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Research article

Analysis of survivorship following periacetabular osteotomy for hip dysplasia based on three-dimensional acetabular coverage

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ABSTRACT

Periacetabular osteotomy (PAO) is an established procedure for correcting acetabular coverage and preventing osteoarthritis progression in hip dysplasia. However, it is unclear how acetabular coverage changes three-dimensionally after PAO and how it affects survival. Therefore, this study aimed to investigate the change in three-dimensional acetabular coverage preoperatively and postoperatively and identify demographic, clinical and radiographic factors associated with conversion to total hip arthroplasty (THA) and radiographic osteoarthritis progression after PAO. We retrospectively reviewed 46 consecutive patients (66 hips) who underwent PAO, using preoperative and postoperative radiographs and pelvic computed tomography (CT). Three-dimensional acetabular coverage based on CT data was investigated. Kaplan–Meier survival analysis was performed, and hazard ratios were calculated using univariate Cox regression models to identify the risk factors associated with conversion to THA and radiographic osteoarthritis progression after PAO as the endpoints. Radiographic osteoarthritis progression was defined as a minimum joint space of <2.0 mm. The mean follow-up was 10.7 years. Post-PAO, acetabular coverage gradually increased from the anterosuperior to the superior to the posterosuperior direction. The survival rate after PAO was 98.0% at 10 years. Less postoperative superior acetabular coverage, with a hazard ratio of 0.93, was significantly associated with conversion to THA and radiographic osteoarthritis progression after PAO ($P = 0.03$). In this study, poor superior acetabular coverage after PAO was a significant risk factor for conversion to THA and radiographic progression of osteoarthritis. Therefore, surgeons should attempt to prioritize the correction of the superior acetabular coverage when performing PAO.

INTRODUCTION

Periacetabular osteotomy (PAO) is a standard treatment for correcting acetabular coverage and preventing osteoarthritis of the dysplastic hip [1–3]. Although several studies have reported good long-term results with PAO, it does not completely prevent the progression of osteoarthritis [1, 4]. Therefore, it is important to select patients who will receive sufficient benefit from PAO and then perform appropriate surgery with a precise target to prevent the progression of osteoarthritis. Previous studies have reported various demographic and preoperative radiographic risk factors for the progression of osteoarthritis and conversion to total hip arthroplasty (THA) after PAO: advanced age at surgery, severe hip dysplasia, preoperative osteoarthritic change and poor preoperative joint congruency in hip abduction [4–7]. With regard to surgery-related factors, only the lower centre-edge angle on plain radiographs after PAO weakly correlates with the deterioration of osteoarthritis [8, 9].

A previous analysis based on computed tomography (CT) data reported that acetabular deficiency patterns of dysplastic hips have several deficiency types [10]. In PAO, an understanding of three-dimensional acetabular morphology is required to correct acetabular deficiency appropriately. Owing to the limited ability of plain radiography to assess the acetabular morphology of dysplastic hips [10], three-dimensional imaging with CT is becoming the gold standard for analysing acetabular morphology [11]. Biomechanical analysis using the finite element method revealed that insufficient acetabular coverage after PAO results in high mechanical stress at the hip joint [12]. However, with limited data on three-dimensional changes in acetabular coverage after PAO, its surgery-related effect on the progression of osteoarthritis remains unclear, necessitating the need to investigate which part of the three-dimensional acetabular coverage could predict a poor outcome of PAO.

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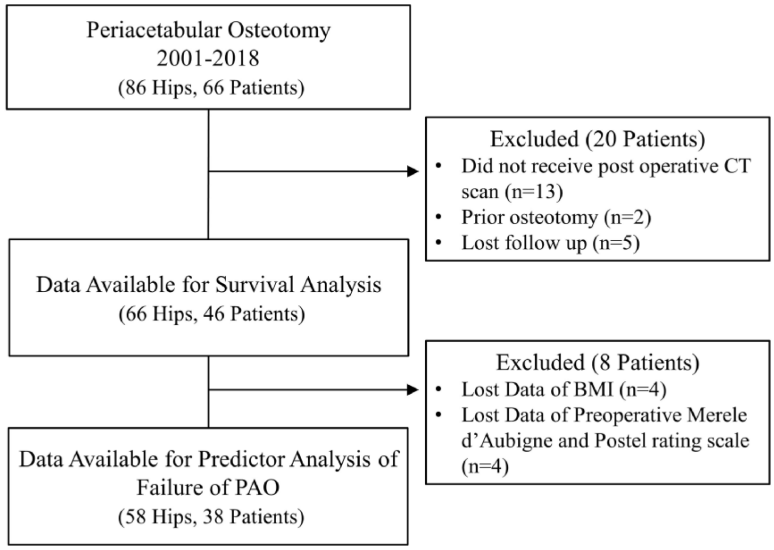

Fig. 1. A flow diagram of the study.

Therefore, this study aimed to identify the demographic, clinical and surgery-related factors associated with conversion to THA and radiographic osteoarthritis progression after PAO by evaluating the hip survival rates and changes in three-dimensional acetabular coverage preoperatively and postoperatively. This study hypothesizes that superior acetabular coverage in the three-dimensional acetabular coverage would have the strongest effect on joint survivorship after PAO.

MATERIALS AND METHODS

Study participants

This retrospective study was approved by the institutional review board. The surgical indications for PAO are as follows: (i) persistent hip pain after conservative treatment for at least 3 months, (ii) lateral centre-edge angle of Wiberg <25° and (iii) a closed epiphyseal line [13]. The contraindications for PAO were (i) advanced osteoarthritis above Tönnis Grade 2 and (ii) no improvement in joint congruity and femoral head coverage by maximum hip abduction on radiography [5]. This study included 66 consecutive patients (86 hips) who underwent PAO in one or both hips to treat hip dysplasia between January 2001 and April 2018. The exclusion criteria are as follows: (i) lost to follow-up within 2 years, (ii) underwent prior pelvic surgery and (iii) did not undergo postoperative CT scans. We excluded five patients (five hips) who were lost to follow-up within 2 years, two patients (two hips) who had undergone prior surgery and 13 patients (13 hips) who did not receive postoperative CT scans. The remaining 46 patients (66 hips) were included in the study group (Fig. 1). The mean follow-up was 10.7 years [range, 2.4–21.9 years; 95% confidence interval (CI), 9.1–12.4 years].

Surgical procedures and postoperative management

All surgeries were performed by an expert surgeon (T.J.) with >20 years of experience in hip surgery. PAO was performed through the trans-trochanteric lateral approach with osteotomy of the greater trochanter, leaving the posterior column intact [14]. Acetabular reorientation was performed to target a 0° acetabular roof angle using intraoperative fluoroscopy [1]. The acetabular fragment was fixed using three cortical cannulated screws. During PAO, acetabular anteversion was monitored using intraoperative fluoroscopy to check the anterior and posterior rims of the acetabulum. After the acetabular fragment was provisionally fixed, we confirmed whether femoroacetabular impingement occurred with 90° of hip flexion, 20° of internal rotation and 30° of abduction. We finally checked the acetabular retroversion using fluoroscopy. When impingement occurred, the acetabular fragment correction was changed. Patients were mobilized the day after surgery, and physical therapists guided the rehabilitation through a regimen of partial weight-bearing using two crutches. In the regimen, for the first 4 weeks, toe touch was permitted; for 5–8 weeks, half partial weight-bearing and for 9–12 weeks, two-third partial weight-bearing. Pelvic radiographs were analysed at 1, 2, 4 and 8 weeks after surgery to confirm that the acetabular fragment was not displaced. After reviewing the radiographs at 12 weeks postoperatively, full weight-bearing was allowed.

Clinical evaluations and radiographic assessment

Medical records were retrospectively reviewed to collect demographic data, including age, sex, body mass index (kg/m^2) and preoperative clinical scores at the time of examination. The demographic data of the 46 patients are presented in Table I. Dysplasia of all hips was classified as Type 1 according to the Crowe classification. Preoperative clinical evaluation was performed using the Merle d'Aubigné and Postel rating scale [15]. Pain, mobility and walking ability were scored from 0 to 6. A high score indicated good hip performance, and a score of 18 was considered perfect. A board-certified orthopaedic surgeon (T.T.) assessed the radiographic measurements based on radiographic parameters as follows: the grade of osteoarthritis according to the Tönnis classification (Grade 0–3) on preoperative radiographs; the lateral centre-edge angle of Wiberg

Table I. ***Demographic data for the 46 patients (66 hips)***

Parameter	***Value***
Age[a] (years)	32 (14–55)
Sex (cases)[b]	
Male	4 (6)
Female	62 (94)
Body mass index[a] (kg/m^2)	23 (15–32)
Tönnis grade (cases)[b]	
Grade 0	25 (38)
Grade 1	38 (58)
Grade 2	3 (4)
Merle d'Aubigné–Postel score[a]	15 (10–18)

[a]Values are presented as the median (range).
[b]Values are presented as a number (%).

in both pre- and postoperative radiographs at 3 months after PAO and minimal joint space width, measured as the smallest width between the sclerotic acetabular zone and the femoral head in pre- and postoperative radiographs at the last follow-up [13, 16, 17]. Radiographic osteoarthritis progression after PAO was defined as less than 2 mm on the minimum joint space width [18]. The endpoints in our survivorship analysis were defined as (i) conversion to THA and (ii) radiographic osteoarthritis progression [1]. All assessments were performed using a supine pelvic anteroposterior radiograph taken annually postoperatively.

Three-dimensional acetabular coverage evaluation

To measure the acetabular coverage angle on CT, we modified and extended the measurement method reported by Anda et al. [20]. Similar measurement methods have been used and validated in previous studies of acetabular coverage in hip dysplasia [24]. Pelvic CT was performed with the patients in the supine position before surgery and within 3 months after surgery. Images were obtained from the superior rim of the iliac wing to the distal femur, including the femoral condyles, at 1.0-mm intervals. Once data were downloaded from these scans in Digital Imaging and Communications in Medicine format, the following measurements were performed using image-processing software (3-D template; Kyocera Medical Corporation, Osaka, Japan). First, the pelvic position was standardized regarding the anterior pelvic plane (APP) coordinate system, defined by the bilateral anterosuperior iliac spines and midpoint between the pelvic tubercles (Fig. 2a) [19]. The APP angle in the supine position was measured as the angle between the APP and the horizontal plane [16].

Second, acetabular coverage was defined as the angle measured between a horizontal line through the centre of the femoral head and a line connecting the centre of the femoral head and the acetabular edge. The acetabular coverage was measured in 12 directions by rotating the pelvis in the sagittal plane every 30° and measuring the acetabular coverage in the reconstructed coronal plane (Fig. 2b). Along the clock face, we labelled the directions as follows: superior (labelled as 12 o'clock), supero-anterior (labelled as 1 o'clock), antero-superior (labelled as 2 o'clock), anterior (labelled as 3 o'clock), antero-inferior (labelled as 4 o'clock), infero-anterior (labelled as 5 o'clock), inferior (labelled as 6 o'clock), infero-posterior (labelled as 7 o'clock), postero-inferior (labelled as 8 o'clock), posterior (labelled as 9 o'clock), postero-superior (labelled as 10 o'clock) and supero-posterior (labelled as 11 o'clock) [16, 20]. The anterior centre-edge angle

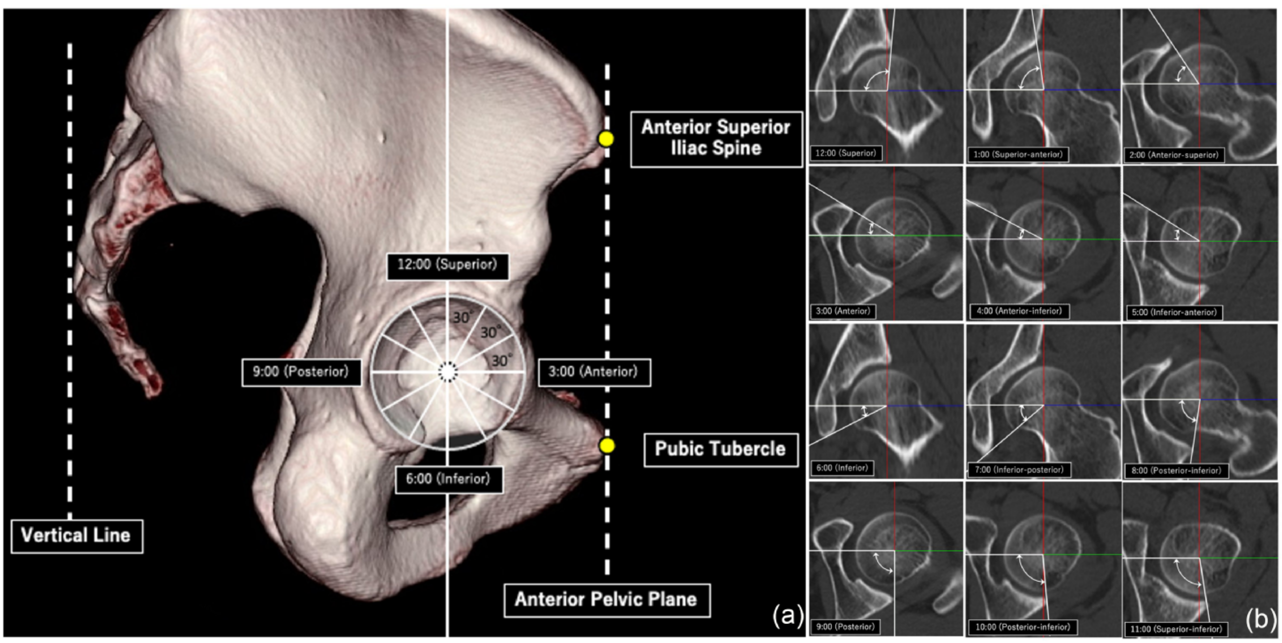

Fig. 2. Methods for measuring the three-dimensional acetabular coverage. (a) The pelvic position is standardized with reference to the APP coordinate system. (b) The acetabular coverage was defined as an angle between a line connecting the acetabular edge and femoral head's centre and a horizontal line. The three-dimensional acetabular coverage was measured in 12 directions on the acetabular clock face.

Table II. ***Intra-observer reliability and inter-observer reliability***

Parameter	*Intra-observer reliability*	*Inter-observer reliability*
Preoperative acetabular coverage 12:00	0.97 (0.94–0.99)	0.97 (0.91–0.98)
1:00	0.99 (0.97–0.99)	0.96 (0.89–0.98)
2:00	0.99 (0.96–0.99)	0.94 (0.84–0.97)
3:00	0.97 (0.92–0.98)	0.99 (0.96–0.99)
4:00	0.93 (0.84–0.97)	0.82 (0.59–0.92)
5:00	0.95 (0.87–0.97)	0.89 (0.75–0.95)
6:00	0.98 (0.94–0.99)	0.88 (0.71–0.94)
7:00	0.91 (0.78–0.96)	0.84 (0.63–0.93)
8:00	0.96 (0.89–0.98)	0.89 (0.74–0.95)
9:00	0.98 (0.96–0.99)	0.98 (0.93–0.99)
10:00	0.99 (0.96–0.99)	0.98 (0.93–0.99)
11:00	0.96 (0.89–0.98)	0.95 (0.87–0.97)
Postoperative acetabular coverage 12:00	0.95 (0.88–0.98)	0.96 (0.89–0.98)
1:00	0.91 (0.77–0.96)	0.95 (0.87–0.98)
2:00	0.98 (0.94–0.99)	0.97 (0.93–0.99)
3:00	0.96 (0.90–0.98)	0.94 (0.86–0.97)
4:00	0.91 (0.78–0.96)	0.86 (0.67–0.94)
5:00	0.86 (0.68–0.94)	0.92 (0.80–0.96)
6:00	0.98 (0.94–0.99)	0.98 (0.94–0.99)
7:00	0.91 (0.78–0.96)	0.99 (0.98–0.99))
8:00	0.86 (0.67–0.94)	0.94 (0.86–0.97)
9:00	0.96 (0.90–0.98)	0.95 (0.87–0.98)
10:00	0.96 (0.89–0.98)	0.93 (0.83–0.97)
11:00	0.96 (0.90–0.98)	0.95 (0.88–0.98)

Values are presented as numbers (95% CI).

and acetabular anteversion were quantified in sagittal and transverse sections through the centre of the femoral head, respectively [16]. All measurements of the acetabular CT parameters were performed with correction to the APP. Measurement of femur anteversion was performed according to the retrocondylar plane [25]. A board-certified orthopaedic surgeon (T.T.) performed all measurements. The intra-observer reliability of the CT parameters was tested by repeating the measurements as a blind test on 20 randomly selected hips more than 4 weeks later. The inter-observer variability of the CT parameters was assessed in a subset of 20 hips by two board-certified orthopaedic surgeons (T.T. and Y.N.). Inter- and intra-observer reliabilities were evaluated using intraclass correlation coefficients. The intraclass correlation coefficients of intra- and inter-observer reliabilities for acetabular coverage in all directions were 0.91–0.99 and 0.82–0.98 preoperatively and 0.86–0.96 and 0.86–0.99 postoperatively, respectively. The data for all directions are listed in Table II.

Statistical analysis

Data are presented as means with standard deviations when the distribution was normal and as medians with interquartile ranges when the distribution was skewed. Based on the distribution, a *t*-test for normal distribution and Wilcoxon signed-rank tests for skewed distribution were performed to compare continuous parameters. Correlations between preoperative and postoperative three-dimensional acetabular coverage in three directions (superior, anterior and posterior) were calculated using Spearman's rank correlation coefficients with Bonferroni correction for multiple comparisons. In addition, correlations between the postoperative lateral centre-edge angle and the postoperative three-dimensional acetabular coverage were calculated using the same method. The correlation coefficient was evaluated as weak (range, 0–0.4), moderate (range 0.4–0.7), strong (range 0.7–0.9) or excellent (range 0.9–1.0) [21]. Hip survivorship after PAO was visualized using Kaplan–Meier survival analysis. Hazard ratios were calculated using univariate Cox regression analyses to identify demographic, clinical and surgery-related factors (direction in the three-dimensional acetabular coverage) that could be responsible for the conversion to THA and radiographic osteoarthritis progression after PAO. In the Cox regression analysis, eight patients with missing values were excluded from the predictor analysis of PAO failure (Fig. 1). The significance level was set at $P < 0.05$ for all tests. Data were analysed using the STATA 16 software (StataCorp LP, College Station, TX, USA).

RESULTS

Change in three-dimensional acetabular coverage in pre- and postoperative PAO

After PAO, the median lateral centre-edge angle increased significantly from 10° (interquartile range, 2–15°) to 38.5° (interquartile range, 31–43°; $P < 0.001$). The mean minimal joint space width decreased significantly from 5.0 ± 1.0 mm preoperatively to 3.6 ± 1.4 mm at the last follow-up ($P < 0.001$). PAO significantly increased the three-dimensional acetabular coverage gradually from the anterosuperior (2 o'clock) to the superior (12 o'clock) and finally to the posterosuperior (10 o'clock) direction. It significantly decreased the radial acetabular coverage in the anteroinferior (4 o'clock), inferior (6 o'clock) and posteroinferior (8 o'clock) directions (Table III).

The superior (12 o'clock) direction showed the greatest increase in acetabular coverage at an increased angle of 29° (Fig. 3). A moderate correlation was observed between postoperative and preoperative acetabular coverage in the superior (12 o'clock) ($r = 0.55$; $P < 0.001$) and posterior (9 o'clock) ($r = 0.52$; $P < 0.001$) directions. The postoperative lateral centre-edge angle significantly correlated only with the postoperative acetabular coverage at the 12:00, 1:00, 11:00 and 10:00 directions. Of these, the postoperative lateral centre-edge angle correlated most strongly with the 12:00 direction ($r = 0.81$, $P < 0.001$). PAO increased the anterior centre-edge and acetabular anteversion angles by 28° and 17°, respectively.

Survival analysis and risk factors of conversion to THA or progression to advanced osteoarthritis

Conversion to THA and radiographic osteoarthritis progression after PAO were observed in 7 of the 66 hips (10.6%) at 1.8–19.0 years, among which two were converted to THA and five showed progression of osteoarthritis. With the conversion to THA or progression of osteoarthritis as the endpoint, Kaplan–Meier analysis showed a survival rate of 98.0% (95% CI, 89%–99.8%) at 10 years (Fig. 4). In the comparison of the

Table III. ***Comparisons of acetabular parameters between preoperatively and postoperatively***

Parameter	*Preoperative*	*Postoperative*	*Difference (95% CI)*	*P value*
Three-dimensional acetabular coverage (°)[a]				
12:00 (superior)	101 ± 11	130 ± 10	29 (27–32)	<0.001
1:00	94 ± 9	122 ± 20	28 (24–32)	<0.001
2:00	63 ± 14	77 ± 35	14 (7–22)	<0.001
3:00 (anterior)	43 ± 9	38 ± 21	−4 (−9 to 1)	0.130
4:00	39 ± 7	25 ± 15	−14 (−17 to −10)	<0.001
5:00	34 ± 6	17 ± 13	−17 (−20 to −14)	<0.001
6:00 (inferior)	32 ± 4	13 ± 13	−18 (−21 to −15)	<0.001
7:00	62 ± 13	25 ± 25	−37 (−43 to −31)	<0.001
8:00	83 ± 8	66 ± 19	−16 (−20 to −12)	<0.001
9:00 (posterior)	93 ± 8	96 ± 15	3 (0.5–7)	0.050
10:00	100 ± 8	118 ± 13	18 (15–21)	<0.001
11:00	103 ± 9	129 ± 11	27 (24–29)	<0.001
Acetabular anteversion angle (°)[a]	25 ± 6	29 ± 16	4 (0–8)	0.060
Anterior centre-edge angle (°)[a]	42 ± 17	59 ± 14	17 (12–21)	<0.001
Femur anteversion (°)[a]	30 ± 15			
APP angle (°)[a]	6.0 ± 4	4.8 ± 6	−1.2 (−2 to −0.1)	0.03

[a]Values are presented as the mean ± standard deviation or the median (interquartile range).

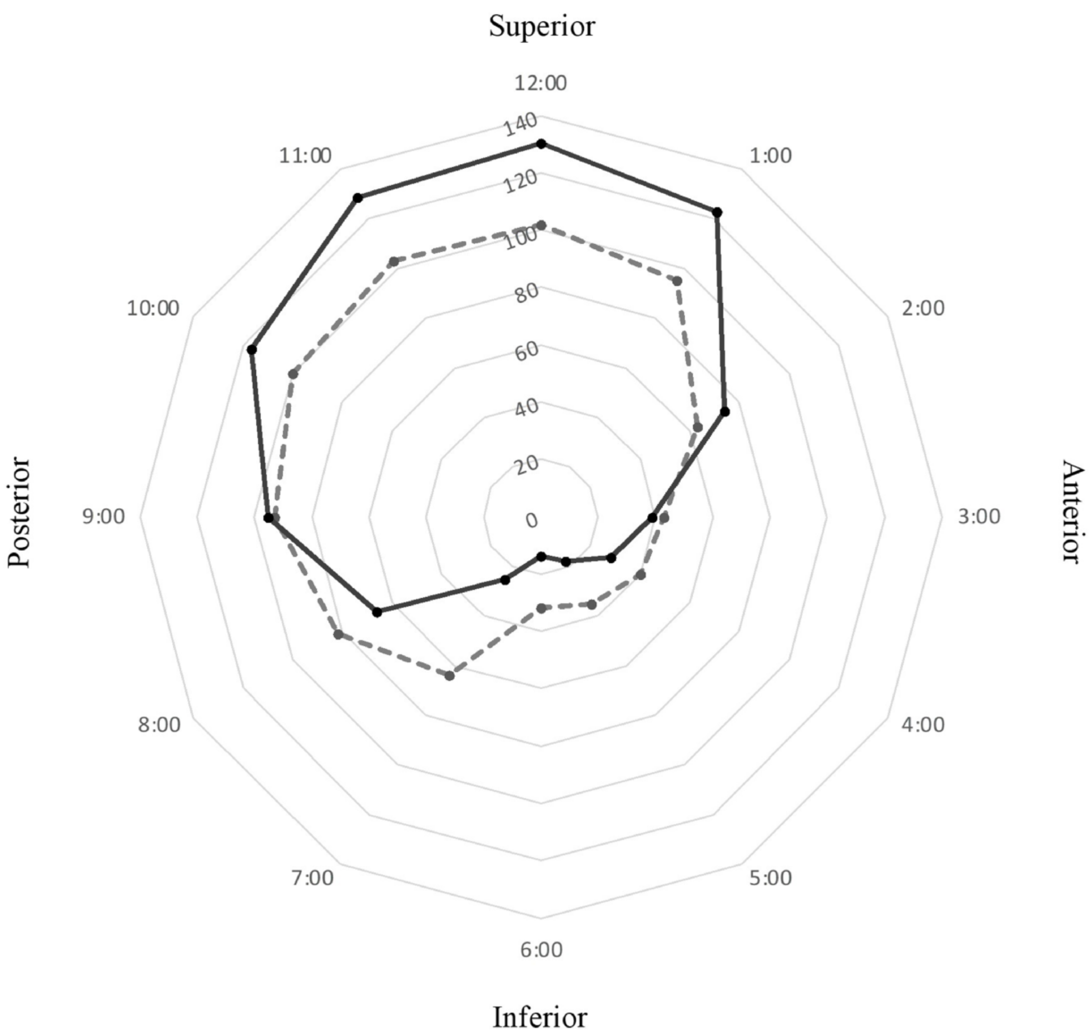

Fig. 3. Differences in the three-dimensional acetabular coverage between preoperative (dotted line) and postoperative (solid line). There is a statistical increase in the direction from 2 o'clock to 10 o'clock after PAO.

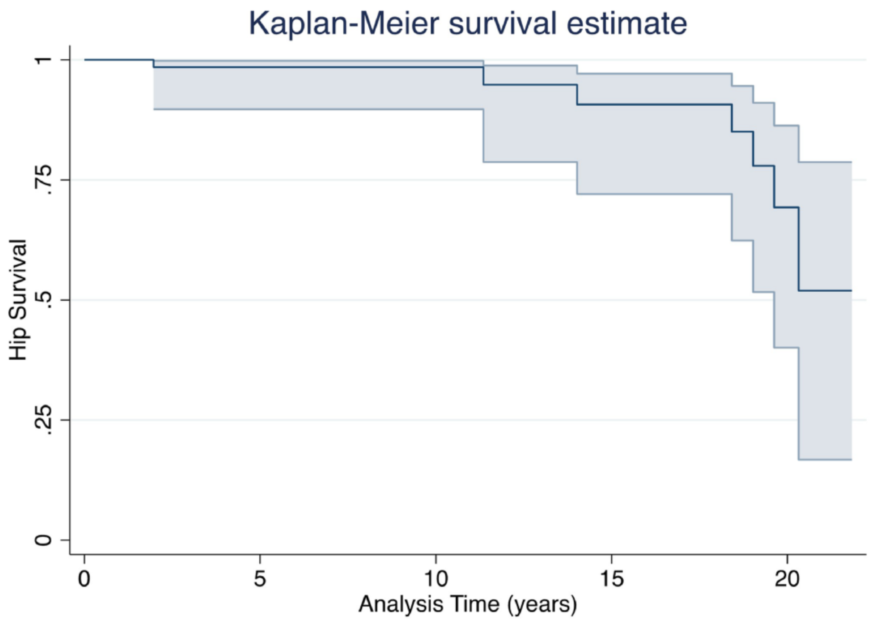

Fig. 4. A Kaplan–Meier survivorship curve with 95% CI. The endpoints after PAO are defined as conversion to THA or radiographic progression of osteoarthritis (minimum joint space width < 2.0 mm). The hip survival rate is 98.5% (95% CI, 89.7%–99.8%) at 10 years.

cases with radiographic OA progression and conversion to THA (seven hips) and the cases without OA progression (59 hips), the preoperative lateral centre-edge angle was 3.4 versus 8.4 degrees ($P = 0.06$), the postoperative lateral centre-edge angles was 21.7 versus 39.1 ($P = 0.001$), the preoperative acetabular coverage at 12:00 was 99.9 versus 101.4 ($P = 0.7$) and the postoperative acetabular coverage at 12:00 was 123.0 versus 131.6 ($P = 0.03$), respectively.

Univariate analysis of risk factors responsible for the conversion to THA or progression to advanced osteoarthritis was identified to be a surgery-related factor: the postoperative superior acetabular coverage (labelled as 12 o'clock), with a hazard ratio of 0.93 (95% CI, 0.86–0.99, $P = 0.033$) (Table IV). The preoperative minimal joint space width, as well as all the other demographic and clinical factors, did not show any significant correlation with PAO failure with a hazard ratio of 0.59 (95% CI, 0.31–1.11, $P = 0.1$).

DISCUSSION

The most important finding of the current study was that poor postoperative superior acetabular coverage was a significant risk factor associated with conversion to THA and radiographic osteoarthritis progression after PAO based on the analysis of three-dimensional acetabular coverage. We observed that the acetabular coverage of a dysplastic hip increased from the anterosuperior to the posterosuperior direction after PAO. These results indicate that it is critical to improving the superior acetabular coverage when performing PAO.

Koga et al. reported that the postoperative centre-edge angle influenced the progression of osteoarthritis after PAO [8]. Consistent with these findings, we demonstrated that decreased postoperative superior acetabular coverage was a significant risk factor for conversion to THA and radiographic osteoarthritis progression after PAO based on CT data (hazard ratio, 0.93). We found only a moderate correlation between preoperative and postoperative superior acetabular coverage ($r = 0.55$). These results may support the fact that superior postoperative acetabular coverage is vital. Because decreased preoperative acetabular coverage in the three-dimensional analysis was not a significant risk factor, we considered that the cause of decreased postoperative superior coverage was not the preoperative shallow acetabulum but the inaccurate intraoperative confirmation regarding the achievement of the desired acetabular correction. In contrast, previous reports have shown that acetabular overcorrection or acetabular retroversion is associated with a risk of postoperative femoroacetabular impingement [9, 22, 26]. In this study, however, postoperative acetabular retroversion was not a significant risk factor (hazard ratio, 0.96; $P = 0.196$). Although further studies are needed to prove that avoiding acetabular retroversion after PAO might reduce the risk of femoroacetabular impingement, surgeons should improve superior acetabular coverage and pay attention to acetabular retroversion when performing PAO.

Steppacher et al. reported that the risk factors for PAO leading to conversion to THA were advanced age at surgery and high osteoarthrosis grade [4]. However, our study did not show a significant association with advanced age (hazard ratio, 1.07). In our study, less preoperative minimal joint space width was not a significant risk factor for PAO failure (hazard ratio, 0.59), which might be due to our strict operative indications for advanced osteoarthritis. Only three hips (4%) in our study were Tönnis Grade 2 or higher. As a result, our study's preoperative Merle d'Aubigné and Postel score was relatively high at 15. However, Lerch et al. reported that preoperative Merle d'Aubigné and Postel score <15 was a risk factor for progression of osteoarthritis after PAO [26], and we believe that the strictness of our PAO indication was appropriate.

Table IV. ***Hazard ratios for predictors of conversion to THA or progression of osteoarthritis***

Parameter	*Hazard ratio (95% CI)*	*P value*
Demographic and clinical data		
Age at surgery	1.05 (0.96–1.14)	0.258
Body mass index	1.08 (0.73–1.61)	0.699
Merle d'Aubigné–Postel score	0.71 (0.38–1.31)	0.268
CT data		
Preoperative acetabular coverage 12:00	0.96 (0.88–1.04)	0.338
1:00	0.94 (0.85–1.04)	0.234
2:00	1.02 (0.97–1.08)	0.497
3:00	1.02 (0.92–1.13)	0.746
4:00	1.04 (0.91–1.19)	0.599
5:00	1.06 (0.89–1.27)	0.493
6:00	1.03 (0.86–1.24)	0.767
7:00	0.99 (0.91–1.07)	0.764
8:00	0.99 (0.88–1.11)	0.850
9:00	0.98 (0.86–1.10)	0.689
10:00	0.93 (0.83–1.05)	0.241
11:00	0.95 (0.84–1.07)	0.406
Preoperative anterior centre-edge angle	0.97 (0.93–1.01)	0.171
Preoperative acetabular anteversion	0.95 (0.82–1.12)	0.563
Femoral anteversion	0.95 (0.88–1.02)	0.143
Preoperative APP angle	0.96 (0.78–1.17)	0.660
Postoperative acetabular coverage 12:00	0.93 (0.86–0.99)	0.033
1:00	0.97 (0.94–1.00)	0.055
2:00	1.00 (0.98–1.03)	0.950
3:00	1.02 (0.99–1.05)	0.282
4:00	1.02 (0.96–1.08)	0.537
5:00	1.06 (0.99–1.13)	0.081
6:00	1.06 (1.00–1.14)	0.063
7:00	1.00 (0.98–1.03)	0.883
8:00	1.01 (0.97–1.05)	0.745
9:00	1.00 (0.93–1.06)	0.895
10:00	0.96 (0.90–1.02)	0.195
11:00	0.94 (0.88–1.01)	0.080
Postoperative anterior centre-edge angle	0.99 (0.94–1.05)	0.784
Postoperative acetabular anteversion	0.96 (0.91–1.02)	0.196
Postoperative APP angle	0.92 (0.77–1.09)	0.305

For the assessment of anterior acetabular coverage, the anterior centre-edge angle on a false-profile radiograph is commonly used [27]. However, this study included only the anterior centre-edge angle on CT. Chen et al. reported no correlation between the anterior centre-edge angle on CT and the anterior centre-edge angle on false-profile view, and the anterior centre-edge angle on CT was a different indicator of anterior instability than that on false-profile view [28]. According to their study, the mean value of the preoperative anterior centre-edge angle on CT in patients with hip dysplasia was 42.6°, which is consistent with the findings of our study (42°). Further research is needed regarding the ideal postoperative anterior centre-edge angle.

Hartig-Andreasen et al. reported that the ideal postoperative centre-edge angle after PAO was 30–40° [9]. Although our results suggest that the ideal postoperative superior acetabular coverage should be as large as possible, Myers et al. reported that overcorrection after PAO was associated with femoroacetabular impingement [29]6. Therefore, we, too, suggested that the ideal postoperative centre-edge angle should be 30–40°. In particular, we considered that it should not be less than 30°. Because the range of the ideal postoperative acetabular superior coverage is relatively narrow, intraoperative fluoroscopy or radiography should be considered. The postoperative lateral centre-edge angle correlated strongly with postoperative acetabular coverage at 12:00, and therefore, we considered that postoperative superior acetabular coverage could be confirmed using the lateral centre-edge angle by intraoperative radiographs or fluoroscopy.

The strength of the present study was the accuracy of the measurement, which helped reveal the preoperative and postoperative three-dimensional acetabular coverage of PAO based on CT data. However, this study had some limitations. First, owing to the single-centre retrospective nature of this study, our findings were based on a relatively small sample size and a small number of endpoints, resulting in somewhat underpowered statistics power. Although performing a multivariate analysis for the risk factors associated with conversion to THA and radiographic progression of osteoarthritis would have been necessary for this study, only univariate analysis was performed to avoid overfitting the models. PAO with anterior approaches, such as the modified Smith–Petersen approach, might have shown different changes in postoperative three-dimensional acetabular coverage. Although this study revealed that decreased postoperative superior coverage was a risk factor after PAO (hazard ratio, 0.93), this result might be influenced by the small number of endpoints. Therefore, there is a need for a large, multicentre, prospective cohort study to evaluate the effects of three-dimensional acetabular coverage on PAO outcomes. Second, in this study, patients with poor joint congruency in hip abduction or advanced osteoarthritis were considered contraindications for PAO due to reports of poor outcomes [4, 9]. This might have resulted in an overestimation of the long-term outcome of PAO and might have underestimated the risk factors for conversion to THA and radiographic osteoarthritis progression, such as advanced age and low preoperative Merle d' Aubigné and Postel scores, which have been reported to be useful in previous studies [23]. Third, the evaluation of postoperative acetabular coverage in this study was performed based on CT data within 3 months after surgery. Therefore, acetabular fragments might have migrated after the CT scans. However, Ito et al. previously reported that radiographic bone union of acetabular fragments after PAO occurs approximately 3 months postoperatively; therefore, it is unlikely that the acetabular fragments migrated after CT scans in our study [23]. In addition, bone union between the acetabular fragment and ilium was observed in all cases postoperatively in this study. There were no cases of delayed unions after PAO. Fourth, the results of this study were based on the APP coordinate system, and the effect of pelvic tilt in the supine and standing positions was not considered. Although standardizing the pelvic position may be advantageous for anatomic and morphologic studies, a functional pelvic position and a weight-bearing position might be more suitable for assessing clinical hip dysplasia. It has been reported that 18% of patients with dysplastic hips have a change in pelvic tilt >10° from a supine to a standing position [16]. In such cases, the effects of pelvic tilt might be more important and affect the measurements of both three-dimensional acetabular coverage and acetabular version. Fifth, we did not include postoperative clinical data regularly. Radiographic osteoarthritis progression did not necessarily mean worsening symptoms or function. For evaluating highly active young patients who need PAO, clinical sores such as the Hip Disability and Osteoarthritis Outcome Score and the University of California, Los Angeles score may be appropriate [30].

CONCLUSION

This study observed that poor superior acetabular coverage after PAO was a significant risk factor associated with conversion to THA and radiographic osteoarthritis progression. The three-dimensional acetabular coverage of hip dysplasia increased from the anterosuperior to posterosuperior direction after PAO. Therefore, surgeons should attempt to prioritize the correction of the superior acetabular coverage when performing PAO.

DATA AVAILABILITY

The data underlying this article will be shared upon reasonable request to the corresponding author.

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CONFLICT OF INTEREST STATEMENT

None declared.

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