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HIP ARTHROPLASTY

Failed periacetabular osteotomy leads to acetabular defects during subsequent total hip arthroplasty

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Abstract

Background Acetabular wall defects after periacetabular osteotomy (PAO) lead to technical difficulties when performing subsequent total hip arthroplasty (THA). There is no unified consensus regarding the solution for THA socket installation after PAO. In the current study, we performed computed tomography (CT)-based simulation of socket installation and evaluated the acetabular defect following THA after PAO and after primary osteoarthritis (OA).

Patients and methods The study group comprised 55 patients (56 hips) who underwent THA after PAO. For the control group, after matching for age, sex, and Crowe classification, we included 55 patients (56 hips) who underwent primary THA for hip dysplasia. We evaluated the anterior, posterior, and superior acetabular sector angle (ASA) and medial wall thickness (MWT) at the anatomical hip center (at the 20-mm vertical hip level from teardrop) in the study group (anatomical PAO group) and control group (primary OA group). In addition, we investigated the changes in the socket covering when the socket was positioned 10 mm above the anatomical hip center (30 mm above the teardrop; elevated osteotomy group).

Results All ASA and MWT values were significantly smaller in the anatomical PAO group than in the primary OA group. In particular, the individuals with a Crowe classification of II/III in the anatomical PAO group presented severe acetabular defects. However, the elevated PAO group had a significantly larger ASA compared to the anatomical PAO group, with improved socket coverings.

Conclusion Acetabular defects in the anatomical hip center following THA after PAO were significantly common compared to those after primary THA. Elevation of hip joint centers as much as 10 mm is one therapeutic option in the case of severe acetabular defects following THA after PAO.

Keywords Acetabular wall defect · Periacetabular osteotomy · Rotational acetabular osteotomy · Eccentric rotational acetabular osteotomy · Total hip arthroplasty

Introduction

Periacetabular osteotomy (PAO) is a treatment used to normalize the hip joint center of the subluxed hip joint and to improve coverage of the acetabulum, which is effective for acetabular dysplasia treatment in young adults, to prevent progression of osteoarthritis (OA) [1–4]. However, some patients who undergo PAO demonstrate long-term progression of OA and require conversion to total hip arthroplasty (THA) [5–13]. Several reports demonstrate that THA after PAO demonstrates the following characteristics: large osteophytes, acetabular sclerosis, and acetabular wall defects [9–13]. Acetabular wall defects due to rotation of the acetabular bone fragment have been reported to affect the socket alignment in the past reports [10, 11]. Inappropriate osteotomy and collapse of rotating bone fragments will eventually result in elevation of the hip joint center, resulting in more complex acetabular deformity and acetabular bone defects. Therefore, compared to primary THA for OA without osteotomy, the acetabular morphology of the acetabulum for THA after PAO is totally different compared to that for primary THA, even if the degree of subluxation is the same according to the Crowe classification.

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Generally, it is preferable to place the socket at the anatomical hip center [14]; however, the surgical technique is difficult because of acetabular defects and morphological deformity of the acetabulum of THA after PAO [10]. Our previous report demonstrated that the socket was positioned approximately 10 mm higher than the anatomical hip joint center for THA after PAO [11]. Other reports also demonstrated the tendency of the socket to be positioned superolaterally [8–10]. However, there is no unified consensus regarding the solution for THA socket installation after PAO.

Based on these backgrounds, in this study, we performed computed tomography (CT)-based simulation for socket installation. First, we compared acetabular defects in the anatomical hip center that underwent THA after PAO to those of primary THA for OA in patients matched for age, sex, and Crowe classification. Second, we compared the acetabular defects when the socket was positioned 10 mm higher than the anatomical hip joint center and investigated the changes after covering the socket during THA after PAO.

Materials and methods

Patients and procedures

This study was a retrospective chart review approved by an institutional review board. All patients provided written informed consent to participate. The study included 55 patients (56 hips) who consecutively underwent THA between April 2010 and December 2017 because of OA progression after PAO. Therefore, the study group comprised 55 patients (56 hips). The types of PAO included eccentric rotational acetabular osteotomy (ERAO) [15], which was performed for 41 hips at our institution, and rotational acetabular osteotomy (RAO) [16], which was performed for 15 hips at other hospitals. Thirteen patients underwent PAO combined with intertrochanteric valgus osteotomy. Patients were 6 men (6 hips) and 49 women (50 hips) with a mean age of 56.6 years (range 27–80 years) at the time of THA. The mean age at the time of PAO was 43.2 years (range 12–63 years). The mean interval between PAO and THA was 14.5 years (range 1–37 years).

We also obtained hospital records to identify patients who underwent primary THA for OA. We designed a case–control study in which patients were matched by age (± 5 years), sex, and Crowe classification during the same period. We identified 55 patients (56 hips; primary OA group) with no history of osteotomy who underwent primary THA for hip dysplasia. There were no significant differences in age, sex, or body mass index between the groups (Table 1).

Acetabular morphologic evaluation of CT simulation

Acetabular morphologic evaluations were performed using preoperative CT scanning (Aquilion One; Toshiba Medical Systems Co, Tochigi, Japan) of the hip. Briefly, the patients were placed in the supine position and images were obtained in the operative plane with 2-mm intervals from the anterosuperior iliac spine to the distal femoral condyle. CT scanning dates were saved in Digital Imaging and Communications in Medicine (DICOM) and computer simulations were performed using a CT-based simulation software (CT-Based Hip; Stryker Orthopaedics, Kalamazoo, Michigan, USA). For measurement, the pelvic position was standardized with reference to the anterior pelvic plane, determined by the anterior superior iliac spines and the pubic tubercles (Fig. 1a) [17].

The acetabular defect was evaluated using the measurement method of Yang et al. [17]. First, we described the 20-mm vertical hip level from the teardrops that was considered the anatomical hip center [18] in the axial view using, and identified the original anterior and posterior acetabular

Table 1 Patients' demographics

	Primary OA group ($n = 56$)	Study group ($n = 56$)	p value
Number of patients	55	55	
Gender (male/female)	6:49	6:49	1
BMI	23.1 ± 3.7	23.7 ± 3.9	0.382
Age at THA (years)	57.1 ± 6.3	56.6 ± 6.4	0.668
Duration PAO to THA (years)	–	14.5 ± 6.6	–
Combined ITVO	–	13	–
Crowe classification			1
Group I	25	25	
Group II	21	21	
Group III	10	10	

OA osteoarthritis, *BMI* body mass index, *THA* total hip arthroplasty, *PAO* periacetabular osteotomy, *ITVO* intertrochanteric valgus osteotomy

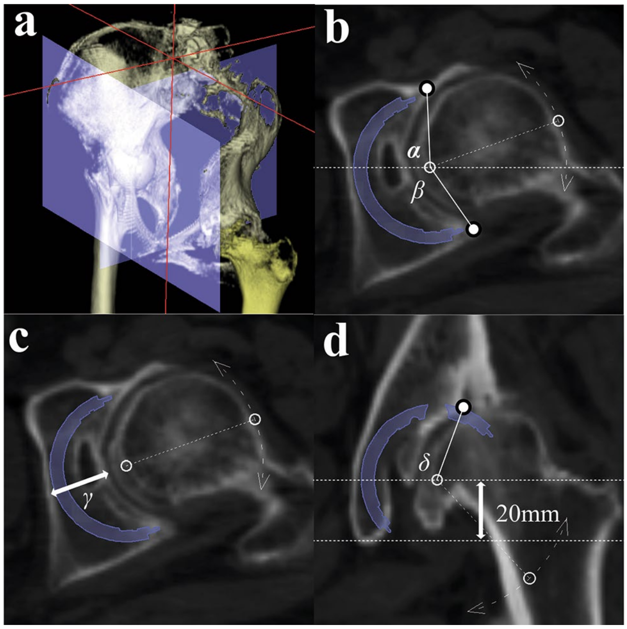

Fig. 1 **a** Anterior pelvic plane, **b** α: anterior ASA, β: posterior ASA, **c** γ: medial wall thickness, **d** δ: superior ASA

walls. Second, we determined socket size according to the anteroposterior acetabular width and placed the socket medially, with the acetabular width at an angle of 20° of anteversion and 45° of inclination. We evaluated the anterior and posterior acetabular sector angles (ASA), which are the angles between the original anteroposterior wall and parallel line connecting the anterior superior iliac spine, with a central focus on the hip joint center (Fig. 1b). In addition, we measured the medial wall thickness (MWT) which is the medial wall length with the axial plane passing through the central focus on the hip joint center (Fig. 1c). Third, to treat the superior acetabular defect, the 20-mm vertical hip level using the coronal view and defined the superior ASA, which is the angle between the original superior wall with a central focus on the hip joint center (Fig. 1d).

Additionally, we evaluated acetabular defects with THA after PAO with the socket in a high position. We described the axial view of the vertical hip level 30 mm from the teardrops and determined socket size according to the anteroposterior acetabular width. We placed socket at the 30-mm vertical hip level in the same way as previously mentioned, and measured the ASA and MWT. Socket positioned in the 20- and 30-mm vertical levels were categorized into the anatomical PAO group and elevated PAO group, respectively.

Inter-rater reliability

Image measurements were performed three times by two physicians, and the median value was used. To assess the reliability of these measurements, 20 hips were chosen at random and assessed by two surgeons. Inter-rater reliability values for the anterior, posterior, superior ASA and MWT were 0.783, 0.801, 0.842 and 0.772, respectively.

Statistical analysis

Statistical analyses of the anatomical PAO group, primary OA group and elevated PAO group were performed using SPSS version 21 (IBM Corp., Armonk, NY, USA). The analyses consisted of Student's *t* test and Chi-squared test for comparison between the two groups, ANOVA and Tukey's test for comparison between the three groups, with the level of significance set at 0.05. Data were expressed as mean ± standard deviation.

Results

The anterior ASAs were significantly smaller in the anatomical PAO group (49.9° ± 21.9°) than in the primary OA group (62.5° ± 7.0°) and the elevated PAO group (57.9° ± 21.1°; $p < 0.01$) (Table 2). The posterior ASAs were significantly smaller in the anatomical PAO group (95.7° ± 18.3°) than in the primary OA group (108.6° ± 7.8°) and the elevated PAO group (106.8° ± 15.5°; $p < 0.01$). In addition, the superior ASA and MWT were significantly different among the anatomical PAO group (95.5° ± 18.9°, 9.9 ± 5.5), the primary OA group (101.2° ± 9.0°, 15.5 ± 5.2), and the elevated PAO group (127.4° ± 16.5°, 12.7 ± 4.6; $p < 0.01$, $p < 0.01$).

With respect to the Crowe classification for group I, the anterior ASA of the anatomical PAO group (53.9° ± 28.1°) was smaller than those of the primary OA group (65.3° ± 6.5°) and the elevated PAO group (63.1° ± 23.6°; $p < 0.01$). The superior ASA of the primary OA group (105.4° ± 8.4°) and the anatomical PAO group (105.9° ± 15.1°) was smaller than those of the elevated PAO group (134.8° ± 10.9°; $p < 0.01$). However, the posterior ASA and MWT were not significantly different among the three groups. Considering a Crowe group II/III, the anterior and posterior ASAs of the anatomical PAO group (46.7° ± 14.1°, 88.3° ± 21.5°) were significantly smaller than those of the primary OA (60.3° ± 7.4°, 110.5° ± 6.5°) and the elevated PAO (53.8° ± 17.6°, 104.2° ± 15.7°; $p < 0.01$ and $p < 0.01$, respectively) groups. The superior ASA and MWT were significantly different among the anatomical PAO (87.3° ± 22.4°, 8.2 ± 5.1), primary OA (97.8° ± 9.2°, 18.8 ± 3.8), and elevated PAO groups (121.6° ± 15.3°, 12.8 ± 4.6; $p < 0.01$ and $p < 0.01$, respectively).

Discussion

Several reports demonstrated morphological changes after PAO, and Peters et al. observed acetabular retroversion were present in 29/83 cases (35%) after PAO [19]. Fukui

Table 2 The morphological comparison of primary THA and THA after PAO

	Primary OA group	Anatomical PAO group	Elevated PAO group	*p* value
Anterior ASA (°)	62.5 ± 7.0	49.9 ± 21.9	57.9 ± 21.1	< 0.01[a,c]
Crowe group I (n = 25)	65.3 ± 6.5	53.9 ± 28.1	63.1 ± 23.6	< 0.01[a,c]
Crowe group II/III (n = 31)	60.3 ± 7.4	46.7 ± 14.1	53.8 ± 17.6	< 0.01[a,c]
Posterior ASA (°)	108.6 ± 7.8	95.7 ± 18.3	106.8 ± 15.5	< 0.01[a,c]
Crowe group I (n = 25)	106.2 ± 8.4	104.9 ± 14.9	110.1 ± 15.2	0.217
Crowe group II/III (n = 31)	110.5 ± 6.5	88.3 ± 21.5	104.2 ± 15.7	< 0.01[a,c]
Superior ASA (°)	101.2 ± 9.0	95.5 ± 18.9	127.4 ± 16.5	< 0.01[a,b,c]
Crowe group I (n = 25)	105.4 ± 6.7	105.9 ± 15.1	134.8 ± 10.9	< 0.01[b,c]
Crowe group II/III (n = 31)	97.8 ± 9.2	87.3 ± 22.4	121.6 ± 15.3	< 0.01[a,b,c]
MADT (mm)	15.5 ± 5.2	9.9 ± 5.5	12.7 ± 4.6	< 0.01[a,b,c]
Crowe group I (n = 25)	11.5 ± 3.6	12.0 ± 6.6	12.7 ± 5.1	0.682
Crowe group II/III (n = 31)	18.8 ± 3.8	8.2 ± 5.1	12.8 ± 4.6	< 0.01[a,b,c]

THA total hip arthroplasty, *PAO* periacetabular osteotomy, *ASA* acetabular sector angle, *MWT* medial wall thickness, *OA* osteoarthritis

[a]Primary OA group vs anatomical PAO group: $p < 0.05$

[b]Primary OA group vs elevated PAO group: $p < 0.05$

[c]Anatomical PAO group vs elevated PAO group: $p < 0.05$

et al. reported that acetabular retroversion and posterior wall defects that accompany THA after PAO affect socket alignment [10]. Similarly, Tamaki et al. reported posterior wall defects and increased anterior and lateral coverage for THA after PAO [12]. In the current study, we demonstrated that not only the posterior but also the anterior ASA were significantly smaller in the anatomical PAO group than in the primary OA group, especially in Crowe II/III. Interestingly, the superior ASA which was thought to be improved with covering due to rotation of the bone fragment was significantly smaller in the anatomical PAO group than in the primary OA group. On the other hand, especially in Crowe I, there were no significant differences in any of the ASAs, except for the anterior ASA, between the anatomical PAO and primary OA groups (Fig. 2). These results suggested that failed PAO leads to circumferential acetabular defects with subsequent THA.

A previous report suggested that stable socket fixation was required when the socket center edge angle was 0° (equal to 90° of superior ASA) or more [20]. The current study demonstrated that for the anatomical PAO groups of Crowe groups II/III, significantly stronger acetabular defects were clearly exhibited, making it difficult to place the socket in the anatomical hip center compared to the primary OA group. The reason for this was considered to be the defects of bone stock in the anatomical hip center. The current study demonstrated that the MWT of the anatomical PAO group was significantly smaller compared to that of the primary OA group. In general, osteophytes often form on the medial side of the acetabular lid when the femoral head center is moved superolaterally over time due to osteoarthritis [17].

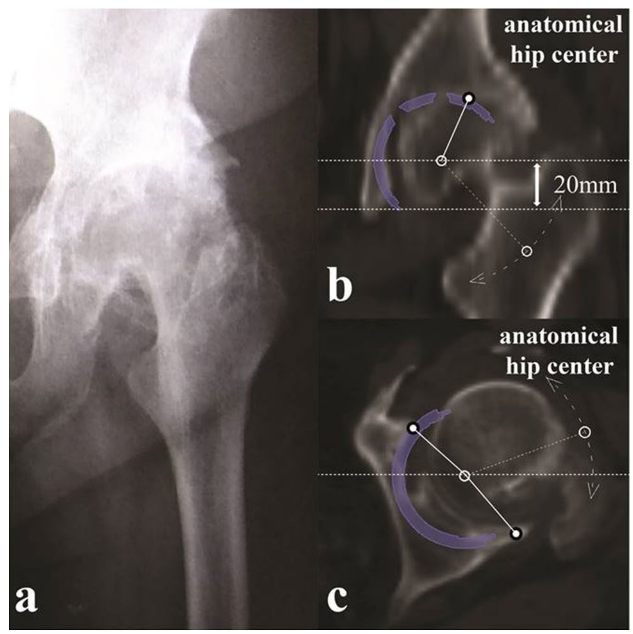

Fig. 2 **a** A preoperative radiograph showing the left hip of a 68-year-old woman with osteoarthritis 12 years after PAO in the Crowe group I. **b** CT-based simulation of coronal image showing sufficient superior coverage for socket in the anatomical hip center. **c** An axial image of the anatomical hip center showing insufficient anterior and sufficient posterior socket coverage

Therefore, with primary THA, it is often possible to cover the socket medially using medial wall osteophytes in the anatomical hip center (Fig. 3). However, the rotating bone fragments collapse and the femoral head center is moved

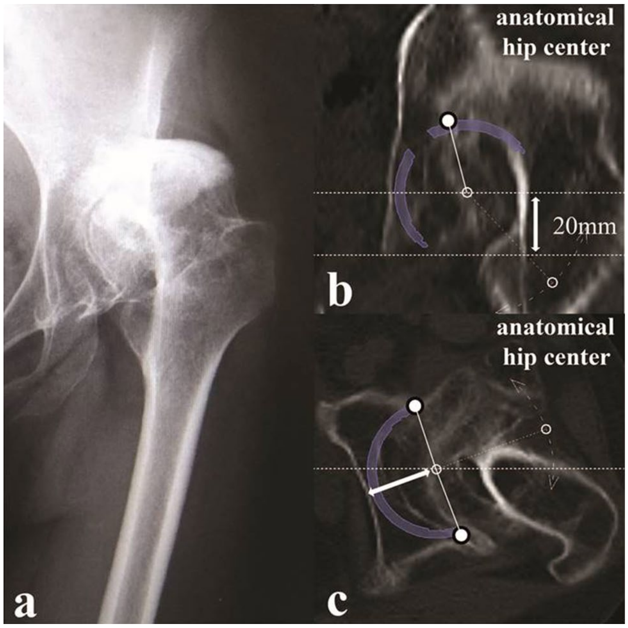

Fig. 3 **a** A preoperative radiograph showing the left hip of a 59-year-old woman with osteoarthritis in the Crowe group III. **b** CT-based simulation of a coronal image showing sufficient bone stock in the anatomical hip center. However, superior ASA was slightly less than 90°. **c** An axial image showing the large medial wall and the possibility of anterior and posterior socket coverage

superolaterally after PAO, and medial osteophyte formation at the anatomical hip center does not occur during OA progression; therefore, subsequent reconstruction is thought to be difficult in THA after PAO (Fig. 4).

Previous reports demonstrated that the postoperative hip joint center tended to have superolateral positioning with THA after PAO [8–11]. When the socket is placed in the anatomical hip center for THA after PAO, many cases require large bone grafts due to extensive wall defects [21], and this surgical technique is considered difficult. The current study demonstrated that it is possible to achieve improvements in the acetabular covering for socket placement by elevating the hip joint center by 10 mm (Fig. 4). Although the socket should be placed in the anatomical hip center [14], an elevated hip joint center is one therapeutic option for cases of severe acetabular wall defects. It may be better to considered bone grafting or using a support plate if the acetabular defect is severe when elevating the hip joint center.

The current study had some limitations. First, the study group was small ($n=56$). In future studies, the sample size should be larger and postoperative CT analysis should be performed. Second, we evaluated CT images in the anterior pelvic plane; we did not evaluate the functional pelvic plane. The results of this study did not consider pelvic tilt, and the results may have differed if we had evaluated CT images in the functional pelvic plane.

In conclusion, anterior, posterior and superior ASAs for THA after PAO were significantly smaller than those of primary OA. Elevating the hip joint center as much as 10 mm creates great improvements in covering the socket and is one therapeutic option for severe acetabular wall defects.

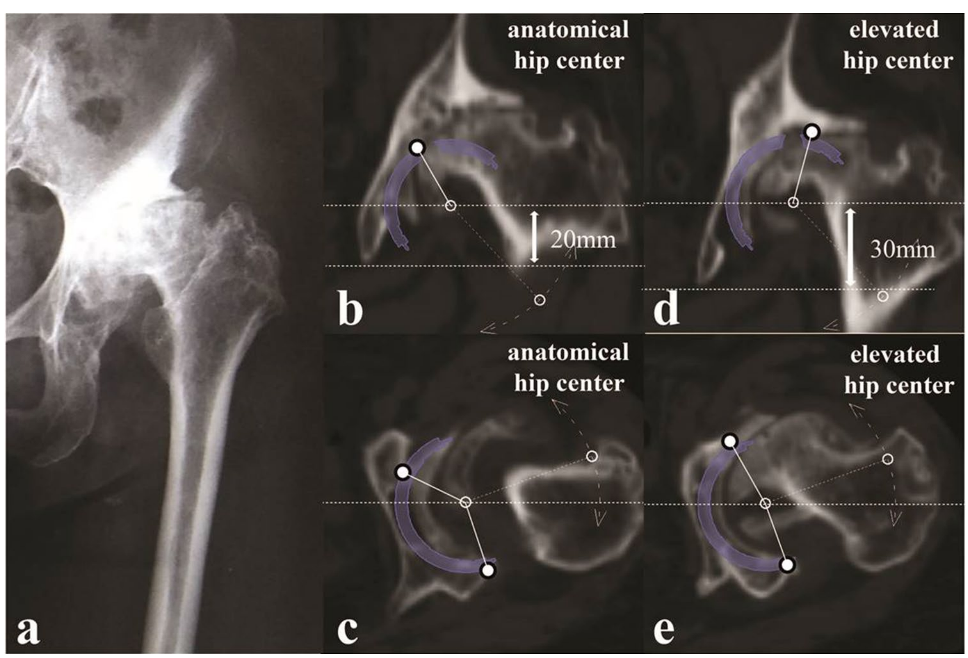

Fig. 4 **a** A preoperative radiograph showing the left hip of a 55-year-old woman with osteoarthritis 6 years after PAO in the Crowe group III. **b** CT-based simulation of coronal image showing severe superior wall defects in the anatomical hip center. **c** An axial image of the anatomical hip center showing insufficient anterior wall coverage. **d** On elevating the hip joint center by 10 mm, the superior ASA improved to more than 100°. **e** An axial image in the elevated hip center showing sufficient anterior and posterior socket coverage

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Compliance with ethical standards

Conflict of interest All the authors state that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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