3D printing navigation template used in total hip arthroplasty for developmental dysplasia of the hip

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Research article

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Abstract

Background: It is difficult to locate the real acetabulum in the total hip arthroplasty (THA) for developmental dysplasia of the hip (DDH), The goal of this study was to explore the application of 3D printing navigation template used in total hip arthroplasty (THA) for developmental dysplasia of the hip.

Methods: Between February 2017 and May 2018, THAs were performed in 25 patients with DDH, all patients (12 cases undergoing THA with 3D printing navigation template, 13 cases undergoing traditional THA) were followed-up for an average of 14.6 months. Surgical information and outcomes treated with different approaches were compared.

Results: The 3D printing group provided shorter operation time, lower intra- and post-operative hemorrhage and higher post-operative Harris scores. postoperative infection and prosthetic loosening were 0 in two groups. There were no significant differences in anteversion angle, abduction angle and the distance from rotation center to the ischial tuberosity connection between ipsilateral and contralateral sides in 3D printing group. The abduction angle and the distance from rotation center to the ischial tuberosity connection were significantly different between the two sides in the traditional group.

Conclusion: The finding suggests that 3D printing navigation template used in total hip arthroplasty is an individualized, accurate technology. Keywords: 3D printing technology, total hip arthroplasty, developmental dysplasia of the hip, navigation template

Introduction

Adult developmental dysplasia of the hip (DDH), the most common cause of secondary osteoarthrosis[–], has the basic pathological change which leads to an unstable hip, as well as anterolateral displacement. Most patients eventually have to undergo total hip arthroplasty (THA), which, one of the most successful surgical interventions in medical field today, provides reliable pain relief and functional improvement to the hip[–]. In a THA of patient with DDH, there will be three major difficulties: acetabular reconstruction, soft tissue balancing around the hip joint and femoral reconstruction[], as for the acetabulum, inadequate acetabular coverage on the femoral head, shallow and small sized acetabulum and mostly coloboma on the anterior lateral wall are the common problems[], especially for Crowe □/□ cases, it is one of the concerned points to locate the real acetabulum during the operation. If the acetabular prosthesis is placed improperly, the prosthesis will easy to loose due to the lack of support[]. Traditional total hip arthroplasty does not adequately consider individual difference, often leads to bias in placement of the prosthesis[–]. The precise placement and size selection of cup depend mainly on the experience of the surgeon, detailed preoperative plans as well as intraoperative techniques are indispensable, any mistakes will affect the surgical results. According to the requirements of precision medicine, a kind of precise and simple surgical procedure is eagerly needed.

Rapid prototyping(RP), an emerging industrial technology, has been developed and jointly applied with the reverse engineering in the medical field, which enables the precise, personalized treatment. It is especially applicable to DDH with different anatomy morphologies. With detailed preoperative parameter measurement and surgical planning, 3D printing guide plate method could effectively reduce errors due to experience lacking or poor surgical techniques. Currently, intra-operative guide plate technology has been applied in precise screw implantation, high tibial osteotomy, and total knee arthroplasty[–]. Intra-operative guide plate assisted total hip arthroplasty at the acetabular side in DDH, however, has not been reported. The aim of this study was to produce the 3D printing guide plate used in THA to locate the real acetabulum and to determine the placement, angle and size of acetabular cup.

Materials And Methods

2.1 General information

25 DDH patients treated in The Second Affiliated Hospital of Soochow University for DDH in the period of February 2017 to May 2018 were involved in this study. The cases (Crowe of 5 cases, Crowe of 14 cases and Crowe of 6) were randomly divided into the 3D printing guide plate group (12 cases) and the traditional total hip arthroplasty group (13 cases), all patients were treated with THA by the same operators. There were 21 males and 4 females, aged from 40 to 75 years with an average of 61.7 years. The post-operation follow-up was carried out from 12 to 18 months, 14.6 months averaged. Because of the need to compare the position of the acetabular cup with the contralateral acetabulum, patients with bilateral DDH or born structural abnormality of contralateral acetabulum were excluded.

2.2 3D printing

DICOM data obtained by CT scan of patients’ pelvises were loaded into Mimics15.0 software (Materialise, Leuven, Belgium) for 3D reconstruction (Fig. 1). With the reference to the contralateral acetabulum center, the real acetabulum at the affected side was located, after setting the position, set the angle according to the contralateral acetabular angle, the size of the acetabular cup would not break through the anterior and posterior walls of the affected real acetabulum. Then, a ring was made and it fell on the same level as the rim of the cup and 2mm larger than the diameter of the cup, this ring represents the position and size of the cup. Using the irregular bone surface of the fake acetabulum as the foundation bed, reverse-forming technique was used to make the matching surface with it, the base was extended and connected with the ring, shaping a guide plate. The base and the ring were detachable with a card slot, 3 K-wires fixing holes were reserved on the base (Fig. 1). The data was saved as STL format and loaded into the 3D printer, a guide plate and actual-sized pelvis model were generated, the printing material was polylactide.

2.3 Operation

At first, simulating operation was performed on the pelvis model (Fig. 2). Then an anterolateral incision of the hip was used to reveal the hip joints, the soft tissues surrounding the fake acetabulum were cleaned up and the bony structure was revealed, the base of the guide was completely matched with the fake acetabulum and fixed by 3 K-wires. The ring was installed into the card slots on the base, fixed with 3 K-wires, the ring pointed to the real acetabulum, then put the acetabular grinding drill into the ring, the grinding plane was parallel to the ring and at the center of the ring. As the grinding diameter was 2mm smaller than that of the ring, took off the guide, the metal cup was placed in the same direction as the ring (Fig. 3). Followed by the completion of acetabular processing, the femur side was treated routinely until the THA was completed (Fig. 4).

2.4 Clinical assessment

For each of those patients, operation time, intra-operative hemorrhage, post-operative drainage and Harris scores were evaluated, CT scanning of bilateral hip joints were used to evaluate the abduction and anteversion angle of the acetabulum, as well as the distance from rotation center to ischial tuberosity connection.

2.5 Statistics

SPSS 17.0 statistical software (SPSS Inc., USA) was applied. All measuring data were expressed as Mean ± Standard deviation. Comparison among groups shall be performed with independent samples t-test and intra-group comparison before and after the surgery with paired t test. As for measuring data, comparison among groups was performed with $\chi 2$ test, with the testing level $\alpha = 0.05$.

Results

There were no statistically significant differences in terms of sex, age, or case category between the groups in this study (Table 1), In other aspects, the operation time(57.8±3.73m vs 62.1±4.19m), intraoperative bleeding (169±34.1ml vs 219±38.0ml) and postoperative hemorrhage (130±27.2ml vs 219.±37.4ml) in the 3D printing group were lower than those in the traditional group (P<0.05), and Harris scores in the 3D printing group were higher than those of the traditional group (93.9±2.87 vs 91.8±3.69, P=0.009). In both of them, postoperative infection and loosening rates were 0 (Table 2). There were no statistical difference in the angles (abduction angle 42.25±4.55° vs 43.60±4.18°; anteversion angle 17.30±5.12° vs 22.70±4.03°) or positions (distance from rotation center to ischial tuberosity connection 80.84±6.21mm vs 78.77±4.69mm) between bilateral acetabular in the 3D printing group, while in the traditional group anteversion angles (15.01±5.68°vs 13.01±5.62°, t=-2.844, P=0.015) and the cup positions (82.92±5.73 mm vs 76.60±2.83mm, t=3.423 P=0.002) at the affected side were larger than that at the unaffected side. However, there was no statistical difference in abduction angles (38.60±3.25° vs 43.30±6.24°, t=2.888, P=0.487) between bilateral acetabular in the traditional group (Table 3).

Table 1 Comparison of general information relating to the template-guided group and traditional

operation group. (M = male; F = female; L = left; R = right).

	Age	Gender		Side		Crowe classification			
	Years	M	F	L	R	□	□	□	□
3D printing group (n=12)	59.8±11.1	2	10	8	4	0	2	6	4
Traditional operation group (n=13)	65.5±10.8	2	11	10	3	0	2	8	3
value	p=0.246	P=0.93		P=0.568		P=0.823			

Table 2 Clinical variables in patients after surgery.

	Operation time (m)	intra-operative hemorrhage (ml)	post-operative drainage (ml)	infection	loosening	Harris score
3D printing group	57.8±3.73	169±34.1	130±27.2	0	0	93.9±2.87
Traditional operation group	62.1±4.19	219±38.0	219±37.4	0	0	91.8±3.69
value	p=0.008	p=0.002	p=0.000			p=0.009

Table 3 Analysis of double side joint angle after hip replacement

	Ipsilateral side(mm/°)	Contralateral side(mm/°)	t-value	P-value
3D printing group				
abduction angle	42.25±4.55	43.60±4.18	0.720	0.487
anteversion angle	17.30±5.12	22.70±4.03	-1.315	0.215
distance from rotation center to ischial tuberosity connection	80.84±6.21	78.77±4.69	0.919	0.368
Traditional operation group				
abduction angle	38.60±3.25	43.30±6.24	2.888	0.487
anteversion angle	15.01±5.68	13.01±5.62	-2.844	0.015
Distance from rotation center to ischial tuberosity connection	82.92±5.73	76.60±2.83	3.423	0.002

Discussion

In patients with DDH, complex acetabular morphologies complicate the preoperative evaluation and surgical planning. Using 3D printing technology to print an actual-sized pelvic model, the surgeons can fully understand the anatomic abnormalities and develop a more complete surgical plan. Hurson et al. described using 3D models to evaluate the acetabulum of the 20 patients, 2 of the cases were changed the original surgical plan after studying full-scale models[]. With the development of digital medicine and 3D printing technology, orthopedic treatments are developing in the direction of individualization, precision and minimally invasion[]. Although 3D printing guide plate produced by reverse modeling and RP technology has been widely used in orthopedics[–], the circular guide plate used in total hip arthroplasty for DDH has not been reported.

In the previous work of YAN et al.[], the team has measured the anatomic morphological abnormalities in the DDH hips based on 3D reconstruction of CT scans and found that the hips were individualized, also the real acetabulums were hard to find during the operation. Based on this research, this study designed a guide plate which locates the real acetabulum based on false acetabulum, the base and the ring were connected with a detachable card slot, which eased the placement of the plate. If there are more osteophytes at the real acetabulum, it is difficult to place the actual ring, concentric rings growing in size can be designed, as the osteophytes are removed by grinding, gradually replace the large ring until it is perfectly matched with the set cup size. This technic makes the operation easy, reduces soft tissue separating, operative time and haemorrhage during and after the surgery. The post-operative CT shows that the placement of cup in the 3D group was more accurate. Other researchers used 3D guide plate for individualized osteotomy in total knee arthroplasty, the cadaveric test showed that individualized osteotomy had a higher accuracy[21]. In addition, the higher postoperative Harris scores of the guide group indirectly suggested that the position and angle of acetabular cup are more closer to the patients' physiological structures and biomechanics. 3D printing guide used in total hip arthroplasty can accelerate the postoperative recovery and improve life quality.

Failed hip arthroplasties are often shown as infection and aseptic loosening. Therefore, we compared the data between the two groups, infection and loosening rate were 0 in both groups, we consider the following reasons: small sample size, short follow-up time. More cases and longer follow-up time are considered in the future, it is believed that because of the shorter operation time and more accurate prosthesis placement, the guide group should have a lower infection rate and aseptic loosening rate than the traditional surgery group.

In conclusion, based on the study, 3D printing navigation template used in total hip arthroplasty is an individualized, accurate technology.

Declarations

Abbreviations:

3D: Three dimensional, DDH: Developmental dysplasia of the hip, THA: Total hip arthroplasty, RP: Rapid prototyping

Declarations

Ethics approval and consent to participate

This study was approved by the medical ethics review board of The Second Affiliate Hospital of Soochow University and informed consent was obtained from each patient.

Consent for publication

Identifiable patient information are not included in the study thus consent for publication is not applicable.

Availability of data and materials

The patients' dataset are confidential and are privately held for patients confidentiality safeguard.

Competing interest

The author declares no competing interest.

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Authors' contribution

Conception and Design: Liang Yan, Haibing Zhou. Data analysis and interpretation: Peng Wang. Manuscript preparation: Liang Yan. Manuscript editing: Liang Yan, Haibing Zhou. Manuscript review: Haibing Zhou. Final approval of the version submitted: Haibing Zhou.

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Tables

Table 1: Comparison of general information relating to the template-guided group and traditional operation group. (M = male; F = female; L = left; R = right).

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value	t=1.886 p=0.246	x^2=0.008 P=0.93		x^2=0.326 P=0.568		x^2=0.389 P=0.823			

Table 2: Clinical variables in patients after surgery.

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Traditional operation group	62.1±4.19	219±38.0	219±37.4	0	0	91.8±3.69
value	t=2.612	t=-3.477	t=-6.767			t=-2.875
	p=0.008	p=0.002	p=0.000			p=0.009

Table 3: Analysis of double side joint angle after hip replacement.

	Ipsilateral side(mm/°)	Contralateral side(mm/°)	t-value	P-value
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Figures

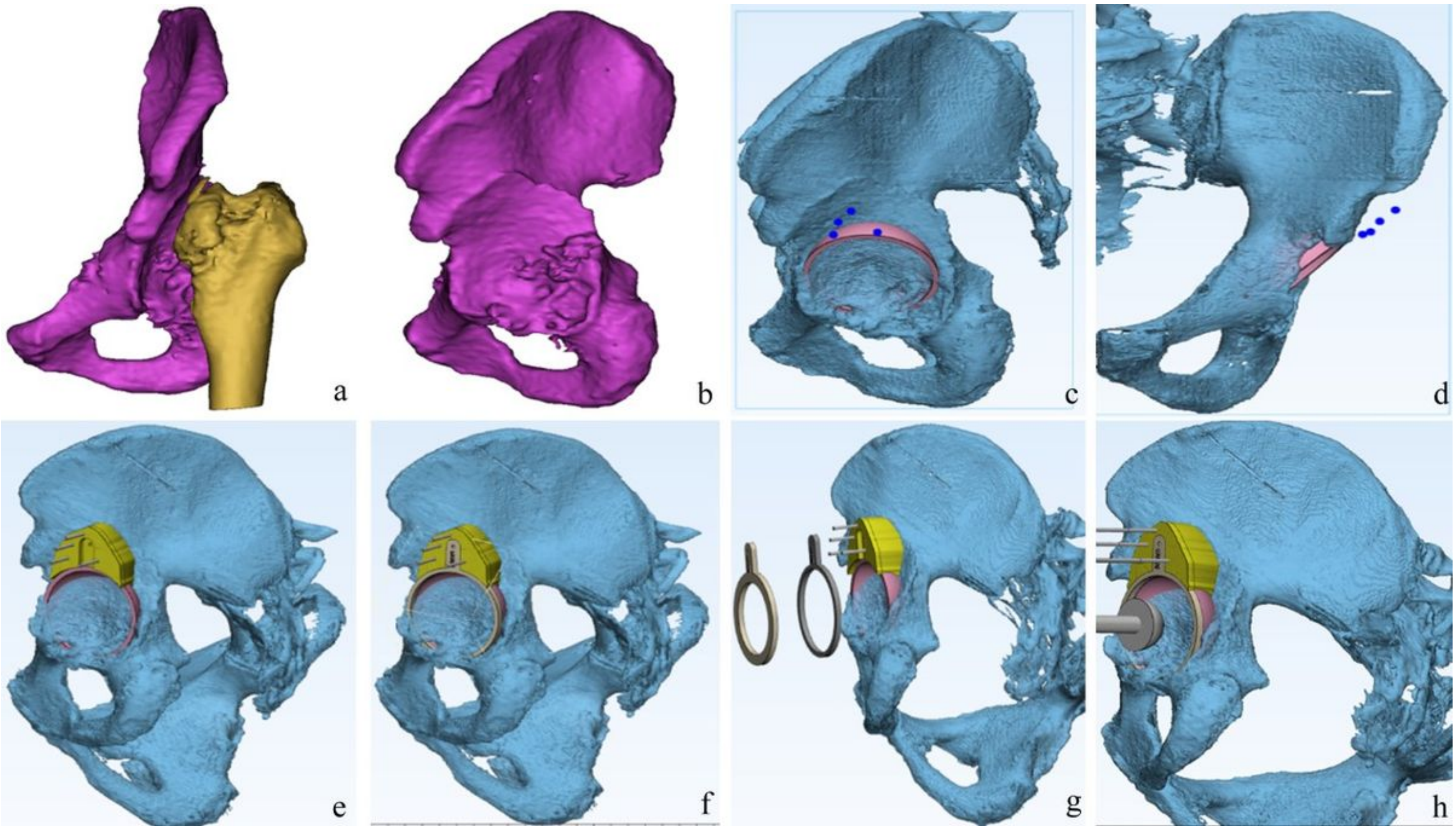

Figure 1

Preoperative design and simulation guide plate production. a, b: 3D reconstruction, removal of the femur, c, d: Find the real acetabulum, design the cup size and angle, e: Using the fake acetabulum to design the base, f: Design the ring fell on the same level of the cup and 2mm larger than the diameter of the cup, the base and the ring were detachable with a card slot, g: A concentric ring growing in size can be designed, as the osteophytes are removed by grinding, h: The grinding plane was parallel to the ring and at the center of the ring

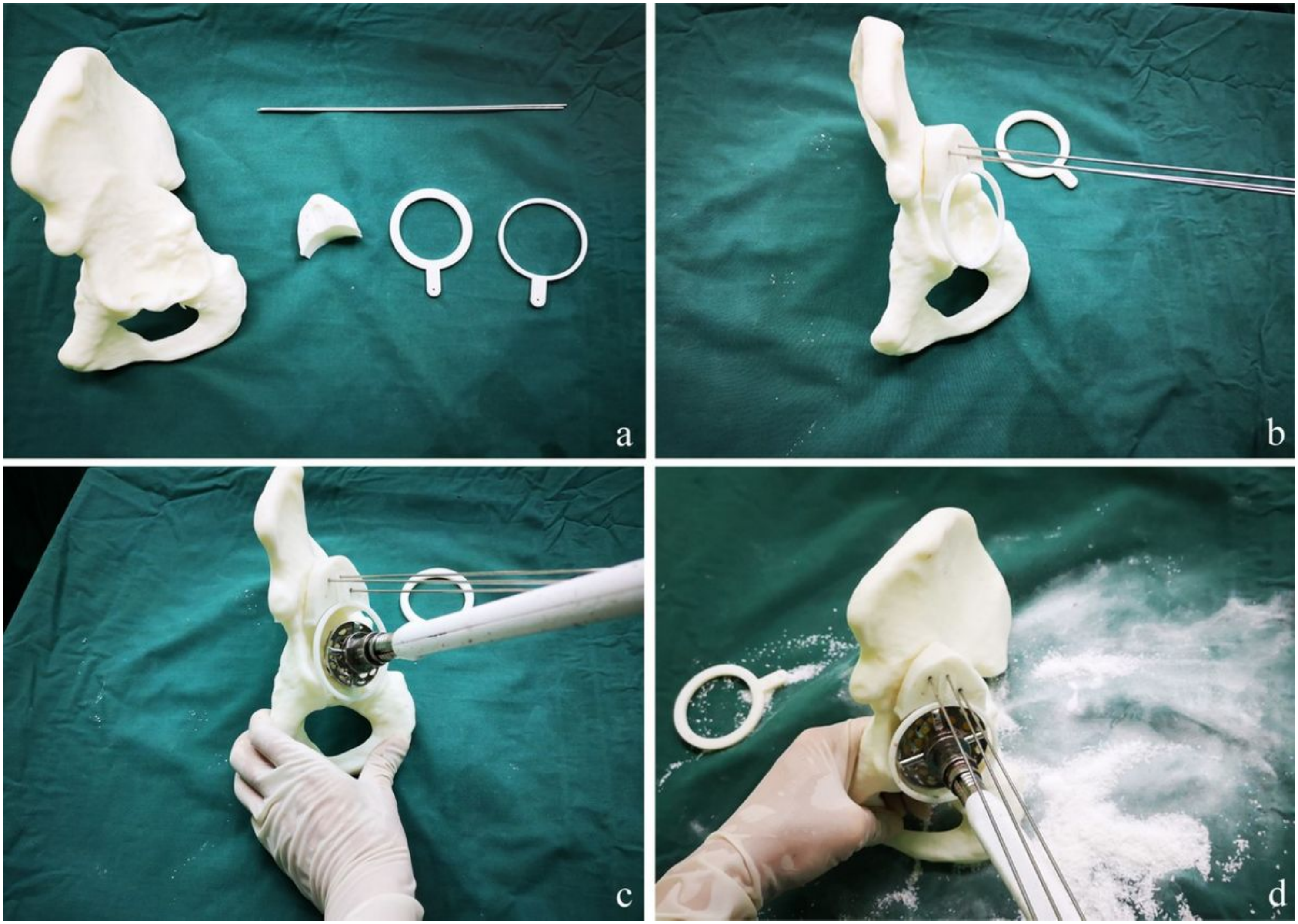

Figure 2

Simulating operation. a: 3D printing assembly, b: Installed the plate with Kirschner wire, c, d: Gradually grinded the acetabulum

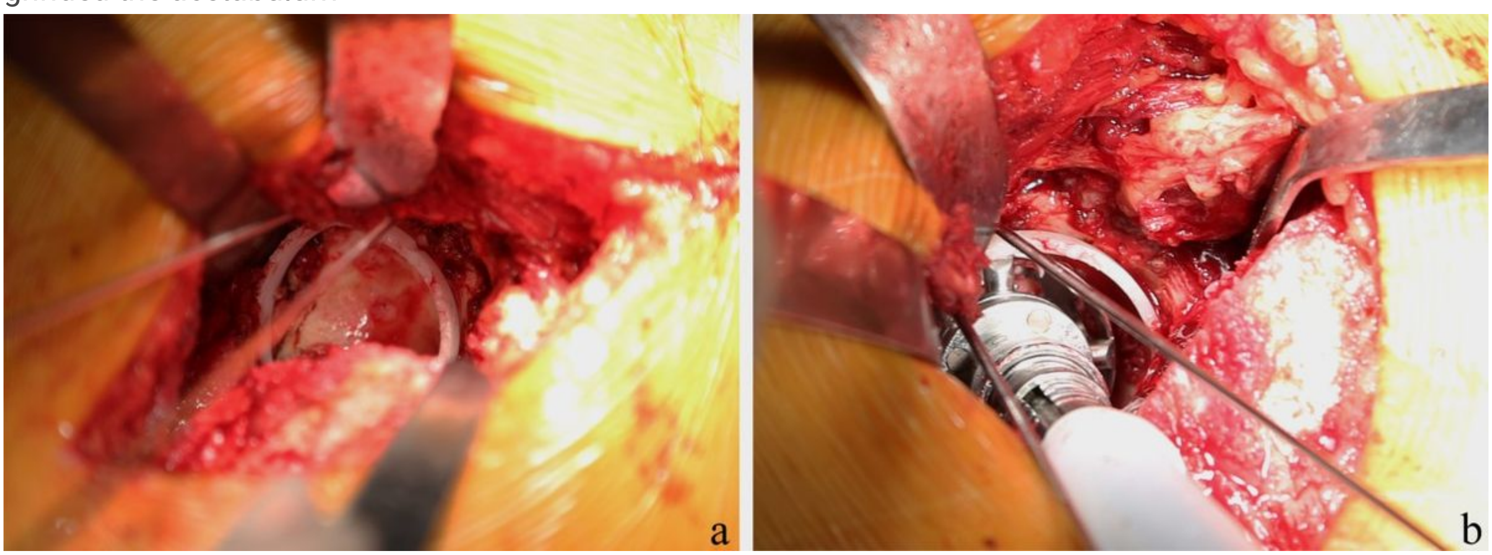

Figure 3

Operation. a: The ring pointed to the true acetabulum, b: Grinded the acetabulum step by step

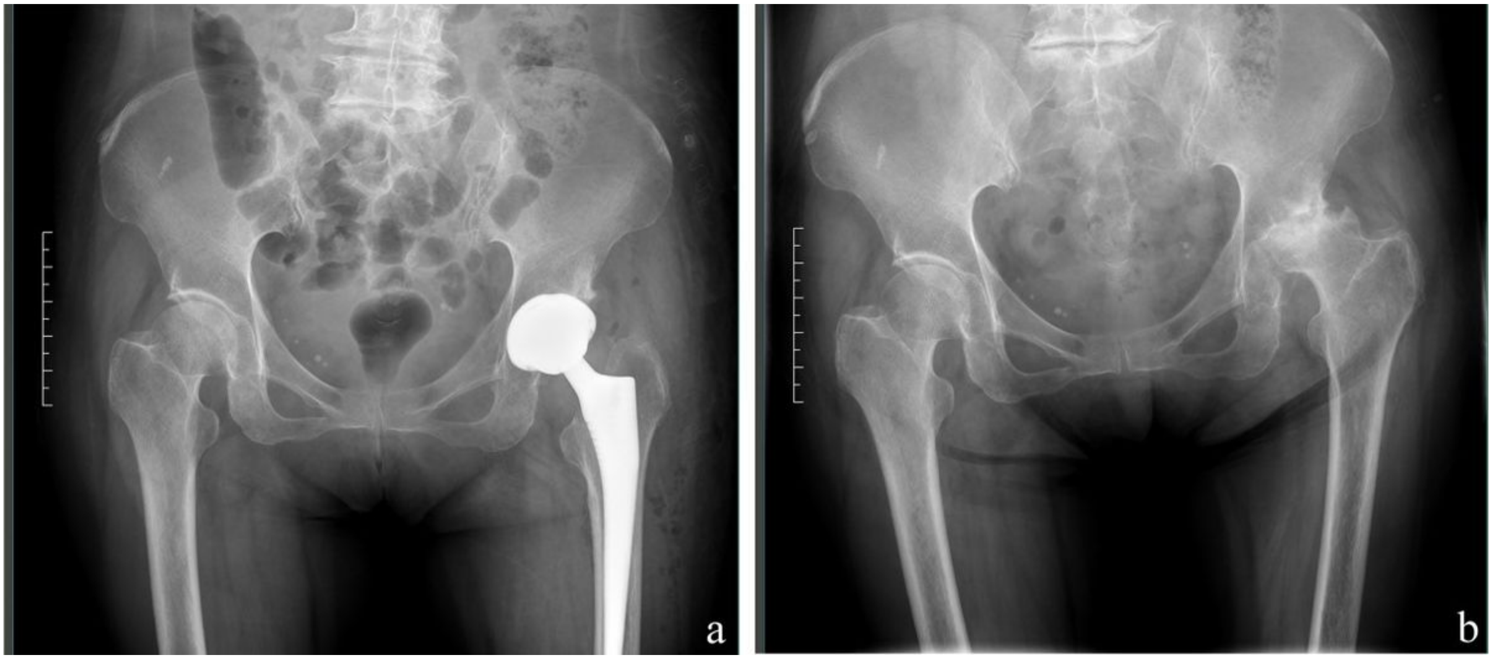

Figure 4

Postoperative and preoperative X-ray