CLINICAL ARTICLE

A Comparative Study of Patients' Subjective Feelings Toward Total Hip Arthroplasty with Patient-Specific Instruments and Traditional Total Hip Arthroplasty

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Objective: To determine whether differences exist in patients' subjective feelings, daily life, and surgical satisfaction between those who underwent surgery for developmental dysplasia of the hip (DDH) using patient-specific instruments (PSIs) and those who underwent traditional surgical total hip arthroplasty (THA).

Methods: We selected 30 adult patients with various types of DDH who underwent surgery during 2016–2017 at our hospital. The patients were divided into PSI surgery group and the traditional surgery group. All patients underwent follow-up, and we collected data on the Harris Hip Score, Oxford University Hip Score (OHS), Forgotten Joint Score (FJS-12), Visual Analogue Scale (VAS) score, patient satisfaction score, intraoperative surgical time, amount of bleeding and postoperative complications incidence for both groups. We then performed statistical analyses on the data.

Results: The Harris Hip Score, OHS, VAS score, patient satisfaction score, and mean bleeding volume did not differ statistically significantly (*t*-tests, $P > 0.05$). No statistically significant differences were found between surgical groups in the incidence of complication and sub-trochanteric osteotomy, or in the surgical side (chi-square tests, $P > 0.05$). For the experimental group, the FJS-12 score was 80.0 ± 12.0, and for the control group the score was 68.5 ± 16.1. The operative time of the experimental group was 138.4 ± 32.2 min, while that of the control group was 88.9 ± 26.8 min. The values of these data differed significantly (*t*-tests, $P < 0.05$).

Conclusions: The novel PSI designed by our group has certain advantages for the short-term subjective feelings of patients after THA, but it may cause prolonged operative times.

Key words: 3D printing; Patients' feelings; Patient-specific instruments; Total hip arthroplasty

Introduction

Developmental dysplasia of the hip (DDH) is one of the most common hip diseases in pediatric orthopaedics worldwide, and the incidence of DDH is 4.9 per 1000 live births[1]. As an individual grows, DDH may lead to hip head palpitations, hip joint dislocation, and acetabular developmental disorders, and the end stage are osteoarthritis and osteonecrosis of the femoral head[2]. Presently, the typical treatment for adult DDH end-stage osteoarthritis is total hip arthroplasty (THA). THA has made rapid progress over the past few decades, but orthopaedic surgeons still face challenges[3,4], such as patients with Crowe type III and IV dysplasia[5]. Common characteristics of those DDH patients include poor development and shallow flatness of the true

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Received 25 July 2019; accepted 3 January 2020

acetabulum, increased acetabular anteversion, bone defects of the anterior and lateral acetabular walls, a small femoral head, a short and an obviously anteverted femoral neck, and a small femoral bone marrow cavity. Therefore, orthopaedic surgeons often encounter difficulties such as how to reconstruct the acetabulum, determine the hip rotation center, and ascertain whether bone grafting and sub-trochanteric osteotomy are needed[6].

Studies have shown that a comprehensive preoperative plan for patients with complex DDH can reduce the duration of surgery and the incidence of intraoperative or postoperative complications[7]. Previously, the surgeon's experience was the most decisive factor in determining the position and orientation of the acetabular component during surgery, which could lack accuracy sometimes. Besides, the location of the acetabular prosthesis may deviate from the ideal position when the patient's gesture changes during surgery.

To improve the surgical outcomes of THA in DDH, some new surgical techniques have been used, such as three-dimensional (3D)-printing technology, navigation techniques, and patient-specific instruments (PSIs), to reduce the uncertainty caused by the surgeon's lack of experience[8–10]. Among them, PSIs have received extensive attention from the medical community, especially in the field of joint surgery[11–15]. Currently, the design and production of PSIs mainly rely on CT scanning, computer 3D design, preoperative planning and 3D printing. Our team chose to combine a 3D-printed preoperative model with surgical-guide positioning technology. In preoperative surgical simulation, the 3D-printed model could aid us in performing some key steps using the computer, such as locating the true acetabulum, positioning the acetabular rotation center, measuring and reaming the acetabulum, performing the femoral neck osteotomy, measuring the femoral isthmus medullary cavity, and performing the sub-trochanteric osteotomy. The previous work of Wang *et al.* showed that the PSI helps the surgical team perform simulated surgery, notably improves the accuracy, certainty, and safety of the surgical procedure, and facilitates communication between doctors and patients[16]. Furthermore, other studies have compared traditional surgery and surgery using PSIs, including assessing the accuracy of the prosthesis positioning, limb alignment, acetabular anteversion angle, acetabular abduction angle, and joint function[12,13]. Most of these studies found that emerging PSI procedures can improve the accuracy of artificial THA and enhance surgical outcomes compared with the traditional method[8,17,18].

Considering that no previous study has compared PSI surgical procedures and traditional procedures in terms of patients' subjective feelings, herein we determined: (i) whether differences existed in DDH patients' subjective feelings, daily life, and surgical satisfaction between those who received surgery using PSIs and those who underwent traditional THA; and (ii) whether the new PSI procedure elicited better subjective feelings and clinical effects than did the traditional surgery from the patients' perspectives.

Patients and Methods

Inclusion and Exclusion Criteria

We chose 15 patients as the PSI experimental group from among those who accepted PSI surgery between April 2016 and June 2017 according to the inclusion criteria, and we randomly selected 15 patients according to the inclusion criteria as the control group from among those accepting THA during the same period.

The inclusion criteria for patients consisted of: (i) patients with Crowe's DDH confirmed by imaging data; (ii) they had a hip replacement in our hospital at least 1 year previous to the study; (iii) they provided informed consent for study; and (iv) the main evaluation indicators included Harris Hip Score, Oxford University Hip Score (OHS), Forgotten Joint Score (FJS-12), Visual Analogue Scale (VAS) score and patient satisfaction score. The exclusion criteria were as follows: (i) age younger than 18 years; (ii) no obvious pain; (iii) DDH combined with hip infection; (iv) suppurative hip sequelae; (v) severe organ complications; and (vi) inability to tolerate surgery.

The PSI surgical group included three men and 12 women, and the traditional surgery group included four men and 11 women. The age of the PSI group was 50.6 ± 13.9 years, and the age of the traditional surgery group was 45.8 ± 13.9 years. In the PSI surgery group, five patients were classified as having type I dysplasia according to the Crowe classification, two had type III, and eight had type IV. In the traditional surgery group, six patients had type I dysplasia, three had type III, and six had type IV. In the PSI surgery group, three patients received bilateral THA and 12 received unilateral THA, while in the control group, one patient received bilateral THA and 14 received unilateral THA. The preoperative characteristics that were compared between the two patient cohorts included age, sex, Crowe classification, follow-up duration, Harris hip scores, and side of surgery (Table 1). These parameters did not differ significantly between the two patient cohorts (sex, Crowe classification, and side of surgery were compared using chi-square tests; age, follow-up duration, and Harris hip scores were compared using *t*-tests). The study has been approved by the Institutional Review Board (IRB) of the authors' affiliated institutions, and informed consent was obtained from all patients. And use of the patients' imaging data was permitted.

Preoperative Preparation

Digital Operative Simulation

All patients underwent a routine pelvic computed tomography (CT) scan (0.6 mm thickness; Philips scanner, Eindhoven, Netherlands), and the pelvic reconstruction data obtained from CT scans of patients who underwent the PSI surgical procedure were exported and preprocessed. We used Mimics 19.0 software (Materialize, Leuven, Belgium) to digitally reconstruct a 3D pelvic model. The digital reconstruction process for 3D-model simulation surgery is divided into

three steps. First, the pelvic position was standardized. The coronal plane was based on the relative position of the anterior and superior iliac spine and pubic tuberosity, and the standardized pelvic position was determined from the reference position of the pelvic coronal plane[19]. Next, based on the patient's acetabular features, a personalized assessment was made to determine the optimal position of the acetabular cup. Finally, optimal placement of the cup in the real acetabulum was simulated using the computer.

We used 3D, sagittal, coronal, and lateral views to confirm the optimal acetabular position. The evaluation criteria for the optimal acetabular position were as follows: (i) fitting edge: the diameter of the cup matched the actual peripheral boundary of the acetabulum; (ii) good cup bone coverage (we generally used 70% cup bone coverage as the standard); and (iii) the best center of rotation, which is generally based on the patient's true position and leg length. If the contralateral acetabulum and femoral head were normal, we used the size and rotation center position as references 16.

PSI Design

After determining the ideal size and position of the acetabular cup, we designed the PSI. This device ensured that the surgeon could restore the position of the acetabular cup during surgery, as in the preoperative simulation. The previous work of Wang *et al.*[16] provides detailed information on the PSI device. The device is divided into a fitter, an acetabular reamer guide plate, and an acetabular screw guide plate (Fig. 1), with the fitter fixed at the predetermined bone mark position. The acetabular reamer guide plate is further installed through the connection. If the acetabulum is to be fixed with screws, the acetabular screw guide plate is installed.

Surgical Procedure

PSI Group Surgery

The same experienced joint surgeon participated in the PSI design throughout the procedure and performed all surgeries. We selected the posterolateral approach with hip dislocation and full femoral head exposure. We followed the steps for using the PSI. First, the superolateral portion of the acetabulum were completely exposed, the fitter was embedded in a specific site with a bony landmark (Fig. 2A). Second, the acetabular reamer guide plate was fixed onto the fitter, and two to three appropriately sized K-wires were placed into the fitter through the guide holes to fix the fitter (Fig. 2B). Then, the reamer was used to ream the acetabulum from small to large to mimic the preplanned model, shaping the ideal acetabulum as designed preoperatively (Fig. 2C). For severe acetabular defects, a structural bone graft was performed during surgery to provide more bone mass for the next revision surgery. The third step was to install the acetabular cup. Based on the preoperative simulation and intraoperative conditions, the surgeon judged whether an acetabular screw was needed to reinforce the cup. If necessary, the acetabular screw guide device was installed to the fitting connector, and methionine was used to label the safe area (Fig. 2D). Finally, the acetabular screws were installed into the labeled safe area (Fig. 2E) and the acetabular lining was installed to complete the surgery of the acetabular side of the hip (Fig. 2F). The surgical procedure was described in detail in the Video S1 attached to the manuscript.

Traditional Group Surgery

The same experienced joint surgeon performed the traditional surgery. After full exposure, the true position and rotation center of the acetabulum were determined based on the surgeon's experience. We used an acetabular reamer to enlarge the true acetabulum and install a suitable cup. After ensuring the position and direction of the prosthesis, the acetabular screw was determined according to cup stability. Finally, we installed the acetabular lining and completed the surgical procedure on the acetabular side of the hip. For the cases in both surgical groups that could not be reduced after intraoperative soft tissue release, we performed a sub-trochanteric osteotomy.

Data Collection

All patients were followed for an average of 23 months (range, 14–35 months). The average follow-up time was 23.4 months in the PSI group and 23.7 months in the traditional surgery group. The data we collected are as follows:

Harris Hip Score (HHS)

The HHS[20] was developed to assess the results of hip surgery, and evaluate various hip disabilities and methods of treatment in an adult population. It assesses symptoms that are characteristic to this condition such as pain, loss of mobility, and muscle function. The domains covered are pain, function, deformity, and range of motion, and each item has a unique numerical scale that corresponds to descriptive response options. The maximum score of HHS is 100. The higher the HHS, the less dysfunction. In the present study, we collected the HHS before and after surgery, and the data is presented in Tables 1 and 2.

Oxford University Hip Score (OHS)

The OHS[21] is another scale to evaluate the outcome after total hip replacement (THR) by measuring patients' perceptions in adjunction to surgery, which assesses pain (six items) and function (six items) of the hip in relation to daily activities such as walking, dressing, sleeping, etc. Each question has 4 answers to select, correspondingly 0–4 scores (worst to best). The overall scores range from 0 to 48, and 48 represents the best score. The higher the score, the better prospects and the lower the dysfunction. In this study, we collected the OHS after surgery, as shown in Table 2.

Forgotten Joint Score (FJS-12)

The FJS-12[22] comprise measures for the assessment of joint-specific patient-reported outcome (PRO): the patient's ability

TABLE 1 Comparison of demographic characteristics between the two groups

Variable	Patient-specific instrument (n = 15)	Conventional instrument (n = 15)	*P* value
Age (year)	50.6 ± 13.9	45.8 ± 13.9	>0.05
Sex, n (%)			>0.05
Men	3 (20.0%)	4 (26.7%)	
Women	12 (80.0%)	11 (73.3%)	
Crowe Classification			>0.05
I	5 (33.3%)	6 (40.0%)	
II	0 (0.0%)	0 (0.0%)	
III	2 (13.3%)	3 (20.0%)	
IV	8 (53.3%)	6 (40.0%)	
Harris hip scores (pre-operative)	66.0 ± 8.7	69.2 ± 8.3	>0.05
Follow-up time (month)	23.7 ± 3.7	25.4 ± 4.0	>0.05
Unilateral/bilateral			>0.05
Unilateral	3 (20.0%)	1 (6.7%)	
Bilateral	12 (80.0%)	14 (93.3%)	

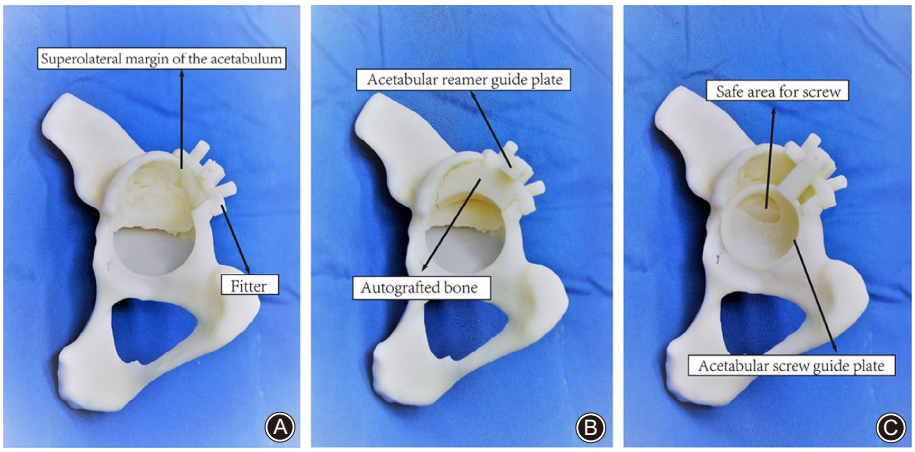

Fig. 1 Inspection of patient-specific instrumentsdesigned by us. (A) the bony landmark and fitter. (B) an acetabular reamer guide plate assembled on the fitter and the zone for autografted bone. (C) an acetabular screw guide plate assembled on the fitter to determine the safe area for screw.

to forget the artificial joint in everyday life. Joint awareness can be simply defined as any unintended perception of a joint. In this questionnaire, 12 questions are answered with either never, almost never, seldom, sometimes, mostly, and "not relevant to me", corresponding from 0 to 4 points. Total points are calculated according to the average score of all answered questions and then multiplied by 25 into centesimal system (0–100 points). Higher scores refer to better outcome, which means a better "forgotten" index of the joint and a low degree of awareness. We collected the FJS after surgery, as shown in Table 2.

Visual Analogue Scale (VAS) Score

The pain VAS score[23] is a unidimensional measure of pain intensity, which has been widely used in diverse adult populations. The VAS scale we used is a straight horizontal line of fixed length, 100 mm. The ends are defined as the extreme limits of the pain to be measured orientated from the left (0) to the right (10). We collected the VAS score after surgery, as shown in Table 2.

Patient Satisfaction Score

The patient satisfaction score is a scale totally based on patients' subjective feelings about their artificial joint after total hip arthroplasty after at least 1 year. Responses are measured on a scale of 1 to 10, with 10 being the best score. Higher scores refer to better satisfaction about this surgical process. We collected the patient satisfaction score after surgery, as shown in Table 2.

Operative Time

The data of surgery time we collected from surgical records are from skin inclusion until surgical closure, which could reflect the proficiency of the operators for two surgical methods, and the unit of time calculation is minutes. We collected all patients' data and did the statistical analysis, and the representation of results are shown in Table 2.

Amount of Bleeding

We defined the amount of bleeding in this study as the intra-operative blood loss[24]. We weigh the used compresses

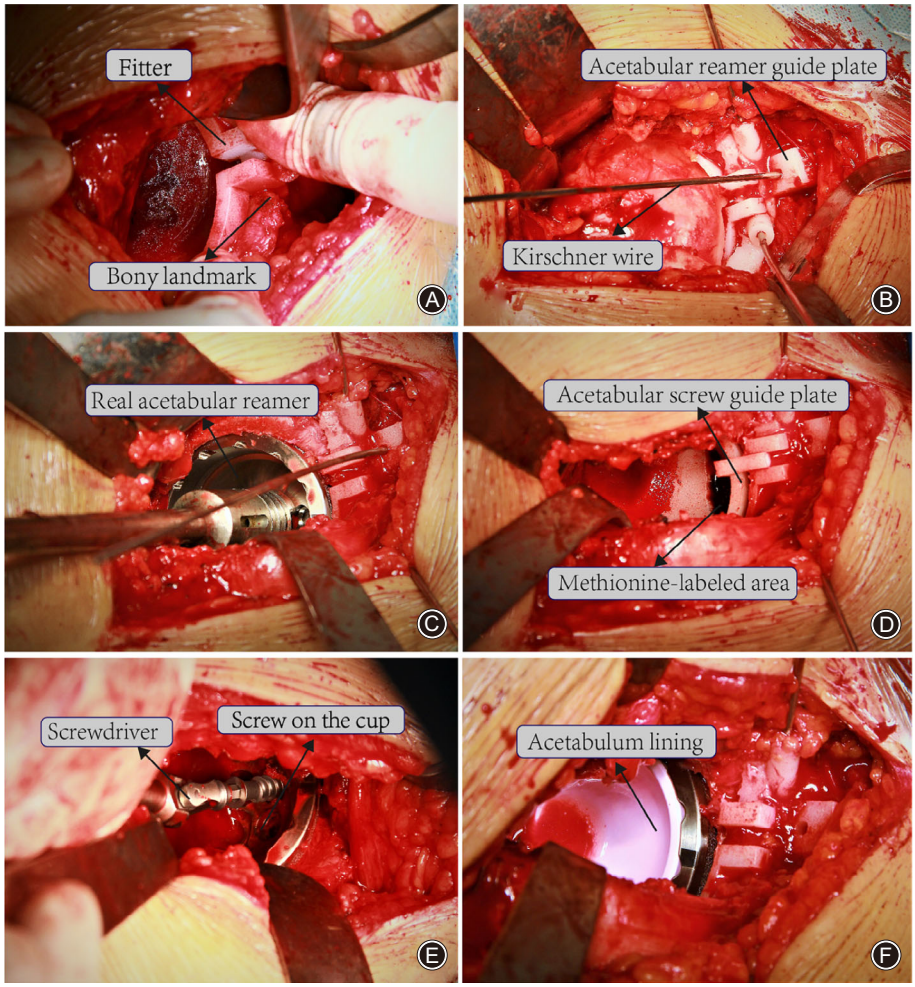

Fig. 2 The steps for using the patient-specific instruments. (A) thesuperolateral portions of the acetabulum were exposed, and the fitter was embedded. (B) the acetabular reamer guide plate was fixed onto the fitter, and K-wires were placed into the fitter. (C) the reamer was used to ream the acetabulum. (D) the acetabular screw guide device was installed, and methionine was used to label the safe area. (E) the acetabular screws were installed. (F) the acetabular lining was installed.

and record the amount of blood in the suction bottle and the filtrated drainage blood which was recycled and transfused to patients by self-blood transfusion equipment during operation to calculate intra-operative blood loss. We did the statistical analysis, and the results are shown in Table 2.

Postoperative Complication Incidence

The postoperative complication of this study included revision, dislocation, wound healing, nerve injury, and thigh pain. The number of patients with complications divided by the number of each group is the incidence of postoperative complication. The results are shown in Table 2.

Statistical Analysis

The data are expressed as the mean and range. Chi-square test was used to analyze the difference of sub-trochanteric osteotomy and complications, and t-test was used to analyze the difference of Harris Hip Score, Oxford Hip Score, Forgotten Joint Score, VAS Score, Patient satisfaction score, operative time and amount of bleeding between two groups. Statistical analyses were performed using SPSS 22.0 software (SPSS Inc., Chicago, IL, USA). P values less than 0.05 were considered statistically significant.

Results

Follow-up

The follow-up time of all patients was at least 1 year. The follow-up time of patients who accepted PSI surgical treatments was 23.7 ± 3.7 months *vs* 25.4 ± 4.0 months of patients who accepted traditional surgery. The difference was not significant ($F = 1.114$, $P = 0.232$).

General Results

Five patients in the experimental group and two patients in the control group received sub-trochanteric osteotomies, but the difference was not statistically significant ($X^2 = 1.677$, $P = 0.195$). The bleeding volume of the experimental group was 470.0 ± 134.7 mL *vs* 453.3 ± 147.0 mL of the control group, and the difference was not statistically significant ($F = 0.008$, $P = 0.748$). The operative time for the experimental group was 138.4 ± 32.2 min, while the mean operative time for the control group was 88.9 ± 26.8 min, which was

TABLE 2 Comparison of postoperative results between the two groups

Variable	Patient-specific instrument (n = 15)	Conventional instrument (n = 15)	*P* value
Subtrochanteric Osteotomy, n (%)			>0.05
Yes	5 (33.3%)	2 (13.3%)	
No	10 (66.7%)	13 (86.7%)	
Harris Score			
3 months postoperatively	81.7 ± 2.5	79.5 ± 3.8	>0.05
2 years postoperatively	91.8 ± 6.1	91.3 ± 4.6	>0.05
Oxford Hip Score	16.3 ± 3.8	16.5 ± 2.8	>0.05
Forgotten Joint Score	80.0 ± 12.0	68.5 ± 16.1	0.035
Visual Analogue Score	0.5 ± 0.6	0.7 ± 0.7	>0.05
Satisfaction Score	9.1 ± 0.8	8.7 ± 1.0	>0.05
Operative Time, n (min)	138.4 ± 32.2	88.9 ± 26.8	<0.001
Amount of bleeding	470.0 ± 134.7	453.3 ± 147.0	>0.05
Complications, n (%)			>0.05
Revision	0	0	
Dislocation	0	0	
Wound Healing	0	0	
Nerve Injury	0	0	
Thigh Pain	1 (6.7%)	1 (6.7%)	

statistically significant ($F = 0.004$, $P < 0.001$). That indicated operative time of PSI group is 55.7% longer than control group.

Functional Evaluation

Harris Hip Score (HHS)

The HHS score of the experimental group was 81.7 ± 2.5 at 3 months postoperatively and 91.8 ± 6.1 at the last follow-up, both of which were significantly better than 66.0 ± 8.7 preoperatively ($P < 0.001$, $t = -6.308$ and $P < 0.001$, t = −13.596). And the control group HHS was 79.5 ± 3.8 at 3 months postoperatively and 91.3 ± 4.6 at the last follow-up, both of which were significantly better from 69.2 ± 8.3 preoperatively ($P = 0.002$, $t = -3.850$, $P < 0.001$, $t = -9.822$). The difference of pre-operative HHS between the two groups was not significant ($F = 0.004$, $P = 0.322$), neither at 3 months ($F = 1.522$, $P = 0.077$) nor at almost 2 years ($F = 1.190$, $P = 0.815$) follow-up.

Oxford University Hip Score (OHS)

The OHS of the experimental group was 16.3 ± 3.8 *vs* 16.5 ± 2.8 of the control group, and the difference was not significant ($F = 2.354$, $P = 0.871$).

Forgotten Joint Score (FJS-12)

The FJS-12 score was 80.0 ± 12.0 for the experimental group *vs* 68.5 ± 16.1 for the control group. There was a statistical difference between these two groups ($F = 0.582$, $P = 0.035$), and the PSI group is more than the control group by 16.8%.

Visual Analogue Scale (VAS) score

The VAS score of the experimental group was 0.5 ± 0.6 *vs* 0.7 ± 0.7 of the control group, and the difference was not significant ($F = 0.248$, $P = 0.597$).

Patient Satisfaction Score

The patient satisfaction score of the experimental group was 9.1 ± 0.8, and the control group was 8.7 ± 1.0. The difference was not significant ($F = 0.600$, $P = 0.234$).

Complications

Mild thigh pain occurred in one patient in each group during movement. However, no patients required non-steroidal anti-inflammatory drugs or opioid analgesics for pain relief at the last follow-up. No dislocation, nerve damage, or delayed wound healing occurred in either group. No revision occurred in either group. Table 2 presents the follow-up outcomes of the two patient groups.

Discussion

PSIs and 3D printing, widely used in clinical medicine, aim to provide personalized medical services for patients to make clinical treatment more individualized and precise. Surgeons have combined 3D-printed surgical models with patient-specific instruments, which have been gradually incorporated to assist with preoperative design, virtual surgery, and intraoperative surgical procedures. PSIs and 3D printing aim to provide personalized medical services for patients to make clinical treatment more individualized and precise.

The PSIs used in this study were original and unique. Our team designed the PSI guide device for feasible bone positioning, and the molds interlocked together, limiting the maximum size and depth of the acetabular reamer. Thus, we ensured the accuracy of the true position and the acetabular reamer's size, angle, and depth. In addition, the safety zones of the acetabular screws were determined, and the position and direction of the screws were planned during the preoperative simulation, thus preventing damage to the nerve and blood vessel when the screws were installed during the operation. Therefore, the PSI guide device designed in this study

is original and innovative and ensures surgical accuracy and safety[16].

Comparing the clinical effects of PSI surgery with traditional surgical procedures is a common concern for orthopaedic surgeons, although the use of PSI procedures has accelerated in recent years. Spencer-Gardner *et al.*[25] compared the accuracy of PSI and traditional surgery based on the position of the acetabular prosthesis, and suggested that using the PSI procedure allowed for more accurate prosthetic positioning than traditional surgery. Zhang *et al.*[26] showed that the accuracy of specific 3D templates in hip arthroplasty was significantly higher than that in traditional surgery.

However, no research has ever compared patients' subjective feelings between THA using a PSI and traditional surgery. This study investigated whether patients who received THA via the PSI procedure had superior subjective feelings and improved quality of life compared with patients who received traditional THA during a short-term follow-up. We used the Harris Hip Score, OHS, FJS-12, VAS, and patient satisfaction scores to evaluate the patients' subjective feelings. The results showed no significant differences in the Harris Hip Score, OHS, VAS, or patient satisfaction scores between the PSI and traditional surgery groups; however, the FJS-12 scores of patients who underwent the PSI procedure were significantly higher than those of patients who underwent traditional surgery. In addition, the patient satisfaction scores of the PSI surgery group were slightly higher than those of the traditional surgery group, although the difference was not statistically significant. These results indicate that the PSI surgery group had a greater advantage in terms of patients' subjective feelings, and the emerging PSI surgical procedure provided a better postoperative experience for these patients.

Besides, the results of the present study revealed that the operating time for the PSI group was significantly longer than that of the traditional surgery group, indicating that the surgeon performing the PSI surgery needed more time to complete the exposure and confirm the bony mark as well as to install the guide plate. Prolonged surgical times inevitably lead to adverse impacts on patients, such as prolonged intraoperative anesthesia, increased intraoperative blood loss, and increased risk of infection. Surace *et al.*[27] investigated the relationship between the operative times of 89,802 hip arthroplasty procedures and their associated short-term postoperative complications and reported that the longer the operating time, the higher the risks of infection, readmission, second operations, wound splitting, and blood transfusion. Wills *et al.*[28] followed 103,044 patients who underwent THA operation and showed that for each additional 10 min of surgical time, the incidence of surgical site infection increased by 7%. We believe that this operational time will gradually be shortened as surgical experience increases.

In the present study, we found that patients who underwent the PSI surgical procedure had better short-term subjective experiences than did those who underwent the traditional surgical procedures, but prolonged operative time may cause some complications post-surgery. The Harris Hip Score, OHS, and VAS scores showed no differences between the PSI and traditional groups in our study, indicating that the PSI procedure did not significantly improve the surgical outcomes. Therefore, the PSI procedure may not be a necessary option for experienced joint surgeons. In addition, the PSI surgery costs more than traditional surgery does. Each PSI surgery costs at least 6500 RMB more than traditional surgery, including design of preoperative 3D models, preoperative surgical procedure simulation, and production and sterilization of acetabular guide plate, which is an economic burden for patients in poor financial situations. As a result, popularizing PSI surgery may face some difficulties in the future.

This study has some limitations. As the retrospective study, the patients were not randomized, which might result in bias within the study. Data of pre-operative patient's subjective feelings were not collected, so we couldn't totally ensure the pre-operative equality of general background between two groups. Besides, the sample size for the follow-up research was small, and the follow-up duration was comparatively short. Further prospective studies with larger sample sizes and longer follow-up times are required to investigate the value of the clinical application of PSIs.

The novel PSI designed by our group has certain advantages regarding patients' subjective feelings after THA in the short term, but these may cause prolonged operating times. Therefore, for experienced joint surgeons, the PSI procedure may be unnecessary.

Disclosure

This study was strongly supported by the Digital Research Institute of Orthopaedics of Xiangya Hospital. This work was supported by grants from the National Natural Science Foundation of China (Grant No. 81601883, 81873988), and was also supported by Hunan Provincial Natural Science Foundation of China (grant NO: 2018JJ3861).

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Video S1 A simulation in computer of PSI design and application in surgery

Reference

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