The hip asphericity angle: a novel angle for measurement of Cam-FAI correction

Mohammad Masoud 1,2*, Adinun Apivatgaroon 3, Hatem Said 1, Mohamed M. Abdel-Hamid 1, Maher El-Assal 1 and Michael Dienst 4

1 Orthopedics and Trauma Department, Assiut University, University Street, Assiut 71515, Egypt,
2 Department of Traumatology, Kreiskrankenhaus, Spitalstr. 25, Lörrach 79539, Germany,
3 Department of Orthopedics, Faculty of Medicine, Thammasat University, 99/209 Khlong-Neung Sub-District, Khlong-Luang district, Pathumthani 12120, Thailand and
4 Orthopädische Chirurgie München (OCM), Steinerstr. 6, Munich 81369, Germany.
*Correspondence to: M. Masoud. E-mail: Masoud.ortho@yahoo.com
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ABSTRACT

The alpha angle is routinely used for the diagnosis and quantitative description of the Cam deformity of the hip. However, a reliable identification of the femoral neck axis as its reference line can be difficult. Moreover, most cam resections include a reduction of the femoral neck diameter with an automatic posteromedial angulation of the femoral neck axis. In consequence, the reference axes for the pre- and postoperative alpha angles are different, and a comparison of both angles underlies a systematic error to relatively higher postoperative alpha angles. In order to avoid this systematic error, we propose the hip asphericity (HA) angle with a reference axis independent of the amount of bony resection. Two retrospective groups were formed, a ‘femoroacetabular impingement (FAI) group’ that had hip arthroscopy for cam resection and a ‘Control group’ without cam deformity. The alpha and HA angles were measured by three examiners. The measurements were repeated 1 month later. In the FAI group, offset correction was calculated using both angles. Statistically significant differences for both the alpha and the HA angles were found between the control and the preoperative FAI group as well as between the preoperative and postoperative FAI groups. The HA angle-correction by a mean of 27.5° was significantly higher in comparison to the alpha angle correction by a mean of 25.4°. The intertester and intratester reliability of both angles were not significantly different. The HA angle is a new and reliable radiographic parameter for measuring cam deformity and proves superior in measuring cam correction.

INTRODUCTION

As the awareness of femoroacetabular impingement (FAI) increases and more FAI patients undergo surgical treatment, the need to reliably identify and quantify the disease becomes compelling. Reliable imaging measurements are important parameters to prove the clinical suspicion. Since its first description by Nötzli in 2002, the alpha angle has been widely used for the diagnosis and assessment of Cam-FAI [1]. This angle was originally measured on magnetic resonance imaging (MRI) axial oblique cuts centered to the femoral neck axis. In the clinical setting, surgeons are used to measure the alpha angle on plain radiographs, supported by several studies which have validated the radiographic alpha angle [2–4]. Originally, Nötzli described a threshold of the alpha angle of 50° to separate a normal head–neck–contour from a cam-type deformity [1]. However, different thresholds were suggested by other authors. Several studies suggested a higher cutoff at an alpha angle of 55° [5–7]. Agricola et al. [8] showed a significant higher risk for the development of osteoarthritis at alpha angles of 78° or higher. Espié et al. [9] described different thresholds for women at 58° and males at 63°. The alpha angle is useful not only in diagnosing cam-type FAI but also for monitoring correction after arthroscopic or open cam resection [10]. Ross et al. [11] showed that higher postoperative alpha angles of >50° were found in
86% of patients undergoing revision hip arthroscopy for persistent symptoms.

Measurement of the alpha angle, however, may be technically difficult and shows a systematic error when it comes to monitoring of correction of big alpha angles. From the authors’ experience, the center of the femoral neck as the second reference point for the femoral neck axis may be difficult to be identified. In addition, in most cam resections, the anteroposterior (AP) and lateromedial diameter of the femoral neck is reduced which automatically results in a posteromedial shift of the center of the femoral neck and posteromedial angulation of the femoral neck axis of the alpha angle. In consequence, the reference axes for the pre- and postoperative alpha angles are different, and a comparison of both angles underlies a systematic error to relatively higher postoperative alpha angles.

In order to find an angle with a possible easier identification and whose reference axis is independent of the amount of cam resection, the authors suggest a new ‘hip asphericity (HA) angle’. In the present study, the ‘HA angle’ is described and tested for validity. In addition, the ‘HA angle’ is compared with the alpha angle regarding its inter- and intratester reliability as well as regarding its use as a new tool for postoperative assessment of cam resection.

**MATERIALS AND METHODS**

In this retrospective study, all patients who underwent hip arthroscopies between January and June 2017 were evaluated. In addition, all patients who had hip injections under fluoroscopic control for unclear hip pain without pathologic radiographic findings from January to December 2017 were analyzed. Of those patients, two groups were formed: an FAI group and a control group (Table I).

Between January and June 2017, 135 hip arthroscopies were performed. Inclusion criteria for allocation into the FAI group were no or minimal signs of osteoarthritis (Tönnis 0–1), an arthroscopic operation during the aforementioned time period with a cam resection for management of FAI and patients who had digital pre- and postoperative frog leg lateral radiographs. All radiographs had to be taken in the authors’ own radiology unit with the X-ray-beam centered over the hip, placing the hip in 70° of flexion and 40° of abduction with the ipsilateral foot touching the inside of the contralateral knee. By using this technique, the anterolateral head-neck-junction was imaged where most of cam pathologies are located. Patients with radiographic signs of more advanced osteoarthritis (Tönnis 2–3) [12], resection of femoral osteophytes and acetabular bone resection for Pincer-FAI were excluded. The FAI group consisted of 50 hips in 46 patients.

Inclusion criteria for patients in the control group were patients with unclear pain around the hip region with no groin pain, a negative impingement test, a complete pain-free range of motion including at least 20° of internal rotation and a negative intraarticular injection test under fluoroscopy denoting exclusion of intraarticular cause of symptoms. AP pelvis and frog leg lateral X-ray of these patients were evaluated and only subjects with no loss of anterolateral offset on frog leg films with an anterolateral head neck offset ratio >0.18 [13] and no radiologic signs of osteoarthritis or any other hip pathology were included in this group. Twenty patients met these inclusion criteria.

The measurement process (Fig. 1) for both angles started with drawing the best fitting circle on the femoral head. As defined by Nötzli, the alpha angle was measured between the femoral neck axis and the line from the center of the circle to the proximal border of the anterolateral cam deformity [1]. The femoral neck axis was defined as the line connecting the center of the circle and the midpoint of the narrowest part of the femoral neck, the anterolateral line as the connection of the center of the circle and the point where the anterolateral asphericity escapes the circle. For measurement of the HA angle, the same anterolateral line was used. The reference axis and posteromedial line was defined as a line from the center of the circle to the point where the circle cuts the posterior neck. All measurements were made using the digital DICOM viewing and editing software (DICOM PACS View Version 6.0.2.416, Birmingham, UK). Before starting the measurement, the amount of zoom was fixed to 100% to avoid possible errors from bigger or smaller images.

Three experienced orthopedic hip surgeons measured the alpha and HA angles in both groups including both preoperative and postoperative radiographs for the FAI group. The difference of each angle in the FAI group pre- and postoperative was calculated to assess the amount of offset correction achieved by arthroscopy. Two examiners repeated all measurements after 1 month in order to calculate intraobserver reliability.

The ability of both angles to differentiate between the cam deformity and normal head-neck-anatomy was tested
by an independent t test between the control group and the preoperative FAI group. The ability of the HA angle to measure the offset correction was tested by a paired t test. Interclass correlation (ICC) was used to detect inter- and intra-tester reliability of both angles. Statistical analysis was performed using IBM SPSS Advanced Statistics 20.0.

RESULTS
In the control group, the mean alpha angle was 40.8° and the mean HA angle 79.8° (Table II, Figs 2 and 3). In the preoperative FAI group, the mean alpha angle was 67.1° and the mean HA angle 108.6°. In the postoperative FAI group, the mean alpha angle was 41.7° and the mean HA angle was 81.1°. Figures 2 and 3 show the distribution curves of measurement values of the three groups for alpha and HA angles, respectively. There were highly significant differences for both the alpha and HA angles between the

| Groups                      | Angles | Mean | SD  | Min | Max |
|-----------------------------|--------|------|-----|-----|-----|
| Control                     | Alpha  | 40.8 | 3.5 | 34.6| 50.2|
|                             | HA     | 79.8 | 4.3 | 70.7| 89.9|
| FAI preoperative            | Alpha  | 67.1 | 10.2| 47.3| 89.8|
|                             | HA     | 108.6| 10.9| 89.7| 129 |
| FAI postoperative           | Alpha  | 41.7 | 4.6 | 30.6| 54.5|
|                             | HA     | 81.1 | 6.2 | 65.7| 98  |
| Correction angle            | Alpha  | 25.4 | 8.9 | 4.4 | 52.3|
|                             | HA     | 27.5 | 9.1 | 5.5 | 55.4|

Statistical significance: $P < 0.05$.

* Both postoperative mean alpha and HA angles are significantly different compared with preoperative ones.

* HA correction is significantly higher than alpha correction.
Fig. 2. Alpha angle measurements in the control group (black), preoperative cam group (red) and postoperative cam correction (green).

Fig. 3. HA angle measurements in the control group (black), preoperative cam group (red) and postoperative cam correction (green).
preoperative FAI group and the control group ($P < 0.001$). Arthroscopic cam resection showed a highly significant reduction of both angles, by $25.4^\circ$ of the alpha angle and by $27.5^\circ$ of the HA angle ($P < 0.005$). The higher reduction of $2.1^\circ$ by the HA angle was highly significant compared with the alpha angle.

The HA angle showed higher intratester reliabilities than the alpha angle; however, the difference was significant only for one tester in the postoperative FAI group (Table III).

The intertester reliability of both the alpha and HA angles showed no differences for both the control group and the preoperative FAI group (Table IV). In the postoperative FAI group, the inter-tester reliability was higher for the HA angle in comparison to alpha angle; however, the difference was not significant ($P = 0.22$).

**DISCUSSION**

Radiographic assessment of Cam FAI by the use of the alpha angle has become an integral part of every day’s practice of a hip surgeon. It is being used as a measurement tool for both the diagnosis of Cam FAI and the quantification of the amount of resection [10]. Reliability of the alpha angle measurement on plain radiographs can be limited because of both the difficulty of a precise definition of the femoral neck cortical borders and the posteromedial shift of the midpoint of the neck by advancing the Cam resection into the anterolateral neck. In order to find a more precise angle independent of the bias of resection, the HA angle is suggested.

In the present study, the alpha angle showed an excellent intratester reliability with an ICC of 0.89–0.95 and a good to very good intertester reliability with an ICC of

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**Table III. Intra-tester reliability**

| Tester 1 (95% confidence interval) | Tester 2 (95% confidence interval) |
|-----------------------------------|-----------------------------------|
|                                   | Alpha (HA)                        | HA (HA) |
| Control group                    | 0.89 (0.75–0.96) (0.78–0.96)      | 0.91 (0.78–0.96) |
| FAI preoperative                 | 0.95 (0.92–0.97) (0.91–0.97)      | 0.91 (0.85–0.95) |
| FAI postoperative                | 0.90 (0.83–0.93) (0.90–0.96)      | 0.79 (0.67–0.88) |

*P < 0.05.
0.69–0.85. For the HA angle, an excellent ICC of 0.91–0.95 for the intra-tester reliability and a very good ICC of 0.80–0.87 for the inter-tester reliability were found. In comparison to the alpha angle, there was a general tendency for better ICCs. For the intratester reliability in one tester, the ICC was significantly better. Thus, the HA angle offers a highly reliable tool for measurements on the head-neck-junction.

Previous studies have also shown a high reliability of alpha angle measurements when the same imaging modality and the same radiographic projections were used (Table V). However, significant lower reliabilities were shown when different imaging modalities (e.g. radiographs versus MRI) or different radiographic projections were compared. Barlow et al. [14] conducted a reliability study measuring the Alpha angle on axial and axial oblique MRI images. In that study, the inter- and intrarater reliability for the axial images were lower than those for axial oblique images taken in the plane of the femoral neck. The authors related that to the difficulty of a precise determination of the neck axis in axial images. Similarly, Konan et al. [15] found excellent intra- and interrater agreement of the alpha angle measurement on frog leg lateral radiographs. When they compared those measurements with computed tomographic (CT) measurements, a poor ICC was found. On radiographs, the alpha angle was underestimated in 43% and overestimated in 57% of the cases in comparison to measurements on CT scans. Radiological technique variations, x-ray beam projection and patient characteristics were seen as the most important factors for the poor reliability. Hence, the preoperative use of CT scans was recommended for an accurate measurement of the alpha angle [15]. Three studies though have shown a more variable poor to strong intertester reliability of 0.08–0.64, whereas the intratester reliability in the three studies was good to excellent [16–18].

The cause of the variable intertester reliability can be related to the examiner and to differences in the measurement technique. The experience of the examiners frequently varies. Technically difficult can be the clear delineation of the femoral head circle, the precise identification of the starting point of the asphericity and the center of the femoral neck. The variability of alpha angle reliability across different imaging modalities or across different views can be intuitively explained by the three-dimensional shape of the cam deformity that is usually not uniform. Alpha angle will change with rotation of the limb/X-ray beam in radiographs as well as with varying cuts in CT and MRI. Monazzam et al. [19] have shown that femoral rotation has a highly significant impact on the measurement of alpha angles. This questions the reliability of comparing the pre- and postoperative alpha angles on plain X-rays and among repeated X-rays with possible position changes and measurement errors.

In the present study, typical alpha angles were found for both the control group and the preoperative FAI group. For the control group, the mean alpha angle was 40.8° with a small standard deviation (SD) of 3.6° and a maximum angle of 50°. Thus, all patients with no evidence of Cam FAI were underneath the reported thresholds of 50°–55° [1, 20]. In the preoperative FAI group, the mean alpha angle of 67° was clearly pathologic with a bigger range between 47° and 90°. Similar preoperative alpha angles prior to Cam resections were found by Clohisy et al. with 63.9° [40–81], Chiron et al. with 61.8° [48–87], Naal et al. with 69.3° [50–83] and Brunner et al. with 75.9° [21–24, 57–110]. After Cam resection, the alpha angle was significantly reduced to a normal mean alpha angle of 42°. This is consistent with other studies indicating an effective arthroscopic Cam resection to normal alpha angles [10, 24, 25].

The HA angle measurements were about 40° higher than the corresponding alpha angles. The mean HA angle for the control group was 80° and for the preoperative FAI group 109°. By arthroscopic Cam resection, the mean HA angle was significantly reduced to 81°.

The correction angle defined by the preoperative angle minus the postoperative one indicated a significant higher correction of 27.5° for the HA angle in comparison to 25.4° for the alpha angle. Likely, this is caused by the systematic error caused by the postero medial shift of the center of the femoral neck (Fig. 4). Clinical relevance of a difference of 2.1° could be questioned; however, a systematic intrinsic error caused by the alpha angle definition itself could be avoided by using the suggested alternative.

| Groups       | Alpha (95% confidence interval) | HA (95% confidence interval) |
|--------------|----------------------------------|-----------------------------|
| Control      | 0.85 (0.72–0.93)                 | 0.85 (0.72–0.93)             |
| FAI preoperative | 0.87 (0.81–0.92)               | 0.87 (0.80–0.92)             |
| FAI postoperative | 0.69 (0.56–0.79)               | 0.80 (0.70–0.87)             |
The reference axis of the HA angle is independent on bone resection if that is limited to anterolateral aspect of the head-neck-junction. If bone resection, however, is advanced into the posteromedial head-neck-junction, also the reference axis of the HA angle would change. This situation, however, is unlikely with respect to the rare need of a bone resection in this area and the high risk of iatrogenic avascular necrosis. In addition, it need to be considered that deformities of the posteromedial offset such as slipped capital femoral epiphysis may have an impact of the HA angle. Further studies are necessary in order to compare the radiographic HA angle with other imaging modalities such as CT or MRI.

Analyzing the distribution of normal controls and patients with Cam FAI (Fig. 2), the original cut off by Nötzli of 50° between normal and pathologic alpha angles was confirmed [1]. All alpha angles of the controls were below 50° (maximum alpha angle 50.2°). Considering a range of a double SD for normality, the upper alpha for the control groups would be 48°. As indicated above, more recent studies suggest a more ‘careful’ cutoff of 55° to 60° between a normal and Cam-type head-neck-shape [5–9].

For the HA angle, all normal controls showed an angle below 90°, with an upper limit of a double SD range of about 88°. Also from the graphical interpretation, the cutoff for the HA angle between normal shape and Cam

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**Table V. Summary of previous studies testing the reliability of alpha angle measurement**

| Study          | Views         | Intertester ICC | Intratester ICC | Number of hips | Number of testers |
|----------------|---------------|-----------------|-----------------|----------------|------------------|
| Gosvig et al. [26] | AP            | 0.83            | 0.90–0.96       | 2803           | 2                |
| Clohisy et al. [27] | AP            | 0.85            | 0.60            | 85             | 2                |
|                | Cross-table   | 0.56            | 0.50            |                |                  |
|                | Frog leg      | 0.83            | 0.73            |                |                  |
| Pollard et al. [28] | AP, cross-table | 0.84           | 0.91            | 83             | 2                |
| Konan et al. [15] | Frog-leg      | 0.83            | 0.88            | 32             | 2                |
| Mast et al. [29] | AP, cross-table | 0.83           | 0.96–0.98       | 20             | 2                |
| Barton et al. [2] | AP            | 0.95            | 0.88            | 68             |                  |
|                | cross-table   | 0.85            | 0.95            |                |                  |
|                | Dunn view     | 0.90            | 0.98            |                |                  |
| Nicholls et al. [18] | AP            | 0.52–0.64       | 0.77–0.85       | 268            | 2                |
| Carlisle et al. [16] | Cross-table  | 0.08            | 0.76            | 45             | 5                |
|                | Frog-leg      | 0.21            | 0.76            |                |                  |
| Cavaignac et al. [3] | Frog leg     | 0.93            | 0.91            | 19             | 2                |
|                | Cross-table   | 0.87            | 0.92            |                |                  |
|                | Dunn 90       | 0.92            | 0.90            |                |                  |
|                | Dunn 45       | 0.93            | 0.87            |                |                  |
| Barlow et al. [14] | Axial MRI    | 0.84            | 0.85            | 50             | 3                |
| Nepple et al. [17] | Dunn          | 0.43 (0.35–0.56)| 0.92 (0.87–0.95)| 70         | Digital measurement |
| Laborie et al. [30] | Frog leg     | 0.92 (0.89–0.95)| 0.95–0.97       | 100            | 2                |
|                | AP            | 0.89 (0.85–0.93)| 0.96 (0.94–0.98)| Manual and digital |
deformity would be at 90°. With respect to the limited sample size and dominance of females in the control group, the limited strength and reliability of this cutoff needs to be considered. Further studies with a bigger sample size are necessary to further analyze the suggested cutoff between normal and pathologic HA angles.

For both the alpha angle and the HA angle, it needs to be considered that the asphericity of the head-neck-junction is only one piece of a bigger puzzle leading to the diagnosis and classification of FAI. Single radiographic projections show only a limited part of the head-neck-junction. In addition, other factors on the proximal femur such as femoral torsion, acetabular parameters and sequelae damage at labrum and cartilage need to be analyzed on both radiographs and other imaging modalities in order to complete the diagnostic algorithm.

CONCLUSIONS
The present study shows that both the alpha angle and the HA angle are reliable tools for diagnosis of Cam FAI and measurement of bone resection. The HA angle adds a new technique with a stable reference axis if Cam resection is performed at its typical anterolateral position.

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CONFLICT OF INTEREST STATEMENT
None declared.

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