**Original Article**

# Three-Dimensional Reconstruction of Computed Tomography Imaging Is Not Reliable in Assessing Acetabular Rim Osteophytes or Acetabular Rim Pathology in Patients With Femoroacetabular Impingement

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**Purpose:** To determine the reliability of 3-dimensional (3D) reconstruction of computed tomography (CT) imaging in evaluating acetabular rim morphology or acetabular rim osteophyte (ARO) existence and to group patients with femoroacetabular impingement (FAI) by ARO extent on coronal sections of CT and further compare clinical differences among groups. **Methods:** Patients who underwent primary hip arthroscopy for FAI by the same surgeon between August 2016 and December 2018 with minimum 2-year follow-up were enrolled. The ARO was evaluated both on the acetabular gross anatomy (AGA) and coronal sections of CT, for its position, width (unit: mm), area (unit: $mm^2$), and CT value (unit: HU). Patients were divided into 4 groups based on the extent of ARO on coronal CT: group A (ARO anterior to 12 o'clock), group P (ARO posterior to 12 o'clock), group AP (ARO across 12 o'clock), and group N (no ARO). Inter- and intraobserver correlation was analyzed. Demographic data, FAI deformity indicators on imaging, quantitative measurements of ARO, and pre- and postoperative patient-reported outcomes were compared among groups. **Results:** There were 229 patients (229 hips) enrolled in total, 122 male (53.3%) and 107 female (46.7%), with a mean age of 37.2 ± 10.2 years. The correlation between 2 observers for grouping ARO using AGA was positive but poor (Kendall Tau-b coefficient = 0.157, $P$ = .008). Moderate correlation was found between grouping based on AGA and coronal CT by the same observer (Kendall Tau-b coefficient = 0.482, $P$ = .000). The patients were divided into 4 groups: 84 patients (36.7%) in group N, 2 patients (0.9%) in group A, 69 patients (30.1%) in group P, and 74 patients (32.3%) in group AP. Group N was younger in age (35.4 ± 10.7 years) than group P (39.6 ± 10.2 years) ($P$ = 0.012) and had a larger proportion of women (57.1%) than group AP (36.5%) ($\chi^2 = 6.869$, $P$ = .032). There was a greater proportion of positive posterior wall sign in group P (52.2%) than 48.6% for group AP and 33.3% for group N ($\chi^2 = 6.397$, $P$ = .041). Group N had 61 (72.6%) Tönnis grade 0 hips compared with 37 (50%) in group AP ($P$ = .014). No statistical significance was found among groups in pre- and postoperative α angle, lateral center-edge angle, and patient-reported outcomes. The widths of ARO in group AP for the 3 marked points from anterior to posterior were 3.88 ± 1.86, 4.84 ± 2.72, and 6.66 ± 3.18, separately ($P < .001$); 15.73 ± 21.46, 19.22 ± 18.86, and 29.96 ± 17.05 for area ($P < .01$); and 652.67 ± 214.12, 677.10 ± 274.81, and 728.84 ± 232.39 for CT value ($P < .05$). For the ARO posterior to 12 o'clock, the group AP showed a larger width (6.66 ± 3.18), area (29.96 ± 17.05), and CT value (728.84 ± 232.39) than group P of (4.70 ± 2.25), (20.15 ± 12.91), and (641.84 ± 183.33) ($P < .001$). **Conclusions:** The evaluation of ARO on AGA is poor consistent with definite double-rim sign on coronal CT. There is a tendency of size-enlarging and density-increasing for ARO from anterior to posterior along the acetabular rim. Younger age, female gender, lower Tönnis grade, and negative posterior wall sign showed lower rate of ARO development. **Level of Evidence:** Level IV, diagnostic case series.

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Femoroacetabular impingement (FAI) has been recognized as an early stage of hip joint degeneration, with treatment of arthroscopy developed and good outcome yielded.[1] Patients with FAI often develop new osteoid growths along the acetabular margin, which have been described variously[2-9] as acetabular rim osteophyte (ARO), cartilage mineralization, and labral ossification (LO). The pathogenesis and clinical significance of ARO are uncertain,[10-14] and relevant quantitative measurement is scarce.[15-18] Whether the ARO is correlated to the malformation or symptoms of FAI remains controversial. Thus, we believe that more attention is needed to form a better understanding of ARO's clinical interpretation.

Given the reliable capacity of computed tomography (CT) in evaluating mineralized structures,[19-23] we used coronal CT imaging as the main tool to quantitatively study the location, area, and density of ARO in patients with FAI. The double-rim sign was used for standard definition of ARO[3] and reading results of coronal sections were used for analysis. The purposes of this study were to determine the reliability of 3-dimensional (3D) reconstruction of CT imaging in evaluating acetabular rim morphology or ARO existence, and to group patients with FAI by ARO extent on coronal sections of CT and further compare clinical differences among groups. We hypothesized that 3D CT reconstruction imaging of acetabular gross anatomy (AGA) would have low consistency in assessing ARO between observers, and that a larger extent and size of ARO would be associated with more severe FAI deformity measurements and patient-reported outcomes (PROs).

## Methods

This study was approved by the Ethics Committee of the institution (Peking University Third Hospital). From August 2016 to December 2018, patients who underwent hip arthroscopy for FAI were considered for the study. The clinical diagnosis of FAI was based on medical history, symptoms, physical examinations, as well as imaging.[24,25] The exclusion criteria were (1) patients who received hip arthroscopy for a reason other than FAI; (2) ipsilateral hip trauma or surgery history; (3) simultaneous or staged bilateral hip surgery; (4) less than 2 years of follow-up; (5) data deficiency (demographic, hip functional scores, imaging); (6) hip osteoarthritis (OA) with Tönnis grade $\geq 2$; (7) developmental dysplasia of the hip, with center-edge angle of Wiberg $<20°$ as the diagnosis threshold; (8) Legg—Calve—Perthes disease, slipped capital femoral epiphysis, pigmented villonodular synovitis, synovial chondromatosis, or avascular necrosis; or (9) Ehlers—Danlos syndrome or systemic autoimmune disease.

### Clinical Assessment

Demographic data including age, gender, body mass index, affected side, and onset time were recorded. At least 2 years of follow-up was achieved. Pre- and postoperative hip functions were evaluated by the modified Harris Hip Score (mHHS),[26] 12-item International Hip Outcome Tool (iHOT-12),[27] Hip Outcome Score-Activities of Daily Living Subscale (HOS-ADL), and Hip Outcome Score-Sports Subscale (HOS-SS).[28] The patient acceptable symptom state was assessed. We used the visual analog scale (VAS) to grade hip pain pre- and postoperatively, and the satisfaction of hip arthroscopy also was documented. Complications (e.g. infection, lower-extremity deep venous thrombosis) were recorded, as well as the revision hip arthroscopy surgery.

### Imaging

Anteroposterior X-ray films, 45° Dunn X-ray films, and CT were obtained for all patients preoperatively and at the last follow-up for the measurement of lateral center-edge angle (LCEA, on anteroposterior X-ray film), $\alpha$ angle (on 45° Dunn X-ray film), and ARO (on CT). The LCEA and $\alpha$ angle were measured as previous literature has suggested.[24,29] The standard definition of ARO is the double-rim sign on coronal CT sections.[3] The ARO was evaluated both on the AGA and coronal CT sections, quantitatively for its width (unit: mm), area (unit: $mm^2$), and CT values (unit: HU). The image software used was Centricity RIS CE V3.0 (GE, Boston, MA). Using a clock face on the right acetabulum as the standard, with the most cephalic-close point of the acetabular rim as the 12 o'clock, we divided the acetabular rim into 4 quadrants as suggested by Valente et al.[3]: the anterosuperior quadrant, the posterosuperior quadrant, the anteroinferior quadrant, and the posteroinferior quadrant. We assessed the upper semicircle of the rim, with the anterosuperior quadrant being the study zone of "anterior to 12 o'clock" (A) and posterosuperior quadrant being the zone of "posterior to 12 o'clock" (P). Two observers (Y.X., with 20 years of clinical proficiency, H.D. with 3 years of clinical proficiency) separately used AGA to evaluate whether there were thickening, protrusion, or osteophyte existing in the zone A or P. The interobserver agreement was calculated. One researcher independently carried out the coronal sections reading of ARO as mentioned previously. The existence of ARO on coronal sections was defined as "double-rim sign,"[3] consisting of the original contour of the acetabulum and the lateral margin of the osteophyte. The quantitative measurements of ARO on coronal sections included width, area, and CT values. The width was defined as the largest

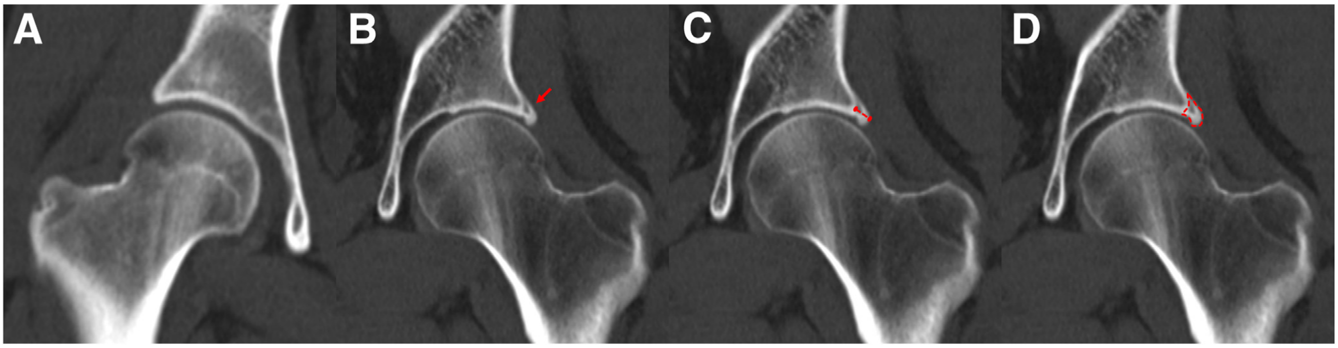


**Fig 1.** (A) Right hip, acetabular rim at 11 o'clock without ARO; (B) left hip, acetabular rim at 11 o'clock with ARO (red arrow indicating double-rim sign); (C) left hip, width measurement of ARO (red dotted line); (D) left hip, area and CT value measurement of ARO (red dotted line). (ARO, acetabular rim osteophyte.)

mediolateral diameter of ARO,[3] which meant the line distance of the most lateral projecting points between the pro-acetabular rim and the osteophyte rim. The profile of ARO was depicted using the "dots-into-line" tool and the region of interest and corresponding area and average CT values were yielded. In case of the unclear demarcation between ARO and native acetabulum, normal anatomical outline of the acetabular rim was estimated to draw the osteophyte integrally. These quantitative measurements of ARO were repeated twice by 2 observers (Y.X. and H.D.), respectively, and the intra- and interobserver correlation analysis were conducted. For each patient, 3 measurement points were taken if ARO existed: anterior (1 o'clock), 12 o'clock, and posterior (11 o'clock); positioning was assisted by cross-reference of the transverse view of femoral head at its maximum diameter (Fig 1).

The classification of anterior inferior spine was recorded, according to a previous literature.[30] Acetabular retroversion was evaluated with "cross-over sign" and "posterior wall sign."[24] Coxa profunda was assessed based on the positional relationship between the medial floor of fossa acetabuli and the ilioischial line.[31] In addition, the Tönnis grade of OA also was documented.[32]

### Statistical Analysis

According to the position of ARO, all patients were divided into 4 groups: group A (ARO only existed on anterosuperior quadrant), group P (ARO only existed on posterosuperior quadrant), group AP (ARO on antero- and posterosuperior quadrants), and group N (no ARO on the superior semicircle of the acetabular rim). Interobserver agreement of grouping based on AGA was calculated with Kendall Tau-b correlation analysis, as well as for the intraobserver agreement of grouping on AGA and coronal planes of CT respectively (Fig 2). The intra- and interobserver correlation analysis of quantitative ARO measurements between 2 observers were conducted using Pearson correlation analysis.

Analysis of variance and least significant difference were applied to 4 groups' comparison for continuous variables, and the $\chi^2$ test was used for categorical variables. Independent samples *t*-test was used to compare ARO measurements between groups, and paired samples *t*-test was used to compare ARO measurements of different positions.

Continuous variables are presented as mean ± standard deviation (range), and categorical variables are given as number (percentage). The agreement coefficients were

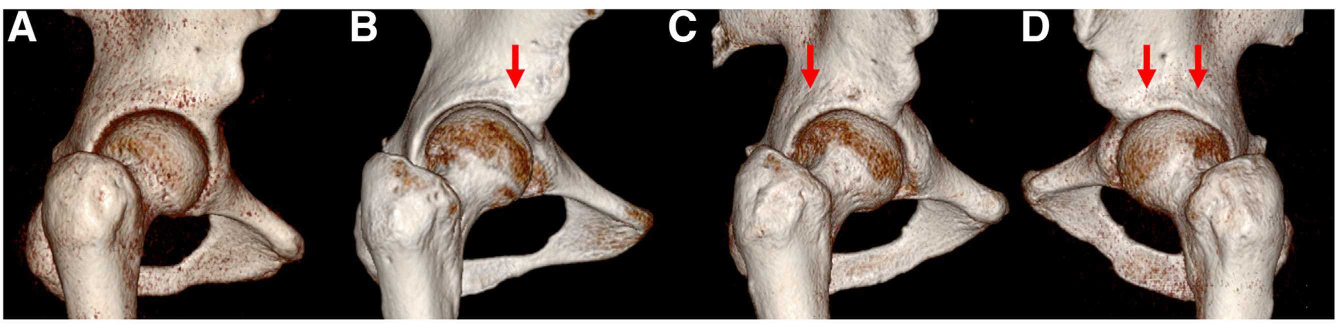


**Fig 2.** (A) Group N, right hip; (B) group A, right hip; (C) group P, right hip; (D) group AP, left hip. Red arrows point to ARO. (A, osteophyte anterior to 12 o'clock; AP, osteophyte anterior and posterior to 12 o'clock; ARO, acetabular rim osteophyte; N, no osteophyte; P, osteophyte posterior to 12 o'clock.)

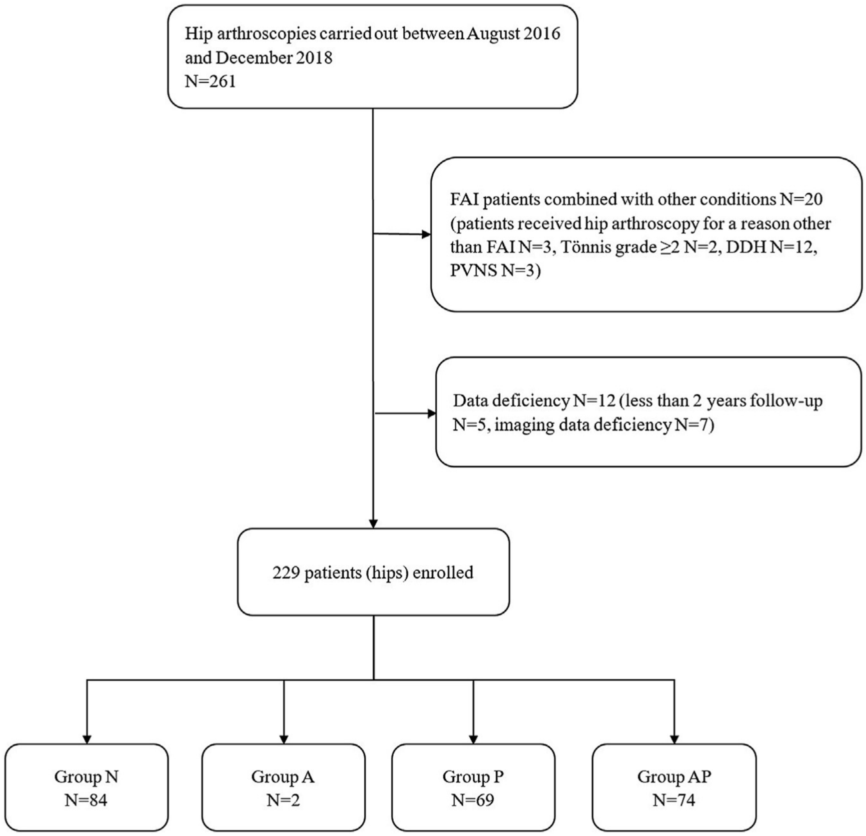


**Fig 3.** Flowchart of patient enrollment. (DDH, developmental dysplasia of the hip; FAI, femoroacetabular impingement; Group A, osteophyte anterior to 12 o'clock; Group AP, osteophyte anterior and posterior to 12 o'clock; Group N, no osteophyte; Group P, osteophyte posterior to 12 o'clock; N, number; PVNS, pigmented villonodular synovitis.)

graded as follows: poor (≤0), slight (0.01-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), almost-perfect agreement (≥0.81). Significance was determined using an alpha level of 0.05. All statistical analyses were performed using SPSS Statistics (Version 26; IBM Corp., Armonk, NY).

## Results

There were 229 hips (229 patients) enrolled in total (Fig 3), 122 male (53.3%) and 107 female (46.7%), with a mean age of 37.2 ± 10.2 (14-61) years, body mass index of 23.2 ± 3.1 (16.9-31.1), and onset time of 18.3 ± 15.3 months. Overall, 110 cases (48.0%) involved the left hip and 119 (52.0%) the right hip, with 142 hips (62.0%) rated as Tönnis grade 0 and 87 (38.0%) as Tönnis grade 1. Additionally, there were 48 patients (21.0%) diagnosed with cam-type FAI and 181 (79.0%) with mixed-type FAI, and corresponding FAI arthroscopy managements (femoroplasty in 229 patients, acetabuloplasty in 181 patients) were carried out, as mentioned previously. The whole cohort patients were divided into 4 groups based on the ARO extent on coronal CT: 84 patients (36.7%) in group N, 2 patients (0.9%) in group A, 69 patients (30.1%) in group P, and 74 patients (32.3%) in group AP. Group AP and group P had, respectively, 89.2% and 92.8% patients underwent labral repair, compared with 97.6% in group N ($P = .289$). Of the 3 patients who underwent labral reconstruction, 1 came from group P and 2 from group AP. All patients were followed up for at least 24 months, with a mean time of 39.1 ± 8.1 (27-55) months. During the follow-up period, no complication of infection or lower extremity deep venous thrombosis was presented, and 8 patients received revision surgery (3 in group N, 4 in group P, 1 in group AP) (Table 1).

The correlation between 2 observers for grouping ARO using AGA was positive but poor, with a Kendall Tau-b coefficient of 0.157 ($P = .008$). There was a moderate correlation between grouping based on AGA and coronal sections by the same observer, with a Kendall Tau-b coefficient of 0.482 ($P = .000$) (Table 2).

There was no significant difference among groups for baseline characteristics apart from age ($P = .042$) and gender ($P = .032$). To illustrate, group N had an overall younger age (35.4 ± 10.7 years) than group P (39.6 ± 10.2 years) ($P = .012$) and a larger proportion of women (57.1%) than group AP (36.5%) ($\chi^2 = 6.869$, $P = .032$). No statistical significance was found for crossover sign or coxa profunda among groups. However, there was a greater proportion of positive posterior wall sign in group P (52.2%), with 48.6% for group AP and 33.3% for group N ($\chi^2 = 6.397$, $P = .041$). Group N had 61 (72.6%) Tönnis grade 0 hips compared with 37 (50%) in group AP ($P = .014$). No statistical

**Table 1.** Patient Characteristics

| Characteristics | Number (Percentage) / Mean ± SD |
|---|---|
| Total enrolled | 229 (100.0%) |
| Sex | |
| Male | 122 (53.3%) |
| Female | 107 (46.7%) |
| Age, y | 37.2 ± 10.2 |
| BMI | 23.2 ± 3.1 |
| Symptoms onset time, mo | 18.3 ± 15.3 |
| Follow-up time, mo | 39.1 ± 8.1 |
| Affected side | |
| Left | 110 (48.0%) |
| Right | 119 (52.0%) |
| FAI subtype | |
| Cam | 48 (21.0%) |
| Pincer | 0 |
| Mixed | 181 (79.0%) |
| Anterior inferior spine subtype | |
| Type 1 | 44 (19.2%) |
| Type 2a | 130 (56.8%) |
| Type 2b | 51 (22.3%) |
| Type 3 | 4 (1.7%) |
| Tönnis grade | |
| Grade 0 | 142 (62.0%) |
| Grade 1 | 87 (38.0%) |
| Labral treatment | |
| Labral debridement | 12 (5.2%) |
| Labral repair | 214 (93.4%) |
| Labral reconstruction | 3 (1.3%) |
| Revision surgery | 8 (3.5%) |
| THA | 0 |
| Crossover sign | |
| Negative | 133 (58.1%) |
| Positive | 96 (41.9%) |
| Posterior wall sign | |
| Negative | 128 (55.9%) |
| Positive | 101 (44.1%) |
| Coxa profunda | |
| Negative | 96 (41.9%) |
| Positive | 133 (58.1%) |

NOTE. Data are presented as n (%) or mean ± SD.

BMI, body mass index; FAI, femoroacetabular impingement; SD, standard deviation; THA, total hip arthroplasty.

significance was found among groups regarding the subtypes of FAI or anterior inferior spine. Most patients (214, 93.4%) underwent labral repair management; nonetheless, 2 patients in group N, 4 patients in group P, and 6 patients in group AP received labral debridement. The 3 patients who underwent labral reconstruction came 1 from group P and 2 from group AP (Table 3).

There was no significant difference found among groups for pre- and postoperative $\alpha$ angle, LCEA, PROs (mHHS, iHOT12, HOS-ADL, HOS-SS), or VAS. The diameter of femoral head, joint space width, and surgery satisfaction held no statistical significance among the 4 groups (Table 3).

High consistency was showed in intra- and interobserver measurements of ARO on coronal CT (Table 4). Based on the quantitative measurements of coronal CT sections, ARO has showed a tendency of width-enlarging and CT value-increasing from anterior to posterior along the acetabular rim. The widths of ARO in group AP for the 3 marked points from anterior going posteriorly were 3.88 ± 1.86, 4.84 ± 2.72, and 6.66 ± 3.18, separately ($P < .001$) and 15.73 ± 21.46, 19.22 ± 18.86, and 29.96 ± 17.05 for area ($P < .01$). In addition, the 3 marked points of group AP had a corresponding CT value of 652.67 ± 214.12, 677.10 ± 274.81, and 728.84 ± 232.39 from anterior to posterior, statistical significances were found in comparison of anterior versus posterior ($P = .001$), and 12 o'clock versus posterior ($P = .011$). As for group P, the width of posterior (4.70 ± 2.25) was significantly larger than that of 12 o'clock (2.06 ± 2.10) ($P < .001$), as well as the area of 20.15 ± 12.91 (posterior) compared with 6.90 ± 7.71 (12 o'clock) (P < .001), and the CT value of 641.84 ± 183.33 (posterior) compared with 356.58 ± 339.46 (12 o'clock) ($P < .001$). These results from group P also confirmed the trend of ARO being enlarging posteriorly, with an increasing density at the same time (Table 5, Fig 4).

The independent samples $t$-test was used for osteophyte measurements comparisons of the same anatomical position between different groups. For the osteophytes at 12 o'clock, group AP showed a significant larger width (4.84 ± 2.72) and area (19.22 ± 18.86) than that of group P (2.06 ± 2.10) and (6.90 ± 7.71), both $P < .001$. The situation was the same for CT

**Table 2.** Inter- and Intraobserver Agreement of ARO Grouping

| | Group N | Group A | Group P | Group AP | | Group N | Group A | Group P | Group AP | |
|---|---|---|---|---|---|---|---|---|---|---|
| Observer A (3D gross anatomy) | 42 | 5 | 57 | 125 | Observer A (Coronal) | 84 | 2 | 69 | 74 | Kendall tau-b coefficient 0.482, $P$ .000 |
| Observer B (3D gross anatomy) | 69 | 12 | 39 | 109 | | | | | | |
| | Kendall tau-b coefficient 0.157, $P$ .008 | | | | | | | | | |

3D, grouping on 3-dimensional reconstruction images of CT; A, osteophyte anterior to 12 o'clock; AP, osteophyte anterior and posterior to 12 o'clock; ARO, acetabular rim osteophyte; CORONAL, grouping on coronal sections of CT; CT, computed tomography; N, no osteophytes; P, osteophyte posterior to 12 o'clock.

**Table 3.** Demographic Data, Radiographic Measurements, and Functional Outcomes among Groups

| Items | Group N | Group A | Group P | Group AP | *P* Value |
|---|---|---|---|---|---|
| Number (percentage) | 84 (36.7%) | 2 (0.9%) | 69 (30.1%) | 74 (32.3%) | |
| Sex | | | | | **.032** |
| Male | 36 (42.9%) | 1 (50.0%) | 38 (55.1%) | 47 (63.5%) | |
| Female | 48 (57.1%) | 1 (50.0%) | 31 (44.9%) | 27 (36.5%) | |
| Age, y | 35.4 ± 10.7 | 30.0 ± 7.1 | 39.6 ± 10.2 | 37.2 ± 9.4 | **.042** |
| BMI | 22.9 ± 3.3 | 24.7 ± 0.3 | 23.2 ± 3.1 | 23.4 ± 2.9 | .604 |
| Symptoms onset time, mo | 18.7 ± 13.6 | 9.0 ± 4.2 | 17.1 ± 13.9 | 19.2 ± 18.3 | .690 |
| Follow-up time, mo | 38.9 ± 8.3 | 40.5 ± 9.2 | 38.2 ± 7.7 | 40.1 ± 8.2 | .380 |
| Affected side | | | | | .294 |
| Left | 46 (54.8%) | 1 (50.0%) | 30 (43.5%) | 33 (44.6%) | |
| Right | 38 (45.2%) | 1 (50.0%) | 39 (56.5%) | 41 (55.4%) | |
| FAI subtype | | | | | .303 |
| Cam | 22 (26.2%) | 0 | 14 (20.3%) | 12 (16.2%) | |
| Pincer | 0 | 0 | 0 | 0 | |
| Mixed | 62 (73.8%) | 2 (100.0%) | 55 (79.7%) | 62 (83.8%) | |
| Anterior inferior spine subtype | | | | | .896 |
| Type 1 | 18 (21.4%) | 0 | 10 (14.5%) | 16 (21.6%) | |
| Type 2a | 47 (56.0%) | 1 (50.0%) | 41 (59.4%) | 41 (55.4%) | |
| Type 2b | 18 (21.4%) | 1 (50.0%) | 17 (24.6%) | 15 (20.3%) | |
| Type 3 | 1 (1.2%) | 0 | 1 (1.4%) | 2 (2.7%) | |
| Tönnis grade | | | | | **.014** |
| Grade 0 | 61 (72.6%) | 2 (100.0%) | 42 (60.9%) | 37 (50.0%) | |
| Grade 1 | 23 (27.4%) | 0 | 27 (39.1%) | 37 (50.0%) | |
| Labral treatment | | | | | .289 |
| Labral debridement | 2 (2.4%) | 0 | 4 (5.8%) | 6 (8.1%) | |
| Labral repair | 82 (97.6%) | 2 (100.0%) | 64 (92.8%) | 66 (89.2%) | |
| Labral reconstruction | 0 | 0 | 1 (1.4%) | 2 (2.7%) | |
| Revision surgery | 3 (3.6%) | 0 | 4 (5.8%) | 1 (1.4%) | .354 |
| THA | 0 | 0 | 0 | 0 | |
| Crossover sign | | | | | .103 |
| Negative | 43 (51.2%) | 1 (50.0%) | 47 (68.1%) | 42 (56.8%) | |
| Positive | 41 (48.8%) | 1 (50.0%) | 22 (31.9%) | 32 (43.2%) | |
| Posterior wall sign | | | | | **.041** |
| Negative | 56 (66.7%) | 1 (50.0%) | 33 (47.8%) | 38 (51.4%) | |
| Positive | 28 (33.3%) | 1 (50.0%) | 36 (52.2%) | 36 (48.6%) | |
| Coxa profunda | | | | | .237 |
| Negative | 31 (36.9%) | 0 | 28 (40.6%) | 37 (50.0%) | |
| Positive | 53 (63.1%) | 2 (100.0%) | 41 (59.4%) | 37 (50.0%) | |
| Femoral head diameter, mm | 52.05 ± 5.69 | 54.7 ± 7.7 | 52.4 ± 5.6 | 53.4 ± 5.3 | .301 |
| Joint space, mm | 4.46 ± 0.78 | 4.5 ± 0.2 | 4.6 ± 0.7 | 4.6 ± 0.8 | .570 |
| $\alpha$ angle, ° | | | | | |
| Preoperative | 65.86 ± 7.78 | 52.8 ± 6.9 | 64.6 ± 7.8 | 66.9 ± 6.8 | .188 |
| Postoperative | 44.49 ± 5.43 | 43.3 ± 6.6 | 43.5 ± 5.9 | 44.0 ± 4.8 | .534 |
| LCEA, ° | | | | | |
| Preoperative | 31.41 ± 5.75 | 27.4 ± 1.1 | 33.0 ± 6.6 | 33.5 ± 7.2 | .105 |
| Postoperative | 29.83 ± 4.89 | 27.5 ± 0.8 | 32.0 ± 6.1 | 30.9 ± 5.3 | .057 |
| VAS | | | | | |
| Preoperative | 5.9 ± 1.3 | 5.0 ± 0.0 | 5.9 ± 1.3 | 6.0 ± 1.3 | .920 |
| Postoperative | 1.8 ± 1.5 | 1.5 ± 0.7 | 1.5 ± 1.4 | 1.6 ± 1.4 | .452 |
| HOS-ADL | | | | | |
| Preoperative | 65.2 ± 8.8 | 58.1 ± 11.4 | 63.9 ± 7.4 | 65.2 ± 9.0 | .565 |
| Postoperative | 89.3 ± 9.5 | 92.6 ± 8.3 | 89.9 ± 8.5 | 90.9 ± 7.9 | .529 |
| PASS (percentage) | 63.1% | 100.0% | 71.0% | 78.4% | .109 |
| HOS-SS | | | | | |
| Preoperative | 33.3 ± 18.6 | 43.1 ± 17.7 | 29.8 ± 20.3 | 32.4 ± 19.4 | .523 |
| Postoperative | 50.4 ± 33.5 | 30.6 ± 43.2 | 44.4 ± 36.8 | 51.1 ± 33.6 | .443 |
| mHHS | | | | | |
| Preoperative | 63.8 ± 7.8 | 61.0 ± 7.0 | 63.2 ± 8.0 | 62.4 ± 7.2 | .485 |
| Postoperative | 88.6 ± 9.0 | 90.1 ± 7.8 | 90.2 ± 8.1 | 90.0 ± 8.8 | .457 |
| PASS (percentage) | 91.7% | 100.0% | 91.3% | 94.6% | .706 |
| iHOT-12 | | | | | |
| Preoperative | 40.6 ± 7.3 | 42.4 ± 0.9 | 42.4 ± 7.2 | 41.8 ± 6.5 | .260 |
| Postoperative | 73.2 ± 10.6 | 71.4 ± 0.6 | 74.2 ± 10.9 | 74.9 ± 9.9 | .576 |
| Patient satisfaction | 84.7 ± 11.9 | 90.0 ± 0.0 | 86.6 ± 10.3 | 85.5 ± 10.5 | .562 |

NOTE. Data are presented as n (%) or mean ± SD.

NOTE. *P* values in bold indicate statistical significance ($P < .05$).

A, osteophyte anterior to 12 o'clock; AP, osteophyte anterior and posterior to 12 o'clock; BMI, body mass index; FAI, femoroacetabular impingement; HOS-ADL, hip outcome score-activities of daily living subscale; HOS-SS, hip outcome score-sports subscale; iHOT-12, 12-Item International Hip Outcome Tool; LCEA, lateral center-edge angle; mHHS, Modified Harris Hip Score; N, no osteophyte; P, osteophyte posterior to 12 o'clock; PASS, patient acceptable symptom state; SD, standard deviation; THA, total hip arthroplasty; VAS, visual analog scale.

values, with group AP at 677.10 ± 274.81 versus group P at 356.58 ± 339.46 ($P < .001$). In regard to ARO posterior to 12 o'clock, group AP also showed a larger width (6.66 ± 3.18) and area (29.96 ± 17.05) than group P (4.70 ± 2.25) and (20.15 ± 12.91), both $P < .001$. Meanwhile, the CT value of posterior ARO in group AP was 728.84 ± 232.39, compared with that of 641.84 ± 183.33 in group P ($P < .001$) (Table 5, Fig 4).

## Discussion

This study shows that the evaluation of ARO on CT reconstruction imaging of AGA is poor, consistent with definite double-rim sign of ARO on coronal sections. Thus, 3D reconstruction of CT imaging is not reliable in assessing ARO or acetabular rim morphology. Based on the quantitative measurements of ARO on coronal CT sections, there is a tendency of size-enlarging and density-increasing from anterior to posterior along the acetabular rim. Younger age, female gender, lower Tönnis grade, and negative posterior wall sign showed lower rate of ARO development.

**Table 4.** Intra- and Interobserver Correlation Analysis of ARO Measurements on Coronal Sections of CT

| | Intraobserver | | Interobserver | |
|---|---|---|---|---|
| | Pearson coefficient | *P* Value | Pearson coefficient | *P* Value |
| Width at 1:00, mm | 0.997 | **.000** | 0.988 | **.000** |
| Width at 12:00, mm | 0.998 | **.000** | 0.993 | **.000** |
| Width at 11:00, mm | 0.997 | **.000** | 0.989 | **.000** |
| Area at 1:00, mm$^2$ | 0.999 | **.000** | 0.995 | **.000** |
| Area at 12:00, mm$^2$ | 0.998 | **.000** | 0.991 | **.000** |
| Area at 11:00, mm$^2$ | 0.995 | **.000** | 0.981 | **.000** |
| CT value at 1:00, HU | 0.996 | **.000** | 0.985 | **.000** |
| CT value at 12:00, HU | 0.996 | **.000** | 0.983 | **.000** |
| CT value at 11:00, HU | 0.995 | **.000** | 0.981 | **.000** |

*P* values in bold indicate statistical significance ($P < .05$).

ARO, acetabular rim osteophyte; CT, computed tomography; HU, Hounsfield unit.

The first hypothesis is largely supported; AGA holds low consistency between observers in assessing ARO. The section of CT has long been regarded as an accurate tool in evaluating bony structures,[19] and the double-rim sign on coronal sections is deemed as the standard definition of ARO.[3] Even within the same observer, the evaluation based on AGA is moderate associated with coronal result.

The osteoid hyperplasia of the acetabular rim is common in patients with FAI, and even in asymptomatic non-osteoarthritic hips of all ages[3]; there has long been debated over its origin, forming mechanism, and clinical relevance.[3,5,6,8,9,33-35] According to Valente et al.,[3] the prevalence of ARO among asymptomatic nonosteoarthritic hips of all ages reaches up to 96%, whereas in our study, the incidence of ARO among patients with FAI was 63.3%. However, there are a few differences to note: First, they used bilateral hips of all patients for study, with risk of high morbidity, since once a person suffered from hip deformity or disordered biomechanics, 2 spatially symmetrical hips were affected at the same time. Second, we focused on the upper semicircle of the acetabular rim because it is mostly related to body weight-bearing, movement involvement, and surgical treatment; yet, the report of Valente et al. included the whole circumference of acetabulum, so the greater incidence rate of ARO is expected. Lastly, our study population has a relatively younger age, 37.2 ± 10.2 years; given that positive correlation between hip joint degeneration and age growth,[36,37] the relatively lower incidence rate of ARO in our study is reasonable.

There are many different descriptions of neo-osteoid growth on the acetabular rim; some have deemed it as LO or mineralization,[8,9] some have speculated it as ossified cartilage or bone growth,[4,7] and some have called it acetabular rim ossification displayed on CT imaging, without describing its histological nature. Byrd et al.[9] conducted histologic examinations on 2 patients, with tissue samples excised during arthroscopic surgery. They suggested 2 sources of the so-called LO: one was a bony extension from the acetabular rim, and the other was an endochondral ossification of the labrum. On histologic section, there was a gradual transition of LO, consisting of hyperdense bone, osteoid with or without calcification, and cartilage calcification and metaplasia,

**Table 5.** Osteophyte Measurements Among Groups

| | Group N | Group A | Group P | Group AP | *P* Value |
|---|---|---|---|---|---|
| Number (percentage) | 84 (36.7%) | 2 (0.9%) | 69 (30.1%) | 74 (32.3%) | |
| Width at 1:00, mm | – | 2.50 ± 0.28 | – | 3.88±1.86[b] | |
| Width at 12:00, mm | – | 1.95 ± 2.76 | 2.06 ± 2.10[a] | 4.84 ±.72[a,b] | **<.01[a]** |
| Width at 11:00, mm | – | – | 4.70 ± 2.25 | 6.66 ± 3.18[b] | **<.01** |
| *P* value | | | **<.01** | **<.01[b]** | |
| Area at 1:00, mm$^2$ | – | 6.70 ± 1.13 | – | 15.73 ± 21.46[d] | |
| Area at 12:00, mm$^2$ | – | 6.23 ± 8.80 | 6.90 ± 7.71[c] | 19.22 ± 18.86[c,d] | **<.01[c]** |
| Area at 11:00, mm$^2$ | – | – | 20.15 ± 12.91 | 29.96 ± 17.05[d] | **<.01** |
| P value | | | **<.01** | **<.01[d]** | |
| CT value at 1:00, HU | – | 543.10 ± 2.12 | – | 652.67 ± 214.12[f] | |
| CT value at 12:00, HU | – | 380.10 ± 537.54 | 356.58 ± 339.46[e] | 677.10 ± 274.81[e, g] | **<.01[e]** |
| CT value at 11:00, HU | – | – | 641.84 ± 183.33 | 728.84 ± 232.39[f,g] | **<.05** |
| *P* value | | | **<.01** | **<.05[f,g]** | |

NOTE. Data are presented as n (%) or mean ± standard deviation.
NOTE. Bold indicates statistical significance ($P < .05$).
NOTE. The lowercase letters (a-g) shown as the upper right corner markers indicate corresponding *P* values.
A, osteophyte anterior to 12 o'clock; AP, osteophyte anterior and posterior to 12 o'clock; N, no osteophyte; P, osteophyte posterior to 12 o'clock.

from the original acetabular margin moving laterally. Earlier, Corten et al.[5] assumed that the LO was formed by subperiosteal bone apposition at the acetabular rim rather than an ossification of the labral substance itself. They included 20 hips in 18 patients to carry out a histologic evaluation and concluded that the labrum was either encased on the capsular side by bone apposition or was pushed forward, thereby becoming thinner. They attributed "double-rim sign" to new bone formation on the native bone edge. Based on the previous literature and our clinical experience, we believe that the new osteoid growths at the acetabular rim, most of the time shown as a triangular cut surface with double-rim sign on CT, are osteophytes of varying degrees of development. Although it is difficult to determine its histologic nature preoperatively, attention is needed to form a better understanding of ARO's clinical interpretation.

In addition to size differences, which in this study measured by width and area, the CT value was also analyzed, for it can reflect the extent of osteophyte proliferation and sclerotin deposition in nature. We believe that CT value could offer information on the histological composition of ARO in a noninvasive way, which can provide new insights into ARO assessment. Given the statistical analysis of PROs, ARO observed on coronal CT is more likely to be a degenerative change, without significant influence on patient symptoms.

We divided the whole population into 4 groups based on the position and scope of ARO and compared the baseline data, the morphology (FAI subtypes, anterior inferior spine subtypes, crossover sign, posterior wall sign, coxa profunda, α angle, LCEA), and PROs (mHHS, iHOT-12, HOS-ADL, HOS-SS, VAS) among groups. There is no significant difference found in hip functional scores pre- and postoperatively among groups,

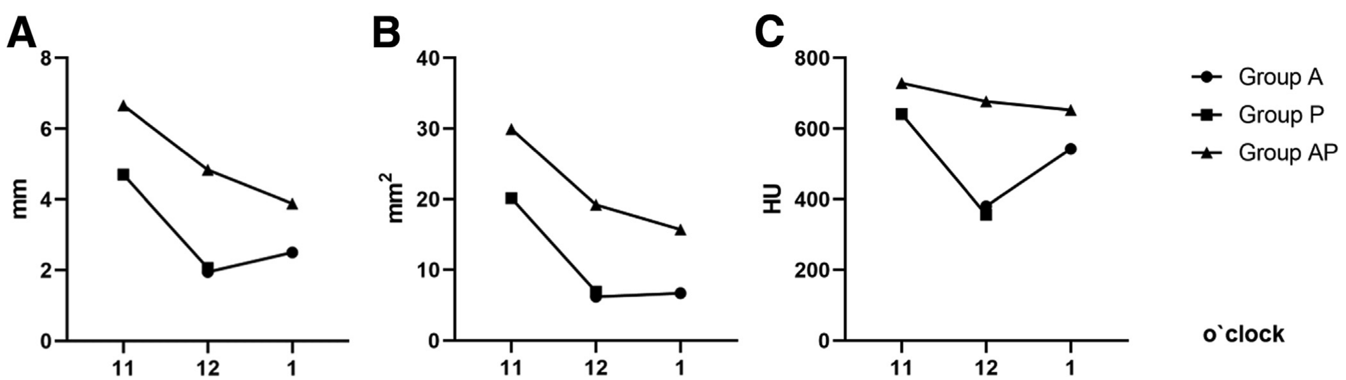


**Fig 4.** (A) Line chart of ARO width among groups; (B) line chart of ARO area among groups; (C) line chart of ARO CT value among groups. Abscissa represents the ARO position using clockface as reference. (ARO, acetabular rim osteophyte; group A, osteophyte anterior to 12 o'clock; group AP, osteophyte anterior and posterior to 12 o'clock; group P, osteophyte posterior to 12 o'clock.)

which suggests a scarce relationship between ARO and clinical symptoms. Therefore, ARO itself should not be regarded as an indicator for acetabuloplasty; many other factors, such as LCEA, acetabular retroversion, cam volume, impact position, as well as the cartilage lesion, should weigh more to achieve a comprehensive decision. In group N, there were significantly more patients with negative posterior wall sign than positive, which sheds light on a possible relation between osteophyte formation and acetabulum retroversion. At the same time, there were more patients classified as Tönnis 0 than Tönnis 1 in group N, and the opposite was true in group AP, inferring the positive relation between degeneration and ARO formation. Group N showed a greater rate of labral repair and lower rate of labral reconstruction and debridement than group P and group AP, suggesting that patients without ARO tend to have less severe and more repairable labral injury. The 3 labral reconstruction patients came 1 from group P and 2 from group AP.

As for demographic analysis, ARO tends to occur in older and male patients, especially posterior to 12 o'clock on the acetabular rim. Given the definite progression of joint degeneration over aging and the greater activity involvement of men, it is worth noting that ARO could be considered as a manifestation of degeneration correlating closely to aging and physical activities. However, with no significant difference found in hip functional scores among groups as mentioned previously, we assume that may have something to do with relatively early stage of osteophyte formation in this study, for osteophyte widths of 217 patients (94.8%) shorter than 10 mm. As the scoring methods and osteophytes develop, the influence of ARO on patients' symptoms may appear.

In order to evaluate ARO in quantitative ways, the width, area and CT value were taken into statistical analysis. In the same patient, the osteophyte shows a tendency of size and density increasing from anterior to posterior along the acetabular rim. There are only 2 patients in group A compared with 69 patients in group P and 74 patients in group AP, suggesting that the posterior margin of acetabulum is the main zone for stress-degeneration processes and develops osteophytes earliest, with a greater density on CT. The comparison between group P and group AP, focusing on ARO at and posterior to 12 o'clock, also confirmed that. Group AP has a more extensive scope of ARO stretching across the 12 o'clock of the acetabular rim; simultaneously, it shows a larger and denser ARO compared with the corresponding sites of group P. The hip joint is different from any other joints in human body because it not only connects the trunk and the lower limbs but also bears the most of weight. Given the bowl-shaped morphology of acetabulum and a much more range of motion of flexion than extension, the superior and posterior regions of acetabulum no doubt experience a great deal of stress impact and thus develop adaptive changes. The development and assessment of hip OA should be distinguished from other joints, not only for the special anatomy and function of the hip joint as we just discussed; in addition, osteophyte in the knee joint often occurs with narrowing of the joint space and helps with OA assessment, whereas large amounts of patients with FAI with ARO could not be classified as OA sufferers, for they were graded as Tönnis 0 and underwent effective arthroscopy operation without revision surgery or THA followed. Some previous researchers also hold the same views,[38] and further studies in regard to progression and cut-off points of hip degeneration are needed, as well as the research focusing on biomechanical and histological assessments of ARO.

### Limitations

Several limitations are acknowledged. Above all, there was no histological assessment in this study. With sufficient assessment of the histological sections from different patients and corresponding complete medical images including magnetic resonance imaging, the evaluation of ARO would be more accurate. However, due to the large sample size and ethic approval process, these need to be completed in future research. Second, some other factors concerning osteophytes may be overlooked in this study, for grouping only based on the position and extent of ARO, and the heterogeneity among patients is un-neglectable. A dynamic continuous study of ARO formation and progression on a per-person basis is highly anticipated. In addition, there have been studies on knee joint showing that the biochemical mediator acting on entire joint may influence the osteophyte progression,[19] and the same goes for hip joint. This study did not take into consideration of the whole joint mediator when comparing the subregions of acetabular rim; the biochemical process, whether it differs in subregions of the acetabular rim, as well as the mechanical mechanism, should also be studied in the future. Lastly, there were only 3 patients who underwent labral reconstruction, so there were not enough data to interpret.

## Conclusions

The evaluation of ARO on AGA is poor, consistent with definite double-rim sign on coronal CT. There is a tendency of size-enlarging and density-increasing for ARO from anterior to posterior along the acetabular rim. Younger age, female gender, lower Tönnis grade, and negative posterior wall sign showed lower rate of ARO development.

## Disclosure

The authors (H.D., M.M., C.J., Y.L., G.G., T.H. Y.X.) declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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