Clinical Outcomes According to Femoral and Acetabular Version After Periacetabular Osteotomy

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Background: Patients with acetabular dysplasia often have abnormal femoral and acetabular version. The effect of combined femoral and acetabular version on clinical outcomes after periacetabular osteotomy for the treatment of acetabular dysplasia remains unclear. The purposes of the present study were (1) to evaluate the association of combined femoral and acetabular version with clinical outcome after periacetabular osteotomy and (2) to investigate the association of femoral version independently with clinical outcome after periacetabular osteotomy.

Methods: We retrospectively reviewed the records for 92 consecutive patients (95 hips) who had undergone periacetabular osteotomy for the treatment of symptomatic acetabular dysplasia. The patient cohort comprised 85 females and 7 males with a mean age of 38.9 years at the time of surgery. The mean duration of follow-up was 4.8 years (range, 2.0 to 7.2 years). Femoral and acetabular version and the alpha angle were measured on postoperative computed tomography scans. Clinical outcomes included range of motion and the modified Harris hip score. Analysis of variance was used to investigate the effect of femoral version on clinical outcomes. Analysis of covariance was used to adjust for potential covariates.

Results: Combined femoral and acetabular version after periacetabular osteotomy was slightly, but significantly, correlated with postoperative flexion \( r = 0.222; p = 0.031 \) and internal rotation in flexion \( r = 0.326; p = 0.001 \). Patients with mild femoral version \( (<15^\circ) \) experienced significantly less postoperative internal rotation in flexion than those with severe femoral version \( (>35^\circ) \); however, this difference was lost after adjustment for potential covariates. There were no differences among femoral version groups (mild, moderate, and severe) in terms of improvements in the clinical outcomes of pain, function, and activity.

Conclusions: Combined femoral and acetabular version after periacetabular osteotomy was significantly correlated with postoperative range of motion. Abnormality of femoral version associated with acetabular dysplasia did not demonstrate any effect on the clinical outcomes of periacetabular osteotomy.

Level of Evidence: Prognostic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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osteoarthritic changes on radiographs at the time of surgery were considered suitable for surgery. Hips with minimal or no osteoarthritic changes on radiographs at the time of surgery were included in this study.

**Surgical Technique**

Curved periacetabular osteotomy was developed for the treatment of acetabular dysplasia in 1995. For this procedure, the patient is placed in the supine position on a radiolucent table. Exposure of the osteotomy sites and osteotomy of the ischium are then performed in the same manner as for Bernese periacetabular osteotomy, and iliac and pubic osteotomies are performed in the same manner as for rotational acetabular osteotomy. The acetabular fragment is rotated to achieve a horizontal weight-bearing acetabulum and medialization of the femoral head with use of intraoperative fluoroscopy. The acetabular fragment is then fixed with 2 or 3 poly-L-lactic acid screws (Fig. 2). To confirm the occurrence of postoperative anterior impingement, the anterior part of the capsule is palpated with the hip in flexion and internal rotation. When impingement is detected between the femoral head-neck junction and the anterior rim of the acetabulum, femoral head-neck osteochondroplasty is performed for the treatment of femoral cam deformity.

Active motion exercises are initiated on the first postoperative day. Partial weight-bearing (10 kg) on 2 crutches or a walker is allowed on the third day, and full weight-bearing is allowed at 8 weeks.

**Clinical Examination**

Range of motion was measured with a goniometer at the time of the latest follow-up. The ranges of passive flexion, rotation (internal and external rotation) at 90° of flexion, and abduction in a neutral hip position were measured with the patient in the supine position with the pelvis stabilized. A previous study demonstrated that goniometric measurements of hip range of motion showed excellent interobserver and intraobserver reliabilities among multiple examiners. Therefore, all range-of-motion measurements in the present study were performed by a single, trained examiner. The anterior impingement test was performed at the time of the latest follow-up. During this test, the hip was rotated internally as it was flexed passively to approximately 90° and adducted with the patient in the supine position. When a sudden sharp pain in the groin was elicited by this maneuver, the anterior impingement test was defined as positive. The modified Harris hip score was used as part of the clinical assessment preoperatively and at the latest follow-up.

**Imaging Technique**

Radiographic evaluation was performed with use of supine anteroposterior pelvic and false-profile lateral radiographs. All radiographs were made according to previously published standardized techniques. Radiographic parameters included measurements of the lateral center-edge angle, acetabular roof obliquity, Tönnis grade, and anterior center-edge angle (on
false-profile lateral radiographs). The magnitude of the lateral center-edge angle was used to determine the severity of dysplasia. All measurements were made with use of digital calipers on the picture archiving and communication system.

Postoperative CT scans were made the week after periacetabular osteotomy. All patients received an explanation regarding the radiation exposure associated with CT, and all consented to our study protocol. All patients were placed in the supine position with the hip in a neutral position during CT scans. We used a 64-channel multidetector CT system (Aquilion TSX-101A/HA; Toshiba Medical Systems), and the scan protocol had a slice distance of 0.5 mm from the anterior superior iliac spines to below the knee. Multiplanar reconstruction images were made with use of a 3-dimensional (3D) workstation (Ziostation 2; Ziosoft).

**Postoperative CT Measurements**

With use of the 3D workstation, an initial correction for rotation in the coronal and axial planes was made by symmetrically aligning the pelvis. Acetabular version was determined in the axial plane by measuring the angle made by a line connecting the anterior and posterior edges of the acetabulum and a line perpendicular to the transverse line connecting the ischial spines (Fig. 3). Acetabular version measurements...
were made in 2 different transverse planes: (1) through the center of the femoral head and (2) more cranially, through the plane corresponding to the position 5 mm caudal to the acetabular roof. Acetabular version was defined as the mean version at the central and cranial positions in order to include global acetabular version rather than just a single axial slice. Femoral version was defined as the angle between the axis of the femoral neck and the posterior condylar axis of the femur in the axial plane.\(^2,21\) (Fig. 4). The combined femoral and acetabular version was defined as the sum of the femoral and modified acetabular versions. The alpha angle was measured with use of the method of Nötzli et al.\(^2\) (Fig. 5). All radiographic measurements were performed by 2 examiners who were blinded to the clinical results and were repeated at least 4 weeks after the first measurements. Intraobserver reliability ranged from 0.70 to 0.99, and interobserver reliability ranged from 0.71 to 0.99.

The severity of femoral anteversion was evaluated as a categorical predictor variable and was characterized as mild (<15°), moderate (15° to 35°), or severe (>35°). These ranges were chosen on the basis of a previous study involving 106 normal hips in Japanese adults in which the mean femoral version (and standard deviation) was found to be 23.6° ± 10.2° on 3D CT images.\(^23\) For the present study, we then selected values that were approximately 1 standard deviation above and below this established mean (i.e., 15° and 35°) as the lower and upper values of the “moderate” category.

**Statistical Analysis**

Statistical analyses were performed with use of SPSS software (version 23.0; IBM). The Spearman rank correlation coefficient was used to analyze the relationships between combined version after periacetabular osteotomy and clinical outcomes at the time of the latest follow-up. Demographic characteristics, radiographic and clinical parameters, and intraoperative procedures were compared among the 3 femoral version groups via analysis of variance (ANOVA) with Tukey-adjusted pairwise comparisons for continuous variables and via the chi-square test for categorical variables.

### TABLE I Radiographic Variables Measured on Postoperative CT Scans

| Variable               | Value* (°) |
|------------------------|------------|
| Acetabular version     |            |
| Cranial                | 8 ± 14     |
| Central                | 19 ± 9     |
| Femoral version        | 32 ± 13    |
| Combined version†      | 46 ± 19    |
| Alpha angle            | 41 ± 6     |

*The values are given as the mean and the standard deviation.
†Combined version was defined as the sum of femoral and acetabular version.
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**Results**

The study cohort comprised 95 hips in 92 patients (85 females, 7 males) with a mean age of 38.9 years and a mean duration of follow-up of 4.8 years (range, 2.0 to 7.2 years). Concomitant femoral neck osteochondroplasty in conjunction with periacetabular osteotomy was performed in 15 hips (16%), No patients underwent concomitant derotational femoral osteotomy for the treatment of abnormal femoral version. A positive anterior impingement sign was seen in 16 hips (17%) postoperatively, and 3 (19%) of these 16 hips had undergone concomitant femoral neck osteochondroplasty in conjunction with periacetabular osteotomy. On postoperative CT scans, the mean combined femoral and acetabular version was 46° ± 19° and the mean alpha angle was 41° ± 6° (Table I). In evaluations of combined version after periacetabular osteotomy, the combined version was slightly, but significantly, correlated with the ranges of flexion (r = 0.222; p = 0.031) and internal rotation in flexion (r = 0.326; p = 0.001) (Table II). There was no correlation between combined version and improvement in any modified Harris hip score category.

Femoral version was mild in 16 hips, moderate in 41, and severe in 38. There were no significant differences among

| Variable                        | Mild (N = 16) | Moderate (N = 41) | Severe (N = 38) | P Value† | Significant Pairwise Differences‡ |
|---------------------------------|--------------|-------------------|----------------|----------|----------------------------------|
| Age§ (yr)                       | 35 ± 11      | 40 ± 13           | 39 ± 14        | 0.403    | –                                |
| Female sex                      | 88%          | 90%               | 97%            | 0.154    | –                                |
| Body mass index§ (kg/m²)        | 22 ± 2       | 22 ± 3            | 22 ± 3         | 0.834    | –                                |
| Duration of follow-up§ (mo)     | 55 ± 15      | 58 ± 17           | 59 ± 15        | 0.749    | –                                |
| Radiographic measurements§#     |              |                   |                |          |                                  |
| LCEA (°)                        | 15 ± 5       | 10 ± 9            | 10 ± 7         | 0.026**  | Moderate, severe < mild          |
| ARO (°)                         | 17 ± 3       | 20 ± 7            | 18 ± 6         | 0.118    | –                                |
| ACEA (°)                        | 12 ± 12      | 10 ± 15           | 16 ± 12        | 0.134    | –                                |
| Modified Harris hip score§      |              |                   |                |          |                                  |
| Pain                            | 26 ± 6       | 26 ± 8            | 27 ± 6         | 0.591    | –                                |
| Function                        | 30 ± 2       | 31 ± 3            | 30 ± 3         | 0.578    | –                                |
| Activity                        | 12 ± 2       | 12 ± 2            | 12 ± 2         | 0.221    | –                                |
| Overall                         | 77 ± 9       | 77 ± 10           | 78 ± 8         | 0.956    | –                                |
| Concomitant procedure (no. of hips) | 5 (31%)  | 7 (17%)           | 3 (8%)         | 0.095    | –                                |

*Femoral version was classified as mild (<15°), moderate (15° to 35°), or severe (>35°). †Comparisons performed with ANOVA (for age, body mass index, duration of follow-up, radiographic parameters, and modified Harris hip score) or the chi-square test (for sex and concomitant procedures). ‡Pairwise comparisons performed with use of Tukey adjustment for multiple comparisons (p < 0.05). §The values are given as the mean and the standard deviation. #LCEA = lateral center-edge angle, ARO = acetabular roof obliquity, and ACEA = anterior center-edge angle. **Significant difference among groups.

**TABLE II Correlation of Postoperative Combined Version with Clinical Outcomes**

| Variable                        | Spearman Rank Correlation Coefficient | P Value |
|---------------------------------|--------------------------------------|---------|
| Range of motion                 |                                       |         |
| Flexion                         | 0.222                                | 0.031†  |
| Abduction                       | −0.061                               | 0.560   |
| Internal rotation in flexion    | 0.326                                | 0.001†  |
| External rotation in flexion    | −0.018                               | 0.864   |
| Change in modified Harris score | −0.070                               | 0.503   |
| Pain                            | 0.043                                | 0.679   |
| Function                        | 0.132                                | 0.202   |
| Activity                        | 0.027                                | 0.801   |

*Combined version was defined as the sum of femoral and acetabular version. †Significant (p < 0.05).
The femoral version groups in terms of age or body mass index at the time of periacetabular osteotomy, sex, duration of follow-up, or preoperative modified Harris hip score (Table III). Patients with mild femoral version had more severe acetabular dysplasia preoperatively than those with moderate or severe femoral version (lateral center-edge angle: 15° ± 5° versus 10° ± 9° versus 10° ± 7°, respectively; ANOVA p = 0.026; Tukey-adjusted pairwise comparisons p < 0.05). The prevalence of concomitant femoral neck osteochondroplasty in conjunction with periacetabular osteotomy did not significantly differ among the femoral version groups (p = 0.095). In postoperative radiographic evaluations, the mild femoral version group had a greater lateral center-edge angle and smaller central and cranial acetabular version than the severe femoral version group (Table IV). The alpha angle was almost equivalent among femoral version groups. Radiographic progression of osteoarthritis at the latest follow-up was observed in 5 hips (5%), but the prevalence did not significantly differ among the femoral version groups (p = 0.979).

The mild femoral version group experienced less postoperative internal rotation in flexion than the severe femoral version group (28° ± 8° versus 35° ± 9°; ANOVA p = 0.030; Tukey-adjusted pairwise comparisons p = 0.023). However, this difference was lost after adjusting for preoperative severity of acetabular dysplasia and postoperative alpha angle and acetabular version (ANCOVA p = 0.162) (Table V, also see Appendix). There were no significant differences among the femoral version groups in terms of the remaining 3 range-of-motion parameters (flexion, abduction, and external rotation in flexion) either before or after adjustment for similar potential covariates. There were no differences among the femoral version

| Variable | Mild (N = 16) | Moderate (N = 41) | Severe (N = 38) | P Value† | Significant Pairwise Differences§ |
|----------|---------------|------------------|----------------|----------|-----------------------------------|
| Non-CT measurements# (*) | | | | | |
| LCEA | 35 ± 7 | 31 ± 7 | 29 ± 7 | 0.021** | Severe < mild |
| ARO | 3 ± 6 | 6 ± 6 | 5 ± 6 | 0.066 | – |
| ACEA | 39 ± 11 | 30 ± 12 | 32 ± 13 | 0.061 | – |
| CT measurements (*) | | | | | |
| Acetabular version | | | | | |
| Cranial | 0 ± 7 | 9 ± 15 | 10 ± 14 | 0.001** | Mild < moderate, severe |
| Central | 14 ± 7 | 19 ± 10 | 21 ± 9 | 0.031** | Mild < severe |
| Femoral version | 11 ± 4 | 28 ± 5 | 45 ± 7 | <0.001** | Mild < moderate < severe |
| Combined version | 18 ± 8 | 43 ± 12 | 60 ± 12 | <0.001** | Mild < moderate < severe |
| Alpha angle | 41 ± 5 | 42 ± 7 | 40 ± 3 | 0.434 | – |

*Femoral version was classified as mild (<15°), moderate (15° to 35°), or severe (>35°). †The values are given as the mean and the standard deviation. ‡Comparisons performed with ANOVA. §Pairwise comparisons performed with use of Tukey adjustment for multiple comparisons (p < 0.05). #LCEA = lateral center-edge angle, ARO = acetabular roof obliquity, and ACEA = anterior center-edge angle. **Significant difference among groups.
The number of patients with a positive anterior impingement for postoperative alpha angle and acetabular version (Table VI).

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**TABLE VI Change in Modified Harris Hip Score by Femoral Version Group**

| Change in Modified Harris Hip Score | Femoral Version Group*† | Crude P Value‡ | Adjusted P Value§ |
|-------------------------------------|--------------------------|----------------|------------------|
|                                     | Mild (N = 16)            |                |                  |
|                                     | Moderate (N = 41)        |                |                  |
|                                     | Severe (N = 38)         |                |                  |
| Pain                                | 12 ± 9                  | 15 ± 10        | 12 ± 8           | 0.336 | 0.748 |
| Function                            | 3 ± 3                   | 2 ± 7          | 2 ± 3            | 0.828 | 0.430 |
| Activity                            | 1 ± 3                   | 1 ± 3          | 2 ± 2            | 0.735 | 0.894 |
| Overall                             | 16 ± 12                 | 18 ± 9         | 16 ± 9           | 0.661 | 0.404 |

*Femoral version was classified as mild (<15°), moderate (15° to 35°), or severe (>35°). †The values are given as the mean and the standard deviation. ‡Compared with use of ANOVA. §ANOVA adjusted for preoperative lateral center-edge angle and modified Harris hip score and for postoperative acetabular version and alpha angle.

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Minor complications were seen in association with 14 hips (15%), including lateral femoral cutaneous nerve dysesthesia (n = 6), delayed union of the pubis (n = 6), and inferior pubic ramus fracture (n = 2). Regarding reoperation, 3 patients underwent arthroscopy for labral treatment. Two patients who had untreated femoral head asphericity experienced groin pain postoperatively during internal rotation in flexion and underwent femoral neck osteochondroplasty at 3.7 and 5.3 years after periacetabular osteotomy. No patient underwent conversion to total hip arthroplasty during follow-up.

**Discussion**

Periacetabular osteotomy is commonly used for the treatment of symptomatic acetabular dysplasia, and clinical outcome studies have indicated that this procedure results in marked pain reduction and functional improvement. However, various factors reportedly have been associated with the outcomes of periacetabular osteotomy. To our knowledge, no previous study has evaluated the effect of femoral and acetabular version on clinical outcomes following periacetabular osteotomy. In the present study, we found that combined femoral and acetabular version after periacetabular osteotomy was significantly correlated with the postoperative ranges of flexion and internal rotation in flexion. However, the degree of femoral version was not independently associated with the clinical outcomes of periacetabular osteotomy when accounting for potential covariates in a general linear model.

Recognition of the interaction between femoral and acetabular morphology is important in clinical practice. The concept of combined femoral and acetabular version has been previously reported in studies of pediatric patients with developmental hip dysplasia, patients who have undergone total hip arthroplasty, and, recently, patients who have undergone surgery for the treatment of femoroacetabular impingement. In the present study, we noted significant associations between combined version and flexion as well as internal rotation in flexion in patients who had undergone periacetabular osteotomy. These findings indicate that it may be better to avoid postoperative acetabular retroversion, especially in patients with decreased femoral version. However, acetabular version should not be considered a preferential parameter in acetabular correction. Acetabular dysplasia presents with varying degrees of acetabular version associated with malalignment of the acetabulum. When performing periacetabular osteotomy for reorientation of the acetabulum, surgeons should pay attention to the interaction between femoral and acetabular version as well as the coverage of the acetabulum. For patients with acetabular dysplasia, it is most important that periacetabular osteotomy result in sufficient coverage of the acetabulum rather than increased acetabular version. Taken together, our results further emphasize the importance of recognizing this combined version, even in patients who undergo periacetabular osteotomy for the treatment of acetabular dysplasia.

Decreased femoral version is a distinct dynamic factor that should be considered in the evaluation of mechanical causes of hip pain. A previous study demonstrated that the range of internal rotation in patients with decreased femoral version was significantly less than that in patients with normal version or increased femoral version both before and after arthroscopic femoral cam decompression (p < 0.05). In the present study, we also found a smaller range of internal rotation in hip flexion in the mild femoral version group after periacetabular osteotomy; however, this difference was lost after adjusting for potential covariates. Our results might be because the mild femoral version group had less acetabular version postoperatively than the severe femoral version group. Fabricant et al. noted that patients with decreased femoral version had smaller improvements in patient-reported outcomes after arthroscopic surgery for the treatment of femoroacetabular impingement. With the numbers available in the present study, we could not find any significant association between femoral
version and clinical outcomes after periacetabular osteotomy. Conversely, excessive femoral anteversion generally can lead to painful restricted external rotation as a result of posterior impingement. However, there were no differences in postoperative range of external rotation among the femoral version groups in the present study. Our results indicated that postoperative posterior impingement was less likely to occur in patients undergoing periacetabular osteotomy because the acetabulum was rotated anteriorly through periacetabular osteotomy. Future research is needed to determine the long-term effect of femoral version on several patient-reported outcomes after periacetabular osteotomy.

One advantage of the present study was the large cohort of patients who were evaluated with CT scans after periacetabular osteotomy. Using these postoperative CT scans, we measured postoperative femoral and acetabular version and alpha angle according to previously published methods. In addition, because of the rigorous exclusion criteria in the present study, we could minimize the effect of degenerative change of the hip joint on the CT measurements. To our knowledge, this is the first study to investigate the associations of femoral and acetabular version with clinical outcomes following periacetabular osteotomy. However, the clinical outcomes of periacetabular osteotomy might be affected by further abnormal morphology. Future research is needed to identify such abnormal morphology.

The present study had several limitations. First, few patient-reported outcomes were evaluated. Although patient-reported outcomes are considered the gold standard when evaluating outcomes in a surgical population, our study included only the modified Harris hip score for clinical scoring. Future research should investigate the effect of femoral and acetabular version on various patient-reported outcomes. Second, the present study lacked evaluation of preoperative acetabular version on CT scans and preoperative range of motion, both of which can affect clinical outcomes. Third, although labral tears are common in patients with acetabular dysplasia, we did not investigate labral pathology in the present study. Because labral pathology also affects clinical outcomes after periacetabular osteotomy, there might be differences in clinical outcomes depending on the presence of labral tears. Last, there were no patients with femoral retroversion in the present study. A further large cohort study is warranted to investigate the effect of femoral retroversion on outcomes after periacetabular osteotomy.

In conclusion, we believe that ours is the first study to investigate the associations of femoral and acetabular version with clinical outcomes following periacetabular osteotomy. We found significant associations between combined femoral and acetabular version and hip range of motion in patients who underwent periacetabular osteotomy. Our results indicate that patients with decreased combined femoral and acetabular version after periacetabular osteotomy may experience restriction of range of motion. Surgeons performing periacetabular osteotomy should pay attention to postoperative acetabular retroversion as it may result in restriction of range of motion, especially for patients with decreased femoral version. Furthermore, we found that femoral version alone may not affect clinical outcomes after periacetabular osteotomy when adjusting for potential covariates such as the severity of acetabular dysplasia, alpha angle, and acetabular version. It may not be necessary to perform femoral derotational osteotomy routinely at the same time as periacetabular osteotomy unless major femoral retroversion is present. Further research regarding the impact of preoperative acetabular version and preoperative range of motion on the outcomes of periacetabular osteotomy needs to be conducted.

Appendix

A table showing general linear models for postoperative hip range of motion is available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A45).

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