Infra-Acetabular Screw Exited Between Ischial Tuberosity and Ischial Spine is more Suitable for Asian Population: A 3D Morphometric Study

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Research article

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Abstract

Background Recently, the infra-acetabular screw was proposed for acetabular fractures as a part of a periacetabular fixation frame. Biomechanical studies showed that an additional infra-acetabular screw placement can enhance the fixation strength of acetabular fracture internal fixation. At present, the reported exit point of the infra-acetabular screw was all located at the ischial tuberosity. However, through great experience in placing the infra-acetabular screw, we realized that when the exit point was located between the ischial tuberosity and the ischial spine, the placement of a 3.5 mm infra-acetabular screw is easier in some patients.

Methods This study used axial perspective based on 3D models to study the anatomical parameters of the two different infra-acetabular screw corridors. Placed the largest diameter virtual screw in the two different screw corridors. The data obtained in this study present the maximum diameters, length, directions, and distances between the entry point and the center of IPE.

Results In 65.31% males and 40.54% females, a Screw I corridor with a diameter of at least 5 mm was found, while in Screw II it was 77.55% in males and 62.16% in females. Compared with screw I, the length of screw II is reduced, the angle with the coronal plane is significantly reduced, and the angle with the transverse plane is significantly increased.

Conclusions For East Asians, changing the exit point of the infra-acetabular screw can increase the scope of use of the infra-acetabular screw, especially for females.

Background

Acetabular anatomy is complex and surrounded by important tissues and organs. Acetabular fracture surgery has been the most complicated and challenging surgery in the field of traumatic orthopedics because of the difficulty of exposure and massive bleeding during the operation. Furthermore, patients of acetabular fracture also face a series of complications such as traumatic arthritis, heterotopic ossification, thromboembolism, and so on. Anatomical reduction and strong internal fixation can reduce the incidence of acetabular fracture complications and improve the clinical prognosis of the patients [1, 2].

In 2010, Culemann et al. [3] proposed that an additional infra-acetabular screw can close the incomplete periacetabular fixation “frame”, consisting of both osseous columns, the ilioinguinal plate, and supra-acetabular screws fixation. Meanwhile, they developed the indications for infra-acetabular screw fixation, including all fracture patterns addressed via an ilioinguinal approach and involving a fracture line descending along the fovea acetabuli and reaching the foramen obturatorium, resulting in a separation of both columns. The acetabular fracture types involved are anterior column fracture, anterior column and posterior hemitransverse fracture, T-type fracture, and both column fracture. Marintschev et al. [4] found in a biomechanical study that the locking plate modality did not reduce the maximum fracture displacement, but the additional infra-acetabular screw placement doubles the fracture fixation strength independent of the used plate system. Marintsche, Gras et al. [5] used the same fracture pattern for a biomechanical study, in which three groups of different screws (group II, titanium; group III, stainless steel; and group IV, biodegradable Poly-L-Lactid) were compared with the standard plate fixation (group I). The results demonstrated that screw fixation is a promising alternative approach for the stabilization of noncomminuted acetabular fractures of the anterior column with equivalent fixation strength to the standard plate fixation, and the additional placement of an infra-acetabular screw significantly increases the fracture fixation independent of the used implant. Clinical applications showed that the infra-acetabular screw can get a good prognosis lead to a high rate of fine reduction, limited complications, a low displacement risk, and good clinical efficacy [6, 7].

Even with good biomechanical performance and clinical outcome, the placement of the infra-acetabular screw is difficult, for the infra-acetabular screw corridor is irregular and narrow. It has been reported that placement of a 3.5 mm infra-acetabular screw in some patients is impossible [8]. Therefore, to provide references for the successful placement of the infra-acetabular screw, many scholars have studied the diameter, length, entry point, spatial position and spatial shape of IAC. Gras et al. [8] presented a mean-shape analysis of 523 healthy pelves and found the existence of an IAC with a minimum corridor diameter of 5 mm in 93% by a biomorphometric CT-based analysis. Arlt et al. [9] demonstrated that the IAC consistently showed a double-cone shape with the isthmus located at the acetabular fovea by a 3D radiomorphometric analysis. What’s more, they found that congenital hip dysplasia does not affect secure infra-acetabular screw insertion. Baumann et al. [10] found the entry point of an ideal infra-acetabular was of high constancy, with an average distance of 10.2 mm caudally and 10.4 mm medially to the IPE, which provided a guideline for placement of an infra-acetabular screw via an intra-pelvic approach. The findings of these scholars could help surgeons safely place an infra-acetabular screw. However, the specimens of these studies were all Westerners and the results of which may not be suitable for Asians. At present, the exit point of the infra-acetabular screw reported was all located at the ischial tuberosity [6, 8–11].

As a trauma center in southern China, we have great experience in placing the infra-acetabular screw. We realized that when the exit point was located between the ischial tuberosity and the ischial spine, the placement of a 3.5 mm infra-acetabular screw is possible and easier in some patients. This provides an alternative for the infra-acetabular screw placement, besides the traditional ischial tuberosity exited infra-acetabular screw. However, data describing the new infra-acetabular screw corridor are lacking. Therefore, this study aims to explore the anatomy differences of the two infra-acetabular screw corridors. We hypothesized that the infra-acetabular screw corridor with an exit point located between the ischial tuberosity and the ischial spine has a larger maximum diameter than the traditional ischial tuberosity exited corridor.

In recent years, the application of computer-aided technology has enabled the rapid development of digital orthopedics. Bio-morphological study of screw corridors around the acetabulum can be performed easily and quickly by computer-aided techniques [12–14]. Our team has proposed the use of "axial perspective" to study the largest anterior and posterior column screw corridors of the acetabulum[13, 15]. Therefore, in this study, “axial perspective” was also used to study the anatomical parameters of the two different infra-acetabular screw corridors.

Methods

1. Data collection

All of the procedures were done in accordance with the declaration of Helsinki and relevant policies in China. 86 human subjects admitted to our institution without pelvic and acetabular injury or lesions were recruited in this study (Table 1). All human subjects underwent a sixteen-line pelvic helical computed tomography scan (GE, US) with 1.0-mm slices at 0.1-s intervals for imaging of the acetabulum. Pelvic CT scans without pelvic tumor, or deformity, were included. The raw data obtained were stored in Dicom format.

Table 1
Characteristics of pelvis specimens

Variable	Pelves	Females	Males	Significance
Number in overall data set	86	37	49	
Mean age [95% CI] (years)	49.90[3.42]	47.08[5.17]	52.02[4.63]	NS
Range of age (years)	19–86	20–73	19–86	
Mean body height [95% CI] (cm)	163.15[1.48]	158.24[1.61]	166.85[1.68]	P < 0.001
Range of body height (mm)	146–178	146–173	150–178	
Mean body weight [95% CI] (kg)	58.15[2.18]	53.01[2.63]	62.03[2.89]	P < 0.001
Range of body weight (kg)	39-82.5	39–72	41-82.5	
CI = confidence interval; NS = not significant.				

2. Model reconstruction

The raw data sets were reconstructed into 3D models using the software MIMICS 17.0 (Materialise, Leuven, Belgium). The left hemi-pelvis was exported in STL format and then imported into the image-processing software Geomagic Studio 2013 (Geomagic, US). Next, the inner triangular patches which represented the contents of the marrow cavity were deleted to make the marrow cavity hollow in the 3D models. After processed in Geomagic Studio 2013, the images were exported in STL format and imported again into MIMICS where all simulations and measurements were carried out.

3. Largest screw path analysis

To distinguish the screw path in the 3D models from the same perspective, we downgraded the transparency of 3D models and turned the 3D models at the axial perspective of the infra-acetabular corridor, a view perpendicular to the cross-section of the two infra-acetabular corridor axis. As a result, a translucent area with a darker outline of each infra-acetabular corridor was seen clearly. The translucent area represented the marrow cavity of the infra-acetabular corridor and the outline showed the cortical bone (Fig. 1, Fig. 2).

First, we adjusted the positions of the 3D model in the axial perspective to find the likely largest triangle-like translucent area by visual observation. Then, a virtual CAD Screw I (2 mm in diameter) was placed perpendicular to the screen at the center of the translucent area. We adjusted the CAD Screw I diameter progressively to accurately determine the maximum implant diameter the triangle-like transparent area could accommodate. The maximum implant diameter was defined as the largest diameter of the screw that did not penetrate the outline of the translucent area (Fig. 1, Fig. 2). After the above steps were repeated in three likely largest triangle-like transparent areas by three observers, we obtained three accurate maximum implant diameters. A comparison was conducted to finalize the accurate maximum implant diameter of the screw the specific 3D model could accommodate. The maximum screw diameters, the caudal and medial distances of the entry point to the center of IPE, the directions of the screw to the transverse, coronal and sagittal planes were measured, respectively. The same procedure was applied to screw II.

4. Statistic analysis

All the experimental data (continuous variables) were presented as the mean and standard deviation (SD) or median and range. An independent sample t-test was used to compare the data between males and females. A paired sample t-test was used to compare the data between screw I and screw II. Linear regression was used to analyze the linear relationships between the two different infra-acetabular parameters and age, body height, and body weight. Statistical significance was accepted at $p < 0.05$. The SPSS statistical software package for Windows (version 19.0) was used for statistical analysis.

Results

In 65.31% males and 40.54% females, a Screw I corridor with a diameter of at least 5 mm was found. The mean maximum diameter and length of Screw I were 5.30 ± 1.25 mm (2.62–7.58 mm) and 94.57 ± 6.07 mm(78.99-105.91 mm), respectively. The caudal and medial distances of the entry point to the center of IPE of Screw I were 7.49 ± 4.68 mm(-6.72-21.43 mm) and 12.32 ± 3.12 mm(5.66–23.17 mm), respectively. The angles of Screw I to the transverse, coronal and sagittal planes were 36.48 ± 8.18°(15.95–54.38°), 52.77 ± 8.14°(35.50-72.52°), -0.49 ± 6.43°(-18.04-11.20°), respectively. All these differences except the coronal angle of the Screw I between males and females were of statistical significance ($p < 0.05$) (Table 2).

Table 2
Differences between males and females

Group	Diameter (mm)		Length(mm)		Anterior(mm)		Medial(mm)		Sagittal (°)		Coronal(°)		Transverse(°)	
	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII	SI	SII
Males	5.63 ± 1.23	6.02 ± 1.36	98.14 ± 4.24	81.05 ± 4.55	6.27 ± 4.11	20.55 ± 4.98	11.20 ± 2.70	11.26 ± 2.60	4.16 ± 2.79	3.86 ± 2.17	51.28 ± 6.61	76.04 ± 6.71	38.30 ± 6.48	12.78 ± 7.11
Females	4.85 ± 1.14	5.23 ± 1.32	89.84 ± 4.74	78.99 ± 4.11	9.12 ± 4.94	19.81 ± 5.05	13.79 ± 3.06	13.94 ± 3.26	-6.65 ± 4.32	-7.88 ± 5.05	54.74 ± 9.55	74.10 ± 7.76	34.08 ± 9.56	12.58 ± 8.01
t	3.039	2.702	8.551	2.176	2.920	0.679	4.154	4.235	13.290	13.260	1.888	1.242	2.313	0.122
p	0.003	0.008	0.000	0.032	0.004	0.499	0.000	0.000	0.000	0.000	0.064	0.218	0.024	0.903

In 77.55% males and 62.16% females, a screw II corridor with a diameter of at least 5 mm was found. The mean maximum diameter and length of Screw II were 5.68 ± 1.39 mm (2.56–8.26 mm) and 80.16 ± 4.46 mm(71.17–89.78 mm), respectively. The caudal and medial distance of the entry point to the center of IPE of Screw II were 20.24 ± 5.00 mm(9.67–32.35 mm) and 12.41 ± 3.18 mm (6.09–21.01 mm), respectively. The angles of Screw II to the transverse, coronal and sagittal planes were 12.69 ± 7.46°(0.03–34.19°), 75.20 ± 7.20°(51.33–88.98°), -1.19 ± 6.91°(-17.26-8.86°), respectively. The differences of diameter, length, medial distance and angles to the sagittal planes of the Screw II between males and females were of statistical significance ($p < 0.05$) (Table 2), but the differences of caudal distance, angles to the transverse and coronal planes of the Screw II between males and females were not of statistical significance ($p > 0.05$) (Table 2).

Both in males and females, the differences of diameter, length, anterior distance, angles to transverse and coronal planes between the Screw I and Screw II were of statistical significance ($p < 0.05$) (Table 2), but the differences of medial distance and angles to the sagittal plane between the Screw I and Screw II were not of statistical significance ($p > 0.05$) (Table 3).

Table 3
Differences between Screws I and Screw II

Group	Diameter (mm)		Length (mm)		Anterior (mm)		Medial (mm)		Sagittal(°)		Coronal(°)		Transverse(°)	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
SI	5.63 ± 1.23	4.85 ± 1.14	98.14 ± 4.24	89.84 ± 4.74	6.27 ± 4.11	9.12 ± 4.94	11.20 ± 2.70	13.79 ± 3.06	4.16 ± 2.79	-6.65 ± 4.32	51.28 ± 6.61	54.74 ± 9.55	38.30 ± 6.48	34.08 ± 9.56
SII	6.02 ± 1.36	5.23 ± 1.32	81.05 ± 4.55	78.99 ± 4.11	20.55 ± 4.98	19.81 ± 5.05	11.26 ± 2.60	13.94 ± 3.26	3.86 ± 2.17	-7.88 ± 5.05	76.04 ± 6.71	74.10 ± 7.76	12.78 ± 7.11	12.58 ± 8.01
t	5.128	4.316	35.447	18.808	21.312	15.860	0.211	0.304	0.776	1.968	23.597	23.353	23.831	20.819
p	0.000	0.000	0.000	0.000	0.000	0.000	0.834	0.763	0.442	0.057	0.000	0.000	0.000	0.000

SI = Screw I, SII = Screw II

Body height and body weight were strongly correlated only with the length of the two different infra-acetabular corridors in males (r□0.3; p□0.05) (Table 4, 5).

Table 4
Correlation analysis of anthropometric and parameters of Screw I

Parameter	**Age**		**Body height**		**Body weight**	
	r value	p value	r value	p value	r value	p value
Females						
Diameter	0.190	0.259	0.124	0.464	0.018	0.914
Length	0.311	0.061	0.240	0.152	0.275	0.099
Anterior	0.085	0.616	0.024	0.889	0.155	0.361
Medial	0.078	0.645	0.051	0.766	0.061	0.719
Sagittal	0.296	0.076	0.014	0.936	0.001	0.994
Coronal	0.088	0.605	0.110	0.517	0.126	0.457
Transverse	0.053	0.754	0.100	0.558	0.112	0.510
Males						
Diameter	0.034	0.819	0.115	0.431	0.089	0.542
Length	0.104	0.477	**0.647**	**5.15E-7**	**0.610**	**3.23E-6**
Anterior	0.272	0.058	0.217	0.135	0.137	0.346
Medial	0.066	0.650	0.170	0.244	0.085	0.561
Sagittal	0.233	0.108	0.112	0.444	0.058	0.694
Coronal	0.130	0.372	0.226	0.119	0.078	0.596
Transverse	0.121	0.406	0.227	0.116	0.077	0.599

Table 5
Correlation analysis of anthropometric and parameters of Screw II

Parameter	**Age**		**Body height**		**Body weight**	
	r value	p value	r value	p value	r value	p value
Females						
Diameter	0.218	0.194	0.067	0.692	0.007	0.965
Length	0.044	0.796	0.269	0.107	0.326	0.049
Anterior	0.066	0.696	0.079	0.644	0.155	0.360
Medial	0.076	0.654	0.251	0.133	0.041	0.809
Sagittal	0.383	0.019	0.180	0.286	0.030	0.860
Coronal	0.048	0.779	0.100	0.558	0.053	0.755
Transverse	0.101	0.551	0.135	0.425	0.024	0.888
Males						
Diameter	0.027	0.856	0.042	0.776	0.019	0.897
Length	0.274	0.057	**0.507**	**2.01E-4**	**0.467**	**0.001**
Anterior	0.124	0.395	0.073	0.620	0.009	0.949
Medial	0.193	0.185	0.028	0.848	0.044	0.766
Sagittal	0.004	0.977	0.078	0.594	0.014	0.924
Coronal	0.127	0.386	0.042	0.772	0.127	0.383
Transverse	0.111	0.448	0.038	0.795	0.144	0.322

Discussion

The value of the infra-acetabular screw is that it is an important part of the periacetabular fixation "frame". Marintsche and Gras et al. [4, 5] have demonstrated that an additional placement of this screw significantly increases the fixation strength of a standard plate fixation for anterior column fractures.

Gras et al. [8] have made a biomorphometric CT-based analysis about sex-specific differences of the infra-acetabular corridor. In this study, the exit point of the infra-acetabular screw was at ischial tuberosity, and the average diameter and length of the infra-acetabular were 7.4 mm (2.8–12.9 mm) and 103 mm (81–122 mm) respectively. Meanwhile, they found that 90% females and 94% males had an infra-acetabular corridor larger than 5 mm in diameter. The 5 mm diameter was chosen as a threshold in infra-acetabular corridor anatomical studies as a corridor with a diameter of at least 5 mm is defined as the threshold for placement of a 3.5 mm cortical screw in the clinical practice [8]. However, in our study, when the exit point of the infra-acetabular screw was at IPE, the average diameter and length of the infra-acetabular were 5.30 mm (2.62–7.58 mm) and 94.57 mm (78.99-105.91 mm) respectively. And only 40.54% females and 65.31% males had an infra-acetabular corridor with a diameter of at least 5 mm. The differences between these two studies may be caused by racial differences.

At present, in the studies of the infra-acetabular screw, the exit point of the screw was all located in the ischial tuberosity. However, our study found that when the exit point of the screw was located between the ischial tuberosity and the ischial spine, there is also an infra-acetabular screw corridor. According to our results, a screw II corridor with a diameter of at least 5 mm was found in 77.55% males and 62.16% females, which increased by 12.24% and 21.62% respectively compared with Screw I corridor. Most of the Screw II corridor diameters increased compared with Screw I, with an average increase of 7.20%. The significance of the Screw II corridor is to increase the proportion of infra-acetabular screw corridor exceeding 5 mm in the Eastern population, which enables the placement of a 3.5 mm screw in some patients with a small screw I corridor, especially in the female patient. Meanwhile, all of the Screw II corridor lengths were shortened, with an average shortening of 15.24%. Length shortening can greatly reduce the difficulty of inserting a long screw in a narrow corridor. In males, the two different infra-acetabular corridors were parallel to the sagittal plane, while the angles to the sagittal plane of the two corridors of females were larger than that of the males, and the directions were from the medial side to the lateral side. Compared with the Screw I, the entry point of Screw II is farther away caudally from the center of IPE.

Due to the narrower corridor of the infra-acetabular screw in the Asian population, some patients are not suitable for the use of infra-acetabular screws. So we recommend that each patient intended to insert an infra-acetabular screw should have a CT scan and use the digital orthopedic software to perform a preoperative virtual placement of the infra-acetabular screw before surgery. In this way, a personalized surgical plan could be developed for the patient to improve the safety of the operation. What's more, intraoperative navigation and 3D printing technology have been used to help place periacetabular screws [11, 16–18], which may also be used to help successfully place an infra-acetabular screw.

Conclusion

Our study provided surgeons with anatomical parameters of two different infra-acetabular screw corridors in the Eastern population. Compared with the study of Gras et al, the proportion of Screw I with a diameter of at least 5 mm was greatly reduced, but Screw II could reduce this gap. This may provide an alternative acetabular infra-acetabular screw placement corridor for the surgeon.

Abbreviations

IAC
infra-acetabular screw corridor; CT:computed tomography; 3D:three-dimensional reconstruction; IPE:ilio-pubic / ilio-pectineal eminence; Mimics:Materialise's Interactive Medical Image Control System; CAD:computer-aided design; Screw I:infra-acetabular whose exit point is located at the ischial tuberosity; Screw II:infra-acetabular whose exit point is located between the ischial tuberosity and the ischial spine; SPSS:Statistical Product and Service Solutions.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the ethics review board of Nanfang Hospital, Southern Medical University. We obtained verbal consent of all human subjects before collecting data of this study.

Consent for publication

Not applicable.

Availability of data and materials

All the data used in this article was collected from raw CT data of 86 human subjects. The dataset in this study are available from the corresponding author on reasonable request.

Competing interests

The authors have no competing interest to declare.

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Authors’ contributions

BC was responsible for the design of the study. FL and XRF were responsible for obtaining anatomical data of the two different IAC and writing the manuscript. KYC, YHD, and JXL collected the data of the characteristics of pelvis specimens. YX and JX performed the statistical analyses. All authors have been actively involved in the critical revision of the manuscript. All authors had read and approved the final manuscript.

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Figures

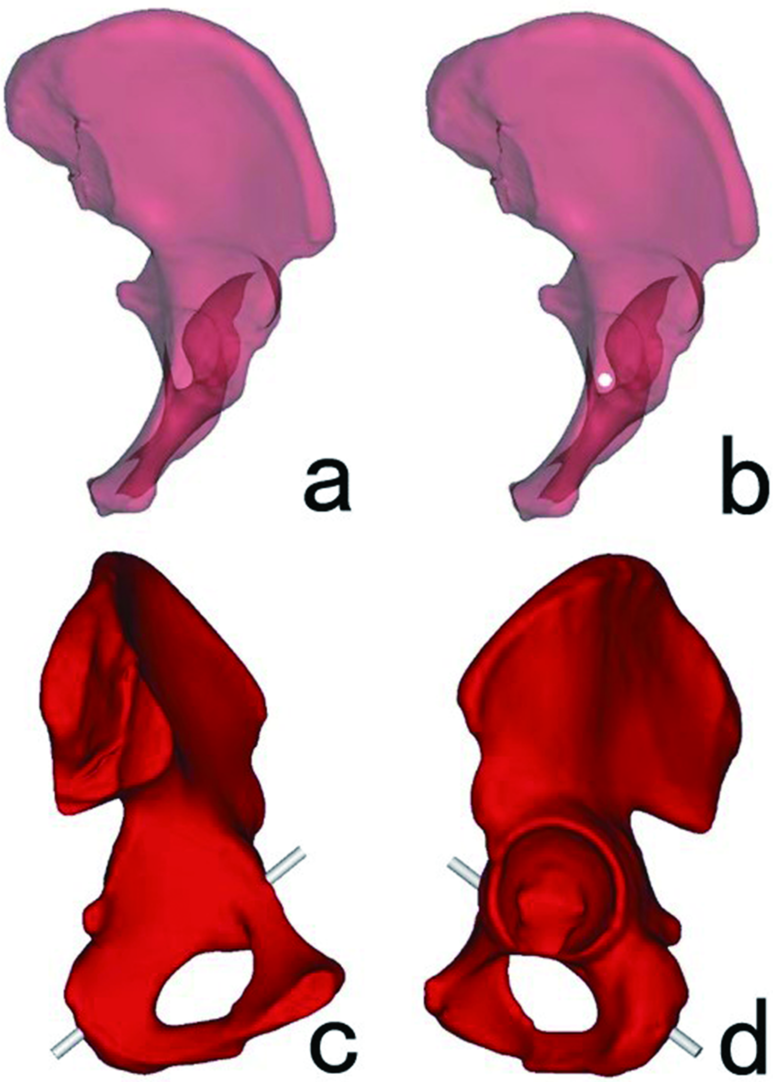

Figure 1

Placement of Screw I. (a) The 3D model was adjusted to find the largest ellipse-like translucent area. (b) A virtual screw was placed in the translucent area. (c, d) The position of Screw I was verified in the opaque 3D model.

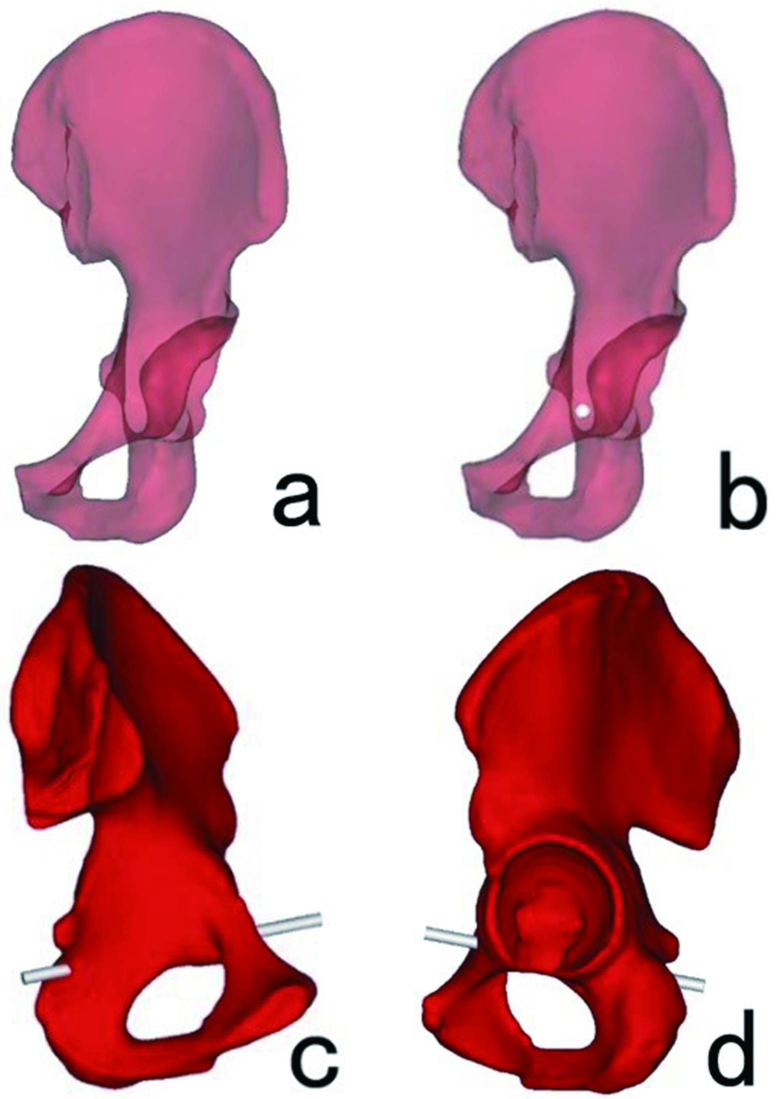

Figure 2

Placement of Screw II. (a) The 3D model was adjusted to find the largest ellipse-like translucent area. (b) A virtual screw was placed in the translucent area. (c, d)The position of Screw II was verified in the opaque 3D model.