Original Article

Visualization of acetabular coverage with radar chart before and after curved periacetabular osteotomy in dysplastic hips

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Abstract

Background: Curved periacetabular osteotomy (CPO) is indicated for patients with developmental dysplasia of the hip (DDH) to prevent progressive osteoarthritis. Patients with DDH have not only lateral acetabulum dysplasia but also anterior and posterior dysplasia. The full circumference acetabular coverage angle (ACA) of the femoral head should be evaluated preoperatively. This study aimed to determine the full circumference ACA in the patients with DDH before and after CPO compared with the coverage in normal patients.

Methods: Twenty-three patients (a total of 24 hips) with DDH undergoing CPO between February 2006 and March 2014 were included in this study. The normal group was defined as the normal side in patients with unilateral osteonecrosis of the femoral head (ONFH) and the non-collapsed femoral head side in patients with bilateral ONFH. Pre- and postoperative hip functions were evaluated using the Japanese Orthopedic Association (JOA) hip score. ACA was measured using pre- and postoperative three-dimensional computed tomography (3DCT) and described as a clock using a radar chart. The ACA of the normal group was evaluated in the same manner as that for patients who underwent CPO. The ACA before CPO was compared with the ACA after CPO, the ACA before CPO was compared with that of the normal group, and the ACA after CPO was compared with that of the normal group at each location.

Results: The mean JOA hip scores improved significantly from 69 preoperatively to 88 postoperatively. The superior, posterior, and anterior ACA after CPO significantly increased and the inferior ACA decreased compared with ACA before CPO. The superior, posterior, and anterior ACA before CPO were significantly smaller than ACA in the normal group. The ACA after CPO were similar to the normal group.

Conclusions: CPO improved the anterosuperior coverage of the femoral head but reduced its inferior coverage. The radar chart could visualize acetabulum full circumference and was useful for three-dimensional pre-postoperative evaluation.

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1. Introduction

Patients with developmental dysplasia of the hip (DDH) have dysplasia of the acetabulum. The acetabular coverage of the femoral head is insufficient, resulting in concentrated stress on the hip joint during loading. This concentrated stress causes cartilage degeneration, resulting in progressive osteoarthritis (OA) of the hip [1]. DDH is associated with not only lateral acetabulum dysplasia but also anterior and posterior dysplasia, with varying degrees of dysplasia. Murphy et al. [2] classified dysplastic acetabulum into anterolateral, posteroslateral, and globally dysplastic groups. Ito et al. [3] assessed 84 hips with DDH using three-dimensional computed tomography (3DCT), and reported that the rate of ante-rior, posterior, and global deficiencies were 26%, 20%, and 39% respectively. Thus, DDH patients have deficiencies in various di-rections [4–8]. In addition, DDH patients have not only acetabular dysplasia of the loaded area but also instability of the hip joint due to anterior and posterior dysplasia. This instability can cause acetabular labral tears and cartilage injuries [9,10]. Curved periacetabular osteotomy (CPO) is indicated for DDH patients because the dysplasia will eventually progress to OA. CPO increases acetabular coverage of the femoral head [9] and reduces mechanical load on the hip.

Although this minimally invasive surgery for rotating the bone fragment improves femoral head coverage and reduces the dy-namic instability of DDH, impingement due to excessive rotation of
the anterior fragment and instability due to the opposite side dysplasia may occur [11–13]. Therefore, the acetabulum should be examined circumferentially before CPO, to determine the rotation direction of the osteotomized fragment. Previously, preoperative planning focused on the center edge (CE) angle and false-profile radiograph [1]. However, a thorough evaluation of acetabular coverage was difficult. In some studies, bone coverage was evaluated by computed tomography [14,15], but few reports describe the full circumference acetabulum. The purposes of this study were to 1) investigate full circumference acetabular coverage of the femoral head in the patients with DDH before and after CPO, and 2) compare the acetabulum coverage with the hips of normal patients.

2. Material and methods

This retrospective study was approved by our Institutional Review Board. Informed consent was obtained from all patients and relevant persons. A consecutive series of patients with DDH who underwent CPO between February 2006 and March 2014 was examined. In principle, CPO was performed for <50-year-old patients with early-stage to progression-stage based on the Japanese Orthopedic Association (JOA) stage classification. However, CPO was performed for patients older than 50 years, if they chose to undergo this surgery. Twenty-five female patients (a total of 26 hips) were included in this study. Two cases with osteotomy that extended to the side where the plane was parallel to the APP and passed through the acetabulum were excluded (Fig. 1). Thus, we analyzed 23 patients and 24 hips (23 females, mean age: 43.8, mean body mass index [BMI]: 22.3, and mean length of follow-up: 69.4 months). The postoperative CT data were obtained at an average of 6 months after CPO. The normal group was defined as the original plane (Fig. 1). A sphere was defined with an anterior pelvic plane (APP) passing through the bilateral anterior superior iliac spine and the pubic symphysis, which was defined as the original plane (Fig. 2). A sphere was created having the same size as the femoral head, and the center of the femoral head was defined as the center of the sphere. The axis was created with the crossing planes passing through the femoral head center parallel and perpendicular to the APP. Multiple radial planes were reconstructed in increments of 15° along this axis (Fig. 3). We defined the cephalic side of the point as the side where the plane was parallel to the APP and passed through the femoral head center.

The osteotomy was osteotomized from the pelvic cavity. The osteotomy fragment was performed using resorbable screws.

2.2. Clinical evaluation

Pre- and postoperative hip functions were evaluated using the JOA hip score. The JOA hip score consists of four subscales for pain, range of motion, ability to walk, and activities of daily living. The ranges of the subscale scores are 0–40, 0 to 20, 0 to 20, and 0 to 20, respectively. The total score has a maximum of 100 points for asymptomatic patients and correlates well with the Harris Hip Score [16]. The postoperative JOA hip score was evaluated at the latest follow-up period.

2.3. Radiological evaluation

Acetabular coverage angles (ACA) of the femoral head were evaluated using pre- and postoperative 3DCT. We analyzed the CT data with 3D template software (ZedHip®, Lexi Corp, Tokyo, Japan), which can reconstruct multiple planes. The 3D pelvic coordinates were defined with an anterior pelvic plane (APP) passing through the bilateral anterior superior iliac spine and the pubic symphysis, which was defined as the original plane (Fig. 2). A sphere was created having the same size as the femoral head, and the center of the femoral head was defined as the center of the sphere. The axis was created with the crossing planes passing through the femoral head center parallel and perpendicular to the APP. Multiple radial planes were reconstructed in increments of 15° along this axis (Fig. 3). We defined the cephalic side of the point as the side where the plane was parallel to the APP and passed through the femoral head center.

Postoperatively, physical therapy was started with non-weight-bearing exercises on the operative side. Partial weight bearing was allowed 3 weeks after the CPO. Full weight bearing was allowed 8 weeks after CPO.

Table 1

| Parameter                  | CPO (n = 24) | Normal (n = 14) | p-value* |
|----------------------------|-------------|----------------|----------|
| Age at surgery             | 43.8 (24–55) | 41.6 (22–66)   | 0.55     |
| Female                     | 24          | 14             |          |
| Height                     | 154.2 (141.4–161.1) | 158.0 (142.9–166.5) | 0.06     |
| Body weight                | 53.1 (40.0–74.0) | 56.7 (43.0–82.2) | 0.29     |
| Body mass index            | 23.3 (17.6–29.5) | 22.9 (15.4–32.8) | 0.67     |
| Sharp angle                | 47.7 (43–60)  | 39.4 (34–46)   | <0.05    |
| Center edge angle          | 9.92 (3–17)  | 32.3 (21–42)   | <0.05    |

All data were expressed as the mean except for sex, (*unpaired t-test).

Fig. 1. Patient selection flow chart.
Fig. 2. The plane through bilateral anterior superior iliac spines (ASIS) and pubic symphysis was defined as the anterior pelvic plane (APP).

Fig. 3. The axis was created with the crossing planes passing through the femoral head center parallel and perpendicular to the anterior pelvic plane (APP). The axis passed through the center of the femoral head (a), and multiple radial planes were reconstructed in increments of 15° along this axis (b). The acetabular coverage angles were measured in each plane.
through the center of the femoral head with the acetabular rim as 0:00. The location of the acetabular rim was given in a clock face system by defining the superior location as 0:00, the anterior location as 3:00, the inferior location as 6:00, and the posterior location as 9:00 (Fig. 4a). Furthermore, the superior area was defined as 10:30 to 1:30, the anterior area as 1:30 to 4:30, the posterior area as 7:30 to 10:30, and the inferior area as 4:30 to 7:30 (Fig. 4b). ACA were measured as the angles between the acetabular rim line from the center of the femoral head and the medial line of the axis in each radial plane, using an image-processing program (Image J, National Institutes of Health, Bethesda, MD, USA).

ACA in each location of the acetabular rim were compared before and after CPO and also compared to normal hips using a radar chart. The radar chart is a useful way to display multivariate observations with an arbitrary number of variables. As a line moves toward the center of the radar chart, ACA decreases, and 90° means half coverage of acetabular.

ACA in each location of the acetabular rim was also measured on the normal side of 14 patients (14 females, mean age 41.6 years old, mean BMI 22.5, mean CE angle 32.3°) with unilateral and bilateral ONFH (Table 1). The ACA of the normal group was evaluated in the same manner as that for patients who underwent CPO. The ACA before CPO was compared with that of the normal group. The DDH types were classified into four groups of deficiency, i.e., anterior, posterior, global, and mild (Fig. 6), according to a study by Ito et al. [3].

2.4. Statistical analysis

Statistical analyses were performed with JMP software version 15.0 (SAS Institute, Cary, NC, USA). Paired t-tests were used to compare ACA before and after CPO at each location. Paired t-tests were also used to compare JOA scores, pre- and postoperative pelvic tilt. Unpaired t-tests were used to compare parameters between the CPO and normal groups. Comparison was performed between the after CPO group and the normal group using a radar chart. Next, the after CPO group was divided into two groups, i.e., with more excessive rotation of the anterior fragment at 3:00 than normal group and without excessive rotation, and then the hip flexion angles were analyzed before and after CPO (paired t-test). Statistical significance was set at p < 0.05. To assess inter—observer
reliabilities for ACA as the intra-class correlation coefficient (ICC), five randomly selected patients were measured by two raters. To assess intra-observer reliabilities for ACA, five randomly selected patients were measured three times each by a single rater.

3. Results

The mean JOA hip scores improved significantly from 69 preoperatively (range, 45–95) to 89 postoperatively (range, 67–100; $p<0.05$) (Table 2).

| JOA H–S   | Before CPO | After CPO | p-value$^a$ |
|-----------|------------|-----------|-------------|
| 69 (45–95) | 89 (67–100) | $<0.05$   |

$^a$ Paired t-test.

The ACA after CPO increased significantly compared with the ACA before CPO at every angle, except four locations (2:30, 3:00, 9:00, 9:30, paired t-test, $p<0.05$) (Fig. 5a). The ACA before CPO at.

Fig. 6. The acetabular coverage angles using the radar chart were compared before curved periacetabular osteotomy and with the normal group. Representative cases are shown, Developmental dysplasia of the hip types was classified into four types of deficiency: anterior (a), posterior (b), global (c), and mild (d).
every location was significantly smaller than the ACA at the corresponding location in the normal group, except at four locations (2:30, 4:00, 8:00, and 8:30). Unpaired *t*-test, *p* < 0.05 (Fig. 5b). The ACA after CPO was significantly larger than the ACA of the normal group at the superior area (0:00–1:30) and smaller than the ACA of the normal group at most of the anteroinferior and posteroinferior areas (Fig. 5c). No significant difference was found in the hip flexion angle between the group with excessive rotation of the anterior fragment (5 hips) and the group without excessive rotation (19 hips). Assessment of the deficiency types in our study showed that 8 (34%) cases had anterior deficiency of acetabulum, 7 (29%) had posterior deficiency, 7 (29%) had global deficiency, and 2 (8.3%) had mild deficiency (Table 3). One case had lateral femoral cutaneous neuropathy and was treated conservatively. No superficial or deep infections occurred. Two of the 24 patients progressed to end-stage hip osteoarthritis, and one case required conversion to total hip arthroplasty 7 years after surgery. The overall survival rate of CPO was 95.3%. Intra-observer and inter-observer reliabilities for the measurement of ACA were 0.99 and 0.99, respectively.

4. Discussion

The radar chart is often used in clinical practice as a diagram to evaluate and visualize multifaceted parameters [17]. In this study, acetabular coverage of the femoral head was described with a radar chart to understand the complex 3D morphology of the acetabulum as a simple figure. Nakahara et al. [15] measured the acetabular coverage angles in men and women with normal hips using an axis perpendicular to the acetabulum; the coverage angles were described as a line graph, and the full circumference was evaluated. However, the acetabulum is difficult to visualize with a line graph. In our study, a radar chart was used to evaluate the ACA at different acetabular locations. The full circumference of the ACA could be visualized with this method. overlaying the radar chart before CPO with the radar chart after CPO helped us understand the acetabular coverage of osteotomized bone, the direction of the bone fragment, and the acetabular dysplasia of the opposite side. In addition, overlaying the radar chart for patients before CPO with that of the normal group enabled visualization of the types of DDH (Fig. 6), which may help surgeons to understand the direction of the bone fragment and the degree of angles in CPO.

Ito et al. classified the acetabulum of DDH into four types of deficiency: anterior, posterior, global, and mild, with incidence rates of 26%, 20%, 39%, and 14%, respectively [3]. Although the deficiency type distribution differed from our data, the proportion of posterior and global deficiency types was similar to our results; more than 50% of DDH cases in our study had posterior deficiency. In the posterior deficiency type, excessive anterior rotation should be avoided, because progressive osteoarthritis may require total hip arthroplasty. In contrast, in the mild deficiency type, rotation should be performed in the superior direction, whereas in the anterior deficiency type, slight rotation should be performed in the anterior direction. Simulation with 3D images can also be performed before surgery; however, this imaging was not possible in this study. We believe that this 3D approach of preoperative imaging will enable more accurate surgery than conventional surgery using preoperative planning based on radiographs.

The axis created by the crossing planes passing through the femoral head center parallel and perpendicular to the APP as a reference axis for 3D comparisons before and after CPO was not affected by the patients’ body positions at the time of CT imaging. In the 3D morphological evaluation of the acetabulum, one report described the use of radial cross-sectional images based on a line perpendicular to the opening of the acetabulum and passing through the femoral head center [15]. However, in CPO, changes in the rotated bone fragment before and after surgery cannot be evaluated if the acetabulum is used as a reference because the acetabulum is moved. Evaluation of the bony coverage of the femoral head using an axis created from the anterior pelvic reference plane, as performed in the present study, allows accurate comparisons of the direction and angle of movement of the rotated bone fragment before and after CPO.

The results of this study showed that coverage at the superior, anterior, and posterior areas of the dysplastic hip was lower (Fig. 5). Miyasaka et al. [18] showed that acetabular coverage angles in each plane were smaller in patients with DDH compared to normal patients, and all directions of the acetabulum had dysplasia. Their study showed that DDH was deficient in various directions, in agreement with our results. The results of this study show that CPO improved ACA to close to the ACA of the normal group, but the inferior ACA was decreased. In addition, anterior ACA after CPO was larger in some locations than the ACA of the normal group. These results indicate that the osteotomized fragment moved excessively anteriorly after CPO. Although our study shows that excessive anterior rotation did not result in hip flexion limitation, this excessive anterior movement may cause femoracetabular impingement (FAI), leading to osteoarthritis and hip pain with deep flexion [13]. Therefore, the direction and distance of the osteotomized fragment should be evaluated properly before surgery.

Regarding 3D preoperative planning using CT for CPO, Tsumura et al. [19] simulated hip joint contact stress when moving the rotated bone fragment on 3DCT images and found that the stress was reduced when the rotation was 15–25° anteriorly and 15–20° laterally and the rotation angles of the bone fragments were different for each patient. To establish 3D preoperative planning specific for each patient, the optimal direction and distance that a rotated bone fragment should be moved need to be determined.

In this study, the radar charts facilitated visualization and presentation of acetabular dysplasia involving the entire circumference and showed that only partial bony coverage can be attained even after CPO and bony coverage decreases after CPO in the portion of the acetabulum that is contralateral to the rotational direction. In addition, planning the direction and distance of bone fragment movement is possible. This technique may be a useful method for 3D preoperative planning.

5. Limitations

This study had several limitations. First, this was a retrospective study. Second, the number of cases was small (24 hips). Third, although this method facilitated a direct understanding of the acetabular coverage, this procedure was complicated and time consuming. Fourth, the reference plane that was used for the measurements in this study was APP, which we considered appropriate for both preoperative and postoperative evaluations because APP is a reference plane that remains unchanged even after CPO. However, pelvic sagittal tilt differs in each patient when the patient is lying in a supine position on the CT table. Therefore, evaluation of acetabular coverage in all directions of the acetabulum using our method in patients with severe anterior or posterior pelvic tilt might differ from that in patients with moderate to less pelvic sagittal tilt [20]. Finally although this method allowed visualization of the dysplasia side and the moving direction, the moving distance could not be
observed. This requires further investigation, including planning a navigation system [21].

6. Summary

The 3D analysis of whole acetabular coverage of the femoral head before and after CPO and in normal hip joints were investigated using radar charts. The dysplastic hip showed less coverage at the weight-bearing area (anterior, superior, and posterior areas) of the acetabulum in comparison with the normal hip. CPO resulted in increased coverage of the acetabulum relative to the weight-bearing area of the femoral head, but after CPO, the coverage of the inferior acetabulum decreased according to the extent of the rotation of the bone fragment. The 3D evaluation of the acetabular coverage using radar charts facilitated visualization of the severity of acetabular dysplasia in an easily understandable manner. This technique may be a useful method for 3D preoperative planning for CPO.

In conclusion, CPO improved anterosuperior coverage of the femoral head but reduced inferior coverage. The radar chart allowed visualization of the full circumference of the acetabulum and was useful for 3D preoperative evaluation.

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Declaration of competing interest

None declared.

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