	0	0	1.78	2.57	Yes	Yes
P5	80	80	8	10	Excellent	0	0	1.10	0.77	Yes	Yes
P6	60	100	9	12	Excellent	0	0	1.97	1.81	Yes	Yes
P7	90	80	9	10	Excellent	0	0	1.86	0.6	Yes	Yes
P8	110	150	12	14	Good	1	0	2.15	1.32	Yes	Yes
P9	80	100	10	10	Excellent	0	0	2.2	1.91	Yes	Yes
P10	90	120	11	11	Excellent	0	0	1.56	1.05	Yes	Yes
Mean	88	110	10.1	11.5				1.95	1.34		
SD	14.76	24.94	1.37	1.78				0.39	0.65		
Min	80	80	8	10				1.1	0.5		
Max	110	150	12	15				2.54	2.57		

Discussion

Anatomical conditions of the transverse sacroiliac screw

Transversal sacroiliac screw placement is often well planned because not all patients are able to accommodate one. Some investigators had previously evaluated and analysed the shape of the sacrum and the parameters of the cancellous corridor for the placement of transverse sacroiliac screws. Thomas et al [8] proposed that the transverse corridor of S1 could accommodate an average of 3.7 screws of 7.3 mm in diameter. Radetzki F [21] found that 20% of pelvises could not allow the implantation of 7.3 mm transverse screws in S1, and 40% of pelvises could not allow the implantation of 7.3 mm transverse screws in S3. Mendel T [22] concluded that 18% of pelvises could not allow the implantation of 7.3 mm transverse screws in S1. However, these parameters are primarily anatomical and are rarely applied in surgery. In our study, we performed anatomic analysis of the pelvises of normal adults in southwestern China, converting the pelvis into a 3D visualization model to better demonstrate the shape and location of the transverse sacroiliac screw cancellous corridor. We measured the long axis and short axis of the cancellous corridor and found that 69 (77%) pelvises could accommodate screws with diameters of 7.3 mm in S1, and all pelvises could accommodate screws with diameters of 7.3 mm in S2. Furthermore, the diameter of the corridors in both S1 and S2 showed a significant difference between sexes. In addition, the location of the optimal entry point in the cancellous corridor was found. From the standard lateral perspective of the sacrum, the optimal entry point of the transverse screw was in the first 1/3 of the cancellous corridor for S1 and the centre of the cancellous corridor for S2.

Advantages of 3D-printed Guiding Template

Although screw placement safety has greatly improved with the introduction of various navigation devices, some screws still break through the cortex. According to Jörn Zwingmann[23], the nail-setting cortex has a breakthrough rate of 30.77% under computer navigation. According to Zwingmann J[24], under computer navigation, 19% of screws break through the cortex. The breakthrough rate of conventional nailing is as high as 50%[23–25]. Under 3D fluoroscopy navigation, the placement of screws has a 50% cortical breakthrough rate [26]. Liu Y et al[27] used a 3D-printed navigation template to assist with the placement of sacroiliac screws, and the operation time and X-ray exposure were significantly reduced compared to percutaneous sacroiliac screws.

In recent years, there have been an increasing number of reports on 3D-printed navigation template-assisted screw placement, but there are few reports on 3D-printed locked navigation template-assisted transverse sacroiliac screw placement. Most of the 3D-printed navigation templates have been reported to be integrated structures, with no significant advantage in reducing intraoperative blood loss [27]. The 3D-printed navigation template in this study was designed in split form and locked as a whole through a threaded structure. During the operation, the base and guide pipe are placed separately, which can not only significantly reduce the size of the incision and blood loss but also effectively avoid the imprecision of screw placement caused by skin tension. In this study, the average deviation of the screw entry point was less than 2 mm and was within the mean of the short axis, and 100% of the screws were safely located within the cancellous corridor. One screw touched cortical bone, but the patient showed no nerve injury symptoms.

Surgical tips

First, the soft tissue under the incision needs to be completely removed to ensure that the navigation template base can tightly attach to the bone. Second, the entry points of transversal sacroiliac screws should be marked on the body surface under fluoroscopy before the operation to reduce skin and muscle tension. Third, the base of the navigation template should be wrapped around the posterior superior iliac spine to prevent movement. Fourth, the guide pipes should be designed with a conical thread structure, which is conducive to assembly with the base during the operation. Last, together with the S1 and S2 screws, the stability of the pelvic ring can be maintained.

Limitation

Some limitations of this study should be noted. First, although the screws were placed in the cancellous corridor in this study, there was still a deviation between the actual screw entry point and the simulated screw entry point. We will correct the navigation template in future studies to improve the accuracy of screw placement. Second, one patient's S1 transverse screw destroyed the bone cortex, and the cause will be further tracked in a later study. Finally, only 10 patients were recruited in this study; the sample size will be expanded in a later study to further verify the safety and accuracy of 3D-printed navigation template-assisted placement of transverse sacroiliac screws.

Conclusion

This study demonstrates that approximately two-thirds of individuals can accommodate screws with diameters of 7.3 mm in S1 and that all individuals can accommodate the same screw in S2. Prior to placing transverse sacroiliac screws, accurate CT scan analysis of the sacrum must be performed in each patient. Transverse sacroiliac screw insertion with patient-specific locked navigation template assistance is clinically feasible and results in little trauma and fluoroscopy radiation and secure screw placement.

Abbreviations

TSS: transverse sacroiliac screw

SI: Sacroiliac joint

Declarations

Ethics approval and consent to participate

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.

Consent for publication

I certify that this manuscript is a unique submission and is not being considered for publication, in part or in full, with any other source in any medium.

Availability of data and materials

The device(s) is/are FDA-approved or approved by corresponding national agency for this indication. The patients' data was authorized to our research.

Competing interests

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript. There is no conflict of interest between authors.

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Authors' contributions

Chao Wu was responsible for experimental design, writting and review, Jiayan Deng for data analysis and paper writing, Jian Pan for data preprocessing, Tao Li and Lun Tan for clinical trials.

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References

[1] Zhang R , Yin Y , Li S , et al. Percutaneous sacroiliac screw, versus, anterior plating for sacroiliac joint disruption: A retrospective cohort study[J]. Int J Surg, 2018, 50:11-16.

[2] Lee P Y , Lai J Y , Hu Y S , et al. Virtual 3d planning of pelvic fracture reduction and implant placement[J]. Biomedical Engineering: Applications, Basis and Communications, 2012, 24(03):245-262.

[3] Matta JM , Saucedo T. Internal Fixation of Pelvic Ring Fractures. Clin Orthop Related R. 1989, 242: 83-97.

[4] Mendel T , Noser H , Wohlrab D , et al. The lateral sacral triangle—A decision support for secure transverse sacroiliac screw insertion[J]. Injury, 2011, 42(10):1164-1170.

[5] K?Nig M A , Sundaram R O , Saville P , et al. Anatomical considerations for percutaneous trans ilio-sacroiliac S1 and S2 screw placement[J]. Eur Spine J, 2016, 25(6):1800-1805.

[6] Percutaneous screw fixation of the iliosacral joint: Optimal screw pathways are frequently not completely intraosseous[J]. Injury, 2015,46(10):S0020138315004106.

[7] Mendel T , Noser H , Kuervers J , et al. The influence of sacral morphology on the existence of secure S1 and S2 transverse bone corridors for iliosacroiliac screw fixation[J]. Injury, 2013, 44(12):1773-1779.

[8] Thomas, Mendel, and, et al. CT-based 3-D visualisation of secure bone corridors and optimal trajectories for sacroiliac screws[J]. Injury, 2013, 44(7):957-963.

[9] Radetzki F , Wohlrab D , Goehre F , et al. Anatomical conditions of the posterior pelvic ring regarding bisegmental transverse iliosacroiliac screw fixation: a 3D morphometric study of 125 pelvic CT datasets[J]. Arch Orthop Traum Su, 2014, 134(8):1115-1120.

[10] Ziran B H , Wasan A D , Marks D M , et al. Fluoroscopic Imaging Guides of the Posterior Pelvis Pertaining to Iliosacral Screw Placement[J]. The Journal of Trauma: Injury, Infection, and Critical Care, 2007, 62(2):347-356.

[11] Sagi, H. C, Lindvall, E. M. Inadvertent Intraforaminal Iliosacral Screw Placement Despite Apparent Appropriate Positioning on Intraoperative Fluoroscopy[J]. J Orthop Trauma,2005, 19(2):130-133.

[12] Van d B E W , Van Zwienen C M A , Van Vugt A B . Fluoroscopic Positioning of Sacroiliac Screws in 88 Patients[J]. The Journal of Trauma: Injury, Infection, and Critical Care, 2002, 53(1):44-48.

[13] Jörn Zwingmann, Konrad G , Kotter E , et al. Computer-navigated Iliosacral Screw Insertion Reduces Malposition Rate and Radiation Exposure[J]. Clin Orthop Relat R, 2009, 467(7):p.1833-1838.

[14] Zwingmann J , Konrad G , Mehlhorn A T , et al. Percutaneous Iliosacral Screw Insertion: Malpositioning and Revision Rate of Screws With Regards to Application Technique (Navigated Vs. Conventional)[J]. The Journal of Trauma: Injury, Infection, and Critical Care, 2010, 69(6):1501-1506.

[15] Thakkar, Savyasachi C, Thakkar, Rashmi S, Sirisreetreerux, Norachart, et al. 2D versus 3D fluoroscopy-based navigation in posterior pelvic fixation: review of the literature on current technology[J]. Int J Comput Ass Rad, 2017,12(1):69-76.

[16] Tsukushi S , Katagiri H , Nakashima H , et al. Computed tomography-guided screw fixation of a sacroiliac joint dislocation fracture: a case report[J]. J Orthop Sci, 2003, 8(5):729-732.

[17] Matityahu, Amir, Kahler, David, Krettek, Christian,. Three-Dimensional Navigation Is More Accurate than Two-Dimensional Navigation or Conventional Fluoroscopy for Percutaneous Sacroiliac Screw Fixation in the Dysmorphic Sacrum[J]. J Orthop Trauma, 2014,28(42):707-710.

[18] Schep NWL , Haverlag R , Van Vugt AB. Computer-Assisted versus Conventional Surgery for Insertion of 96 Cannulated IS Screws in Patients with Postpartum Pelvic Pain. J Trauma Acute Care. 2004, 57: 1299-1302.

[19] Matta JM , Saucedo T. Internal Fixation of Pelvic Ring Fractures. Clin Orthop Related R. 1989, 242: 83-97.

[20] Takao M , Nishii T , Sakai T , et al. Iliosacral screw insertion using CT-3D-fluoroscopy matching navigation[J]. Injury, 2014, 45(6):988-994.

[21] Radetzki F , Wohlrab D , Goehre F , et al. Anatomical conditions of the posterior pelvic ring regarding bisegmental transverse sacroiliac screw fixation: a 3D morphometric study of 125 pelvic CT datasets[J]. Arch Orthop Traum Su , 2014, 134(8):1115-1120.

[22] Mendel T , Noser H , Wohlrab D , et al. The lateral sacral triangle—A decision support for secure transverse sacroiliac screw insertion[J]. Injury, 2011, 42(10):1164-1170.

[23] Jörn Zwingmann, Konrad G , Kotter E , et al. Computer-navigated Iliosacral Screw Insertion Reduces Malposition Rate and Radiation Exposure[J]. Clin Orthop Related R, 2009, 467(7):p.1833-1838.

[24] Zwingmann J , Konrad G , Mehlhorn A T , et al. Percutaneous Iliosacral Screw Insertion: Malpositioning and Revision Rate of Screws With Regards to Application Technique (Navigated Vs. Conventional)[J]. The Journal of Trauma: Injury, Infection, and Critical Care, 2010, 69(6):1501-1506.

[25] Richter P H , Gebhard F , Dehner C , et al. Accuracy of computer-assisted iliosacral screw placement using a hybrid operating room[J]. Injury, 2016, 47(2):402-407.

[26] Takao M , Nishii T , Sakai T , et al. CT-3D-Fluoroscopy Matching Navigation Can Reduce the Malposition Rate of Iliosacral Screw Insertion for Less-Experienced Surgeons[J]. J Orthop Trauma, 2013, 27(12):716-721.

[27] Liu Y , Zhou W , Xia T , et al. Application of the Guiding Template Designed by Three-dimensional Printing Data for the Insertion of Sacroiliac Screws: a New Clinical Technique[J]. Curr Med Sci, 2018.

Figures

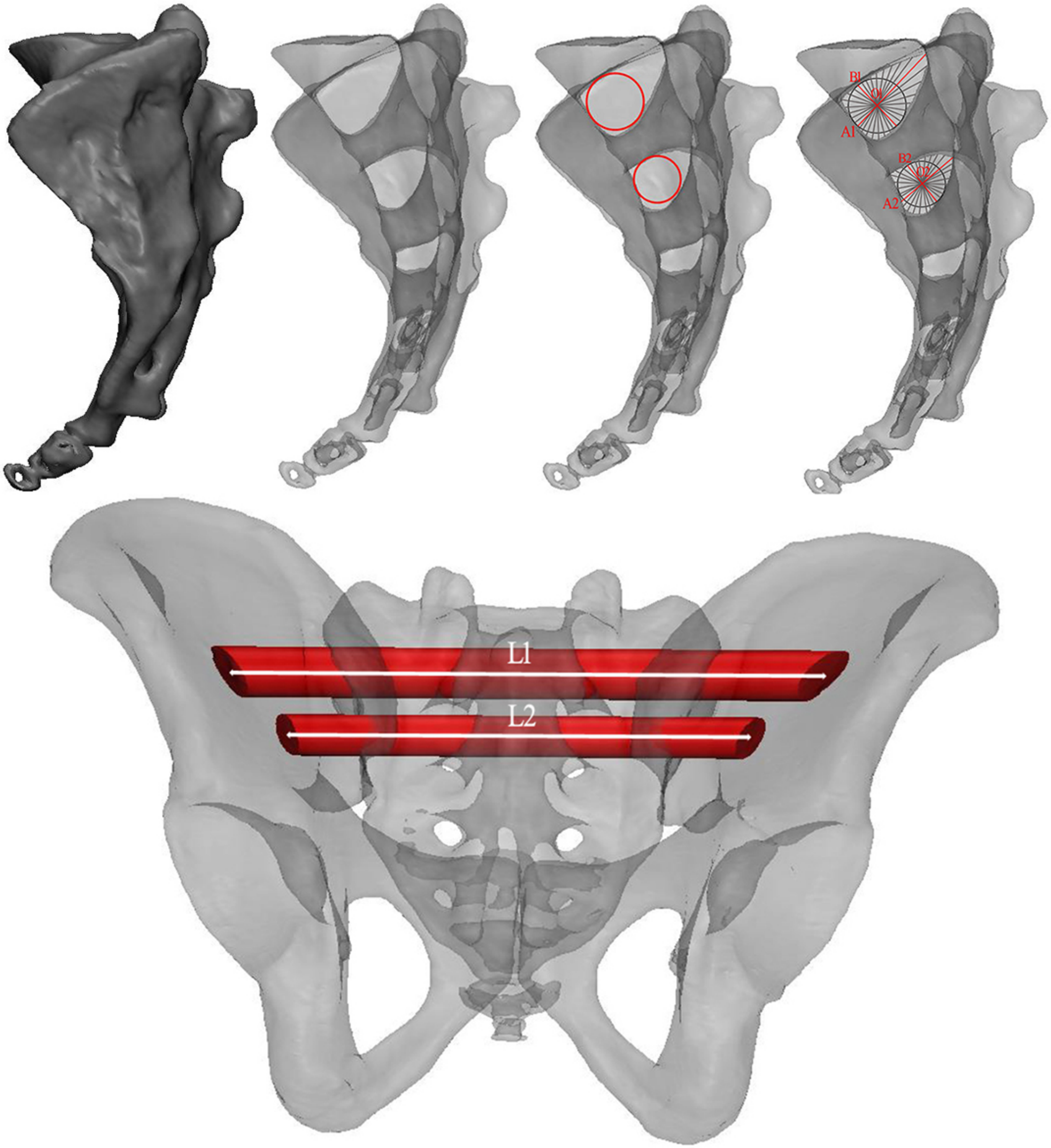

Figure 1

The CT threshold of bone was measured, the sacral cortex was extracted, and a 3D model of the sacrum was constructed (Fig 1a). In the transparent view (Fig 1b), the maximum inscribed circle of the cancellous corridor was marked (Fig 1c). Drawing lines through the centre of the circle, the longest line was considered the long axis of the corridor (A), and the shortest line was regarded as the short axis of the corridor (B) of the cancellous corridor (Fig 1d). The centre of the maximum inner circle (O) is considered the optimal screw entry point, and the proportional position of the optimal entry point on the long axis of the corridor was calculated (Fig 1d). The total corridor length (L1 and L2) was the distance from the centre of the maximum inscribed circle to the projection point on the left pelvic surface and to the projection point on the right (Fig 1e).

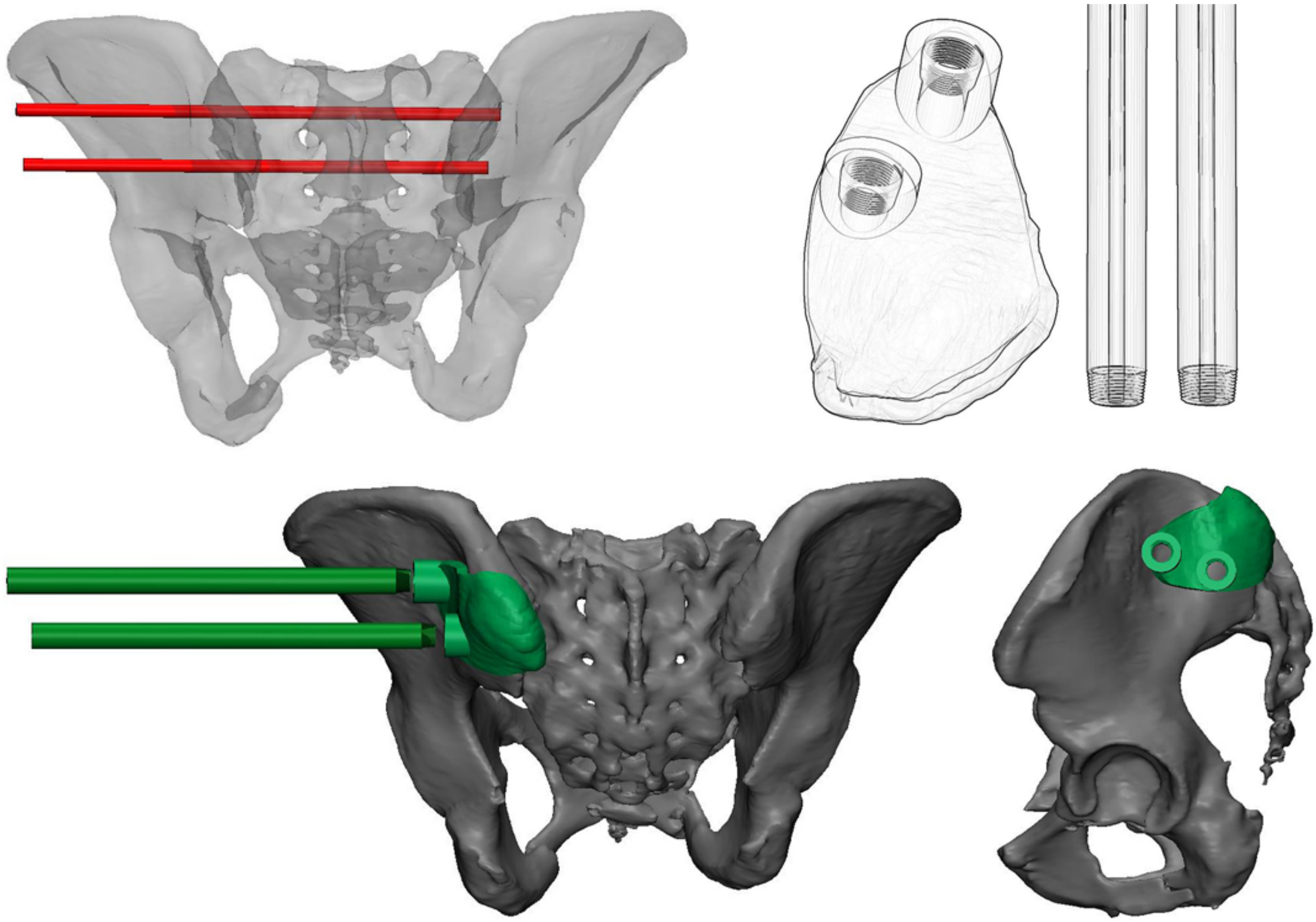

Figure 2

The virtual screw was inserted from the optimal screw entry point and then passed along the optimal screw corridor to complete the simulated screw placement (Fig 2a). The pelvis and virtual screws were imported into 3-matic 13.0 (Materialise, Leuven, Belgium). The guide pipe and locked template were designed according to the direction of the virtual screw (Fig 2b), and the inside of the guide pipe was designed with a diameter of 2.6 mm for passing the 2.5 mm K-wires. The base of the locked navigation template was designed according to the shape of the pelvic surface where the virtual screw on (Fig 2c) and designed with a 9 mm diameter pipe for passing screws (Fig 2d).

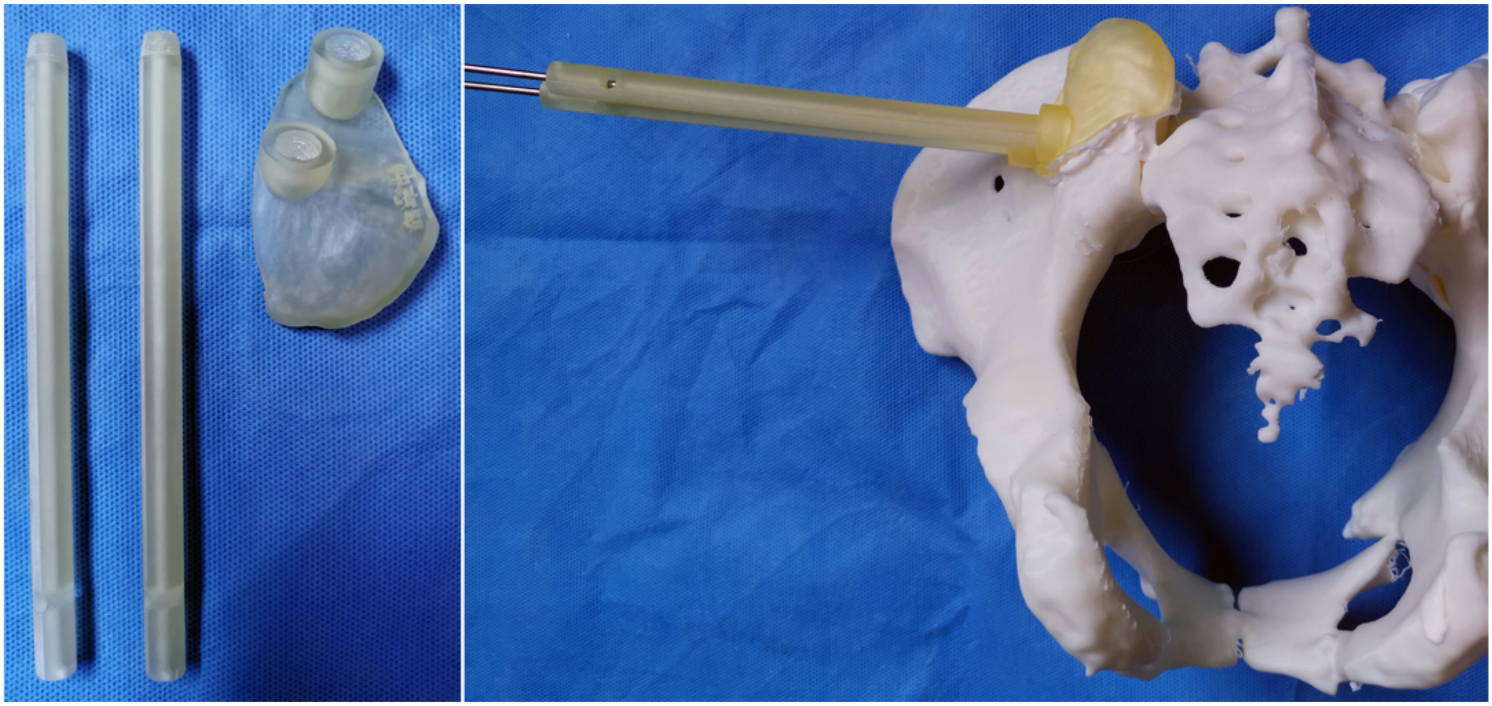

Figure 3

The posterior superior iliac spine and the transverse sacroiliac screw insertion points were located on the body surface (Fig 3a). The incision of the posterior superior iliac spine was performed according to the size of the navigation template base, and soft tissue was stripped from the bones. The template base was inserted through the incision and completely attached to the corresponding anatomical positions on the posterior superior iliac spine (Fig 3b). Second, a small incision was made at the location of the transverse sacroiliac screw entry points, through which the threaded guide pipes were inserted and screwed onto the base (Fig 3c). Third, 2 K-wires with a 2.5 cm diameter were implanted into the sacrum through the guide pipes. Fluoroscopy of the pelvic inlet and outlet and the lateral sacrum were performed to confirm the position of the K-wires (Fig 3d). Then, the guide pipes were removed, and a hollow screw with a 7.3 mm diameter was screwed into the sacrum along the K-wires through the iliac bone (Fig 3e). Fifth, fluoroscopy was performed again to confirm the screw positions. Finally, the K-wires and template base were removed (Fig 3f, g).

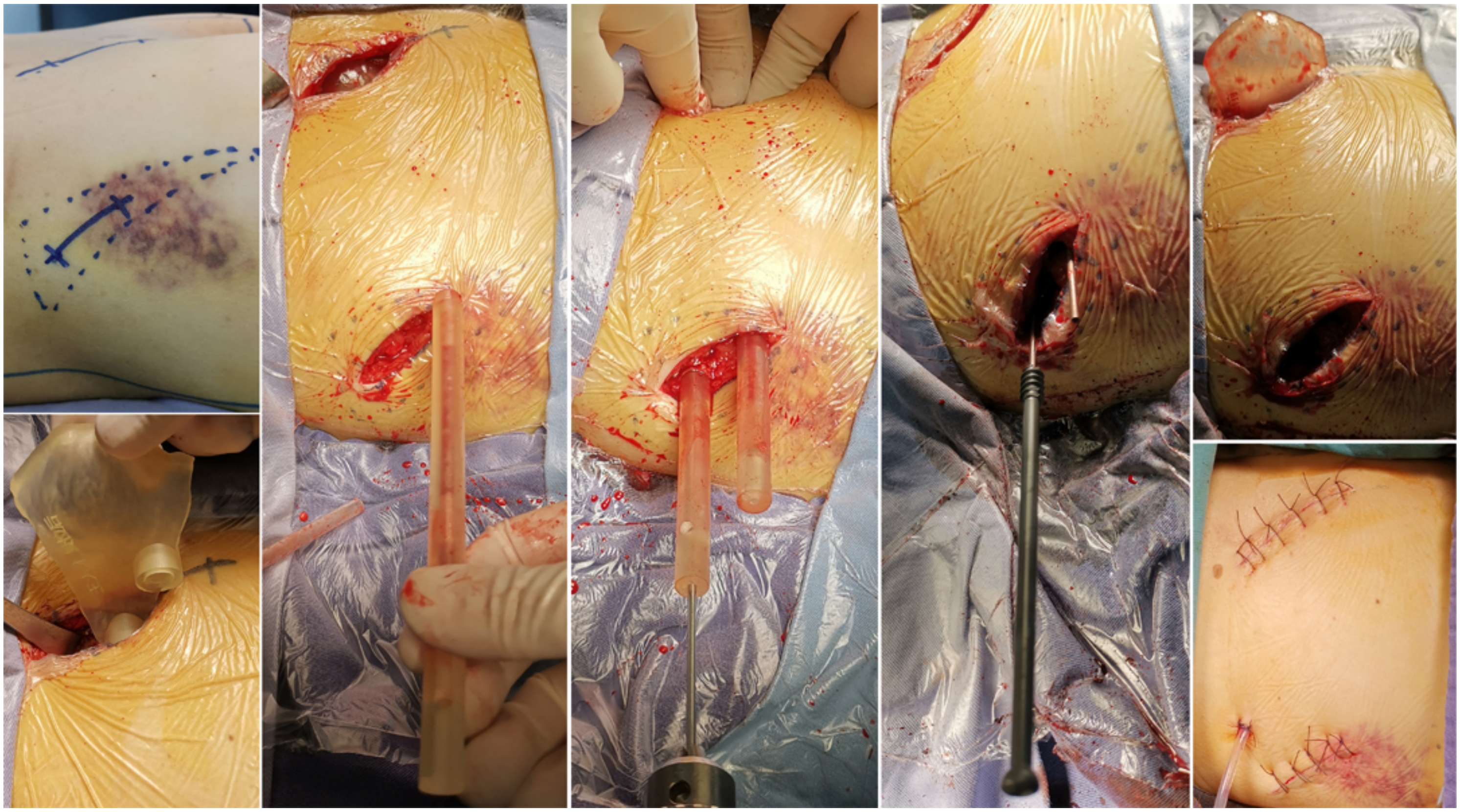

Figure 4

Surgery technique.

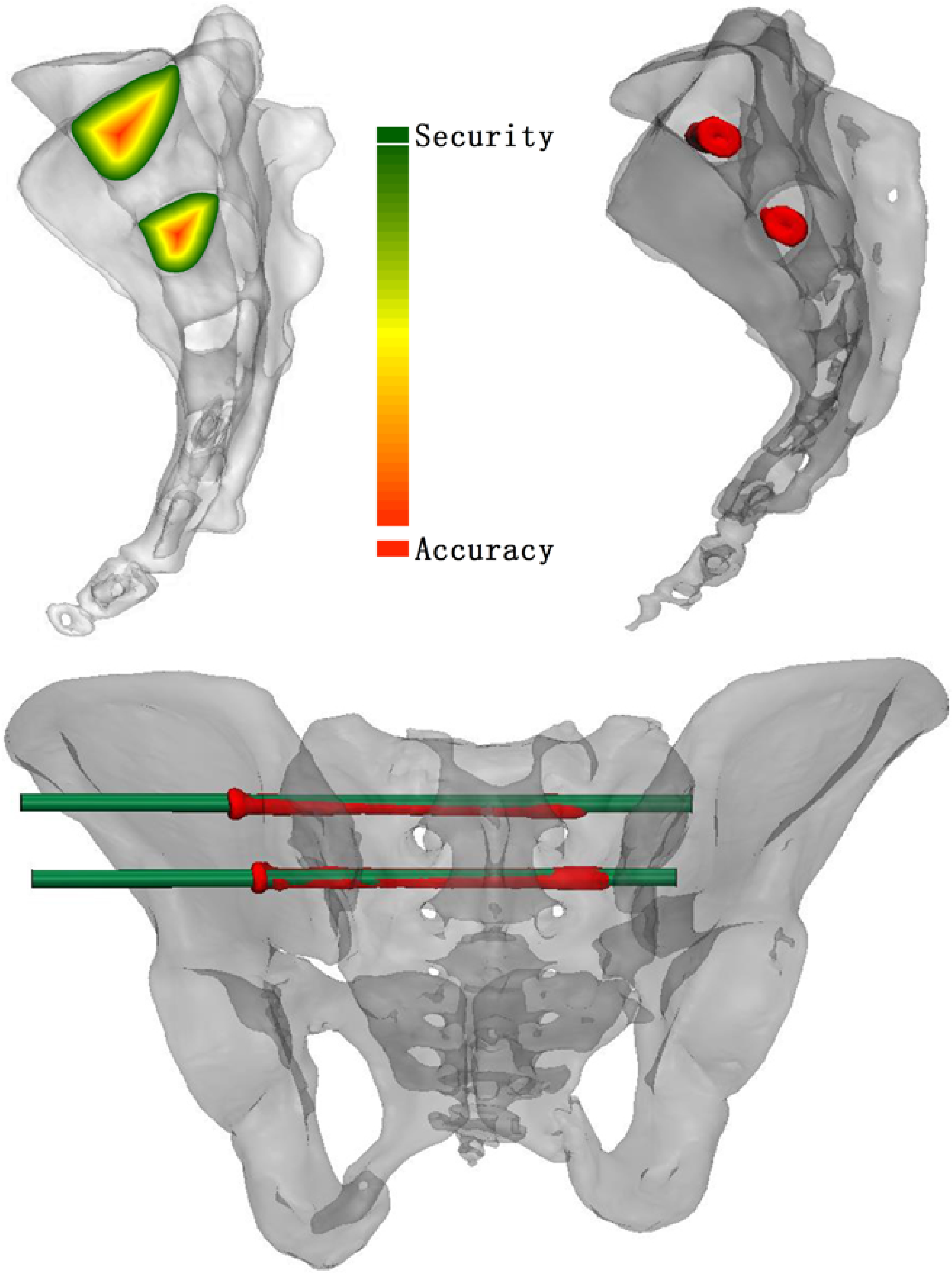

Figure 5

The distance between the actual and planned screws at the point of entrance was measured based on the 3D model [20] (Fig 5b). On the sagittal view of the sacrum (Fig 5c), the screw was evaluated if it was completely located within the cancellous corridor.

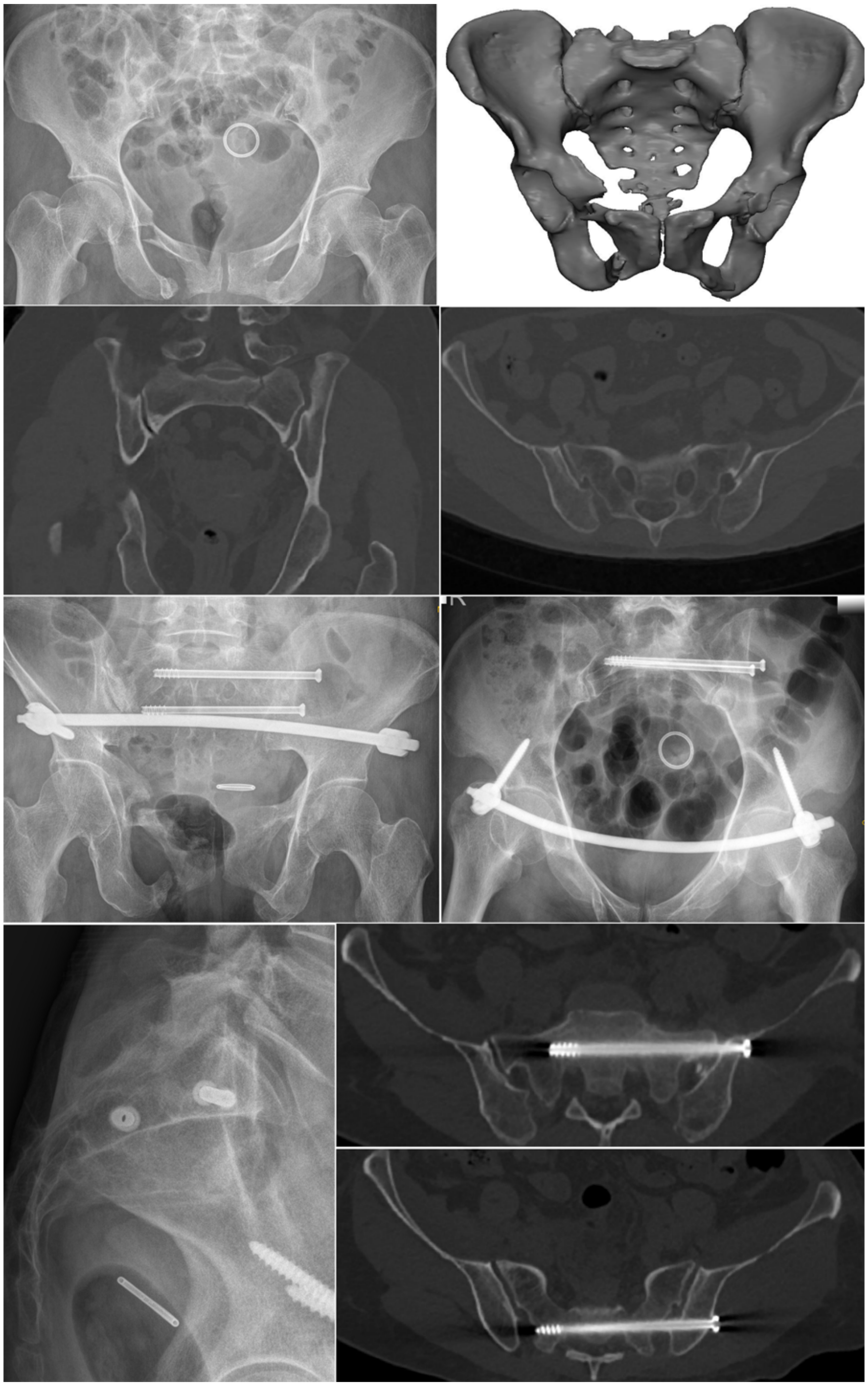

Figure 6

All screw entry point deviations were shorter than the short axis of the cancellous corridor, and all screws were located within the cancellous corridor