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SCIENTIFIC ARTICLE

Cam-type femoral-acetabular impingement: is the alpha angle the best MR arthrography has to offer?

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Abstract

Introduction In our institutional experience, determination of the alpha (α) angle at MR arthrography as an indicator of the likelihood of cam-type femoroacetabular impingement (FAI) is fraught with inconsistency. The aims of this study were to quantify the degree of variability in and calculate the diagnostic accuracy of the α angle in suggesting a diagnosis of cam impingement, to determine the accuracy of a positive clinical impingement test, and to suggest alternative MR arthrographic measures of femoral head–neck overgrowth and determine their diagnostic utilities.

Materials and methods We carried out a retrospective analysis of MR arthrographic studies performed during a 4-year period, combined with chart analysis, which allowed identification of 78 patients in whom surgical correlation was also available. The status of a preoperative clinical impingement test was also noted. Patients were designated as having cam-type FAI (Group A, n=39) if intra-operative femoral head–neck junction bony osteochondroplasty/arthoscopic femoral debridement was performed. Group B (n=39) acted as controls. Three radiologists independently and blindly performed a series of measurements (α angle and two newly proposed measurements) in each patient on two separate occasions. An α angle of greater than 55° was considered indicative of the presence of cam-type FAI.

Results Performance values for α angle measurement were poor for each observer. There was considerable (up to 30% of the mean value) intra-observer variability between the first and second α angle measurements for each subject. Binary logistic regression analysis confirmed that the α angle is of no value in predicting the presence or absence of cam-FAI. A statistically significant difference existed between Groups A and B with regard to the newly proposed anterior femoral distance (AFD; p=0.004). Using an AFD value of 3.60 mm or greater as being indicative of the presence of cam-FAI yields a 0.67 performance measure (95% confidence interval 0.55–0.79). The second proposed parameter (femoral neck ratio) was of no value in suggesting the presence or absence of this condition. The sensitivity, specificity, and positive and negative predictive values of the clinical impingement test were 76.9%, 87.2%, 85.7% and 79.1% respectively.

Conclusions Femoral α angle measurement is associated with considerable variability. This index performed poorly in our patient population and was statistically of no value in suggesting the presence or absence of cam-FAI. One of our proposed measures, the AFD, outperformed the α angle, though to an insufficient degree to suggest its routine incorporation into clinical practice. Our experience suggests that the clinical impingement test remains the most reliable predictor of the presence of this condition.

Keywords Hip · Impingement · Magnetic resonance imaging · Arthrography · Alpha angle

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Introduction

Femoroacetabular impingement (FAI) refers to abnormal contact between the femoral head–neck and acetabulum. It occurs as a result of morphological deformity of one or either structure, and has increasingly been recognized as a significant contributor to labral tear and premature osteoarthritis [1, 2]. This is particularly the case in young, athletic individuals in whom repetitive exaggerated or actively stressed motion at the hip joint may accelerate secondary degeneration [3]. Two subtypes of this entity have been described, "pincer-FAI" related to an abnormality of the acetabulum that results in over coverage of the femoral head, and "cam-FAI" relating to overgrowth of the femoral head–neck junction [4]. It is generally accepted that while isolated pincer-FAI or cam-FAI may be present in any one individual, a combination of both subtypes is usually present [5].

Determination of the degree of femoral epiphyseal overgrowth in suspected cam impingement has largely relied upon measurement of the alpha (α) angle on axial cross-table lateral radiographic projections of the hip joint, or at magnetic resonance (MR) arthrography [6]. Derivation of this angle, initially proposed by Nötzli, involves circular contouring of the femoral head at the level of the fovea (including its overlying articular cartilage) and determination of the angle between the central femoral neck axis and the point at which the anterior femoral head–neck junction exits this circular contour, using the center of the femoral head as a fulcrum (Fig. 1a).

In our institutional experience, determination of the α angle at MR arthrography was fraught with potential inconsistency. We observed that even slight inter-individual variations in the level selected for contouring, the location and size of the circular femoral head contour and determination of the location at which the anterior femoral head–neck junction exits this contour may result in considerable variability in α angle measurements derived. Our experience also indicated that considerable disparity exists between the pre-investigational index of suspicion for the presence of cam-FAI (as indicated by a positive clinical impingement test) and subsequent derivation of an abnormally increased α angle.

Intuitively when one considers the configuration of the femoral head–neck and acetabulum in cam impingement, it seems reasonable to suggest that the *depth* of epiphyseal overgrowth may be of primary importance in determining the presence of FAI and may perhaps be preferable to an indirect measure of the presence of such overgrowth, i.e., the α angle. This consideration was the motivation for the current study. The aims of this study are:

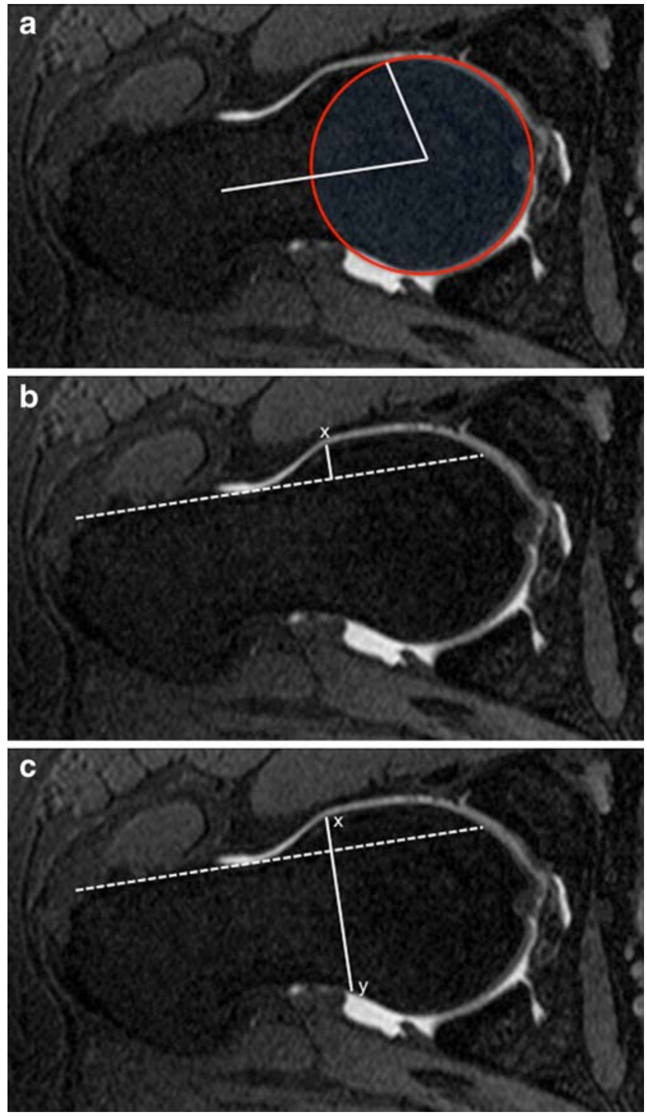

Fig. 1 Axial oblique gradient echo image from MR arthrogram study, obtained at the level of the fovea. The α angle is the angle between a line drawn along the center of the femoral neck to the center of the femoral head "best fit" circle, and then extended to where the anterior femoral head–neck junction exits this circle (*white lines* in **a**). The anterior femoral distance (AFD) is described as the greatest perpendicular depth of epiphyseal overgrowth at the anterior femoral head–neck junction, as measured from a line long the anterior aspect of the femoral neck (distance from point "x" to the dotted line in **b**). The femoral neck diameter is obtained by continuing the AFD line posteriorly to the posterior femoral cortex (point "y" in **c**)

1. To determine the variability in alpha angle measurement in whom femoral head–neck overgrowth (and therefore cam-FAI) was subsequently surgically confirmed or excluded
2. To calculate the diagnostic accuracy of the α angle in suggesting a diagnosis of cam impingement
3. To determine the diagnostic accuracy of a positive clinical impingement test in suggesting the presence of cam-FAI
4. To suggest alternative MR arthrographic measures of femoral head–neck overgrowth (the anterior femoral

distance [AFD] and femoral neck ratio [FNR]) and determine their diagnostic utilities

Materials and methods

A retrospective analysis of all MR arthrographic studies performed during a 4-year period at a single institute on the same 1.5 Tesla MRI scanner (Magnetom Sonata, Siemens Medical Solutions, Malvern, PA) was performed. All patients had been clinically referred for investigation of suspected acetabular labral or articular cartilage abnormalities. An exemption was obtained from the local Institutional Review Board (IRB) prior to study commencement.

Retrospective patient chart analysis allowed identification of the study group, comprising 78 patients in whom surgical correlation, either arthroscopic or open, was available. Exclusion criteria included prior ipsilateral hip surgery or evidence for post-traumatic deformity, Legg–Calve–Perthes disease, osteonecrosis, advanced osteoarthritis, slipped capital femoral epiphysis or hip dysplasia. Note was made during this chart review of the presence or absence of clinical impingement on pre-investigational physical examination. Patients were designated as having cam-type FAI (Group A, n=39, male:female=19:20, mean±SD age=35.4±12.1 years) if intra-operative femoral head–neck junction bony osteochondroplasty/arthoscopic femoral debridement was performed. Group B (all other patients, n=39, male:female=17:22, mean±SD age=35.6±14.1 years) acted as controls, representing patients in whom interventions other than femoral head–neck junction bony osteochondroplasty/arthroscopic femoral debridement was performed (e.g., labral or articular cartilage debridement or repair, joint wash-out). All arthroscopic examinations/procedures were performed by an orthopedic surgeon with over 10 years' experience, while all open surgical procedures were performed by a second orthopedic surgeon with in excess of 25 years' experience.

Imaging technique

Each patient underwent sterile fluoroscopically guided intra-articular injection of approximately 14 mL of 1:200 gadolinium:saline solution (gadopentetate dimeglumine; Magnevist, Bayer HealthCare Pharmaceuticals) within 30 min of commencement of the MR arthrogram examination. The imaging protocol utilized remained unchanged throughout the study period, comprising coronal proton-density-weighted fat-saturated turbo spin echo, coronal T2-weighted 2-dimensional gradient echo, sagittal T1 fat-saturated turbo spin echo, and axial oblique 3-dimensional T2-weighted gradient echo acquisitions along the plane of the femoral neck. Imaging parameters for the latter sequence included TR/TE 22.42/6.15 ms, flip angle 25°, field-of-view 200 mm x 175 mm, matrix 256 x 168, spatial resolution 0.78 mm x 1.04 mm (in-plane), slice thickness 1 mm.

Image analysis

All images were reviewed on a patient archiving and communication system (PACS; GE Medical Systems). Three fellowship trained musculoskeletal radiologists (with 20, 7, and 3 years' subspecialty experience) independently and blindly performed a series of measurements in each patient on two separate occasions separated by 2 weeks. These observers were instructed to use the 3-dimensional axial oblique sequence for all measurements, though all sequences in the protocol were available for review and for cross-referencing purposes.

Measurements obtained by each observer on each occasion included:

1. The α angle, using the technique described by Nötzli. To ensure consistency in the technique applied by the observers a review and discussion of the approach of Nötzli et al. was undertaken by the observers prior to embarking on the study
2. The AFD, the perpendicular distance between a line drawn along the cortex of the anterior aspect of the greater trochanter/anterior femoral neck and the point of maximal femoral head–neck overgrowth (point "x," Fig. 1b). This distance was derived from the same axial oblique image selected for α angle measurement (i.e., along the center of the femoral neck when cross-referenced to coronal images through the hip, ensuring that the fovea capitis was visible)
3. The femoral neck diameter, measured perpendicular to the previously drawn line along the cortex of the anterior femoral neck and extending from the anterior to the posterior femoral cortex at the same location as the AFD measurement (i.e., from point "x" to point "y" in Fig. 1c). This allowed subsequent calculation of the FNR, the ratio of the AFD to the femoral neck diameter

Statistical analysis

An α angle of 55° or greater at MR arthrography was considered indicative of the presence of cam-FAI. The sensitivity, specificity, and positive and negative predictive values of α angle measurement and a positive clinical impingement test were calculated using performance of intra-operative femoral head–neck junction bony osteochondroplasty/debridement as the gold standard. Intra-observer variation between the first and second α angle measurements for each subject was

Table 1 Mean (± standard deviation [SD]), minimum and maximum α angle measurements recorded by each observer on two separate occasions for Groups A and B

		α Angle ± SD (°)		Minimum α angle (°)		Maximum α angle (°)	
	Group	A	B	A	B	A	B
Observer 1	Measure 1	47.4±6.7	48.8±7.1	36.3	36.0	67.8	72.2
	Measure 2	48.6±7.0	48.9 ±7.8	34.6	36.7	63.4	72.5
Observer 2	Measure 1	48.4±9.0	46.3±10.3	32.1	30.4	70.8	80.5
	Measure 2	48.4±9.7	44.3±9.0	31.2	30.0	66.9	76.4
Observer 3	Measure 1	50.6±9.8	50.7±10.0	31.9	25.8	77.4	75.3
	Measure 2	47.6±8.4	48.9±9.5	31.2	32.1	68.3	79.5

determined by calculating the percentage of the difference between the two measurements divided by their average. Binary logistic regression analysis was used to determine the value of each measure (α angle, AFD, FNR) in predicting the presence of cam-type FAI. Receiver-operator curve (ROC) analysis facilitated determination of the measure of performance for our proposed measures (AFD and FNR). The unpaired Student's *t* test was used to evaluate for differences between calculated means, with a *p* value of <0.05 considered indicative of statistical significance.

Results

All MR arthrogram studies were successfully performed without incident related to intra-articular contrast medium injection or MR image acquisition.

Alpha angle measurement

Table 1 outlines the mean (± standard deviation), minimum and maximum α angle measurements recorded by each observer on two separate occasions for Groups A and B. Calculated *p* values between each set of mean values (Group A versus Group B) were >0.05 in all cases. The degree of intra-observer variability between the first and second α angle measurements for each subject is shown in Fig. 2. Differences of up to 30% of the mean value were seen in the case of each observer, with variation of greater than 10% in 37.2% of cases for observer 1, 52.6% of cases for observer 2, and 43.5% of cases for observer 3. This intra-observer variability was responsible for disparate test results (i.e., one "negative" or <55° and one "positive" or >55° result on the two separate occasions) in 15/78 cases for observer 1 (19.2%), 12/78 cases for observer 2 (15.4%), and 17/78 cases for observer 3 (21.8%).

The overall performance level of α angle measurement was poor, with sensitivities of 35.8%, 43.5%, and 38.5% for Observers 1, 2, and 3 respectively (mean 39.3%), specificities of 69.2%, 79.5%, and 61.5% respectively (mean 70.1%), positive predictive values of 46.1%, 68%, and 50% respectively (mean 54.7%), and negative predictive values of 51.9%, 58.5%, and 50% respectively (mean 53.5%). Binary logistic regression analysis confirmed that the α angle is of no value in predicting the presence or absence of cam-FAI.

Anterior femoral distance

Mean (± standard deviation), minimum and maximum AFD measurements recorded by each observer on two separate occasions for Groups A and B are provided in Table 2. Student's *t* test analysis confirmed the presence of a significant difference between the mean values obtained for Group A and those for Group B ($p=0.004$). Binary logistic regression analysis indicated that the performance of this test is maximized when an AFD value of 3.60 mm or greater is considered to be "abnormally increased" ($p=0.015$). The corresponding ROC curve is shown in Fig. 3, yielding a 0.67 performance measure (95% confidence interval 0.55–0.79). The overall performance level of AFD measurement was on the whole superior to that of the α angle, with sensitivites of 58.9%, 53.8%, and 52.6% for Observers 1, 2, and 3 respectively (mean 55.1%), specificities of 68.4%, 66.7%, and 56.4% respectively

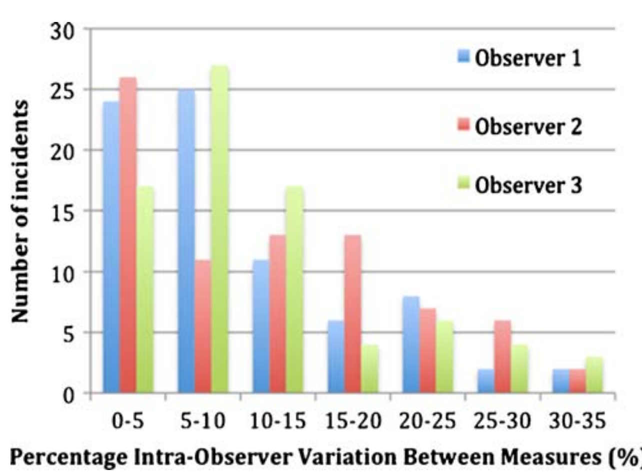

Fig. 2 Degree of intra-observer α angle variation for each observer

Table 2 Mean (± standard deviation), minimum and maximum anterior femoral distance (AFD) measurements recorded by each observer on two separate occasions for Groups A and B

		AFD ± SD (mm)		Minimum AFD (mm)		Maximum AFD (mm)	
	Group	A	B	A	B	A	B
Observer 1	Measure 1	3.46±1.2	2.95±1.5	1.1	1.0	6.4	8.3
	Measure 2	3.62±1.1	2.77 ±1.4	2.0	1.2	6.3	6.7
Observer 2	Measure 1	3.89±1.3	3.20±1.2	1.8	1.0	7.1	7.4
	Measure 2	4.09±1.2	3.31±1.2	2.5	1.5	7.9	7.2
Observer 3	Measure 1	3.96±1.1	3.64±1.5	1.9	1.9	6.6	7.8
	Measure 2	3.82±1.1	3.63±1.5	2.1	2.0	6.3	6.9

(mean 63.8%), positive predictive values of 65.1%, 61.7%, and 54.6% respectively (mean 60.5%), and negative predictive values of 62.5%, 59.1%, and 54.3% respectively (mean 58.6%).

Femoral neck ratio

Mean FNR measurements for Observers 1, 2, and 3 were 0.11, 0.12, and 0.12 respectively for Group A and 0.09, 0.11, and 0.12 respectively for Group B (p=0.2). Binary logistic regression analysis confirmed that the FNR measurement is of no value in prediction of the presence or absence of cam-FAI.

Clinical impingement

Review of patients' electronic notes allowed determination of the status of the clinical impingement test prior to surgical intervention. The sensitivity, specificity, and positive and negative predictive values of this test were 76.9%, 87.2%, 85.7%, and 79.1% respectively in suggesting the presence or absence of this condition.

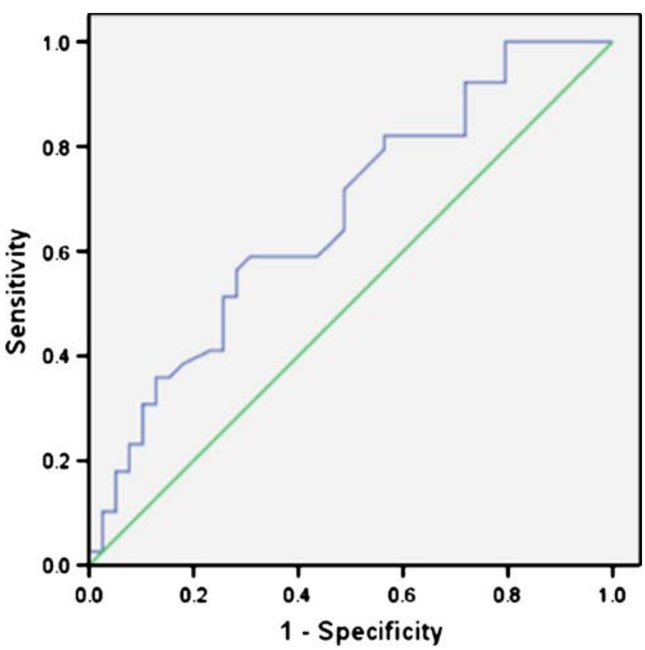

Fig. 3 Receiver-operator curve for performance of the AFD (with a cut-off value of 3.60 mm) in suggesting the presence or absence of cam-FAI

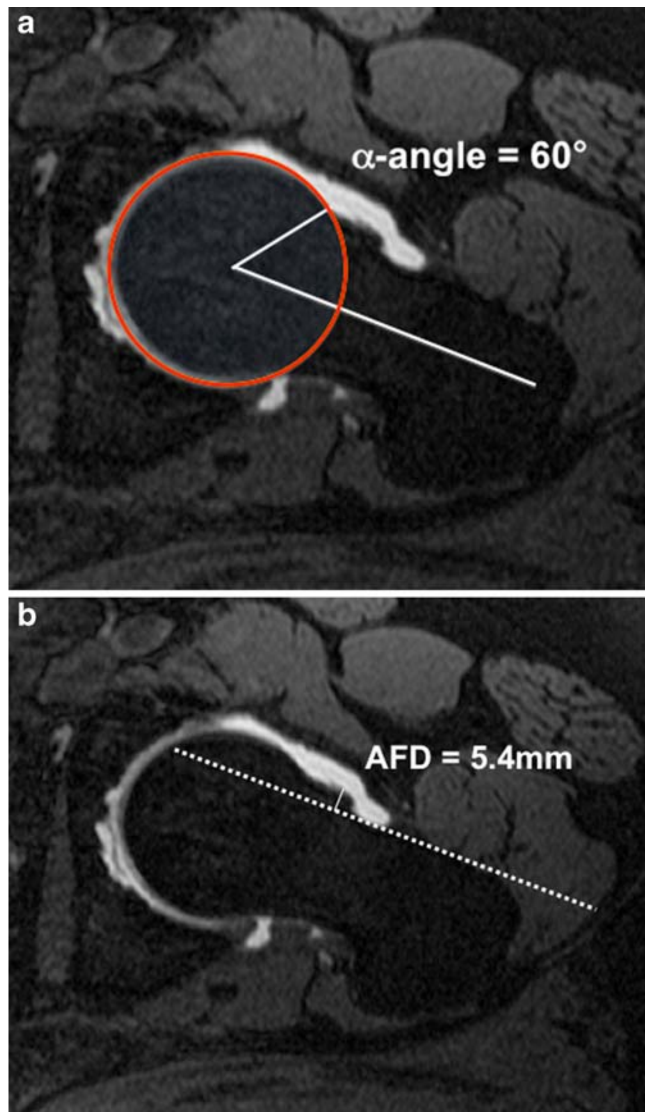

Fig. 4 A 36-year-old male patient with a positive clinical impingement test and surgically confirmed cam-type FAI. Both the α angle (**a**) and AFD (**b**) are abnormally increased

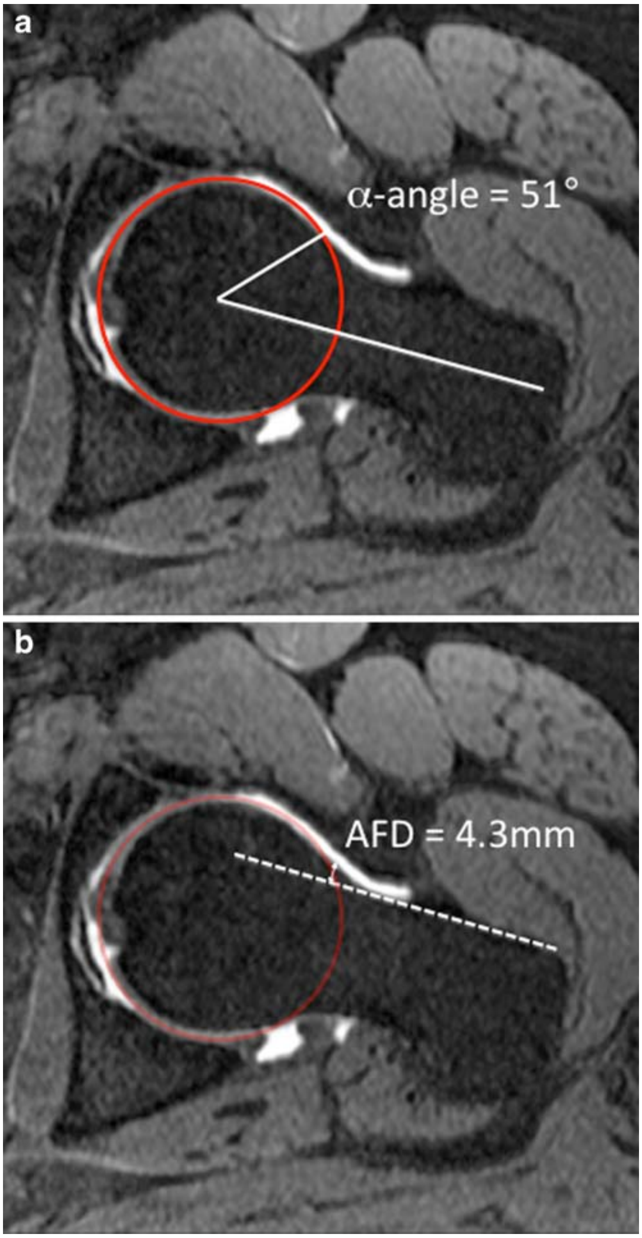

Fig. 5 A 28-year-old male patient with positive clinical impingement test and surgically confirmed cam-type FAI. The α angle is within normal limits (false negative result, **a**), while the AFD is abnormally increased (true positive result, **b**)

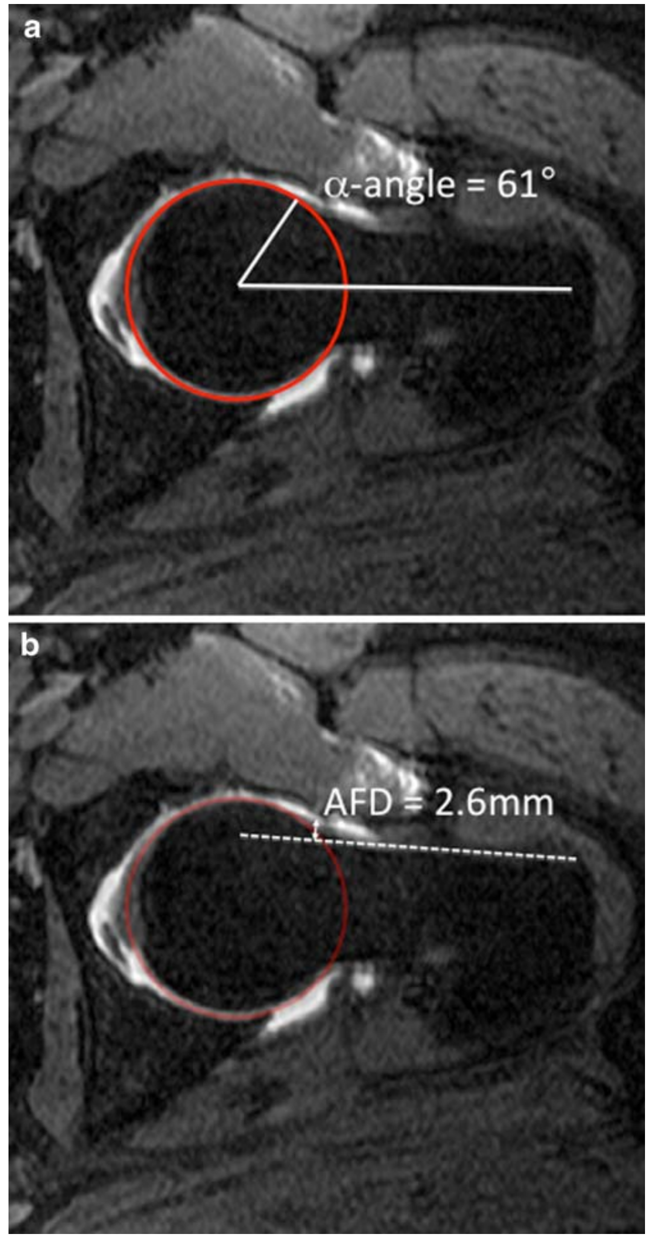

Fig. 6 A 32-year-old female with surgically excluded cam-type FAI. The α angle is increased (false positive result, **a**), while the AFD is below the threshold level of 3.6 mm (true negative result, **b**). The clinical impingement test was negative

Discussion

The described results confirm our initial hypothesis that femoral α angle measurement is associated with considerable variability, with variation of up to 30% of the mean seen in the case of all three observers. This index performs poorly with regard to sensitivity, specificity, and positive and negative predictive values, and was found to be statistically of no value in suggesting the presence or absence of cam-FAI. Similarly, one of our newly suggested indices, the FNR, bears no relationship to femoral head–neck overgrowth and should not be used in this capacity.

Of potential value is the AFD, providing superior performance values for each observer compared with α angle measurement. Our findings suggest that the performance of this measurement is optimized when a value of 3.6 mm of greater is considered as abnormally increased (Figs. 4–6). Again, however, the sensitivity, specificity, and predictive values of the AFD preclude recommendation of use of this parameter as the sole indicator of the presence or absence of cam-FAI at MR arthrography. Interestingly, the parameter that proved of most value in pre-investigational suggestion of the presence or absence of cam-FAI is the clinical impingement test, an examination that is routinely and rapidly performed in the majority of cases prior to referral for hip imaging.

The findings of the current study contradict those of previously published papers, including the seminal study of Nötzli et al. [6] and that of Kassarjian et al. [7]. These authors evaluated MR arthrogram studies from patients with positive clinical impingement tests, and in the case of the former compared α angle measurements with those of asymptomatic controls. Nötzli reported an average α angle of 74° in a patient group that comprised 39 subjects (compared with 42° in the control group), all of the α angle measurements in the patient group being in excess of 55°. Kassarjian found an abnormally increased α angle in 39 of the 42 hips (93%), with a mean α angle measurement of 69.7°. It may be that this marked contrast in findings may be explained at least in part by selection bias, given that Nötzli and Kassarjian selected patients for inclusion on the basis of a positive clinical impingement test and thus a high pre-test probability of more advanced femoral head–neck overgrowth. In contrast, we included all patients in whom MR arthrography was performed, regardless of clinical symptomatology. Interestingly, had we selected only patients in whom clinical impingement was evident prior to the MR arthrogram study (35 of the 78 hips), the mean α angle would have been 49.9°, with an α angle greater than 55° in only 10 of these 35 hips (29%). This suggests that the level of disparity between the current results and those of Nötzli and Kassarjian cannot be simply explained on the basis of selection bias alone. In a more recent study performed by Nouh et al. the authors found significant intra-reader variation in alpha angle measurement, while also determining that subjective estimation of the alpha angle was a poor surrogate for direct measurement [8].

One of the theoretical limitations of α angle measurement is that it is derived from an oblique axial image along the plane of the femoral neck and at the level of the central head and neck. Thus, only epiphyseal overgrowth along the anterior femoral head–neck junction is considered in the figure derived. Not infrequently, however, the greatest depth of epiphyseal overgrowth in cam-FAI is situated along the anterosuperior aspect of the femoral neck. As a result, some have advocated radial reconstruction of volumetric data acquisition using the center of the femoral neck as a fulcrum [9, 10]. While this approach provides a series of images from which the largest α angle measurement may be derived, it places increased demands upon the performing technologist and results in a greater number of study images requiring evaluation, thus prolonging study interpretation, all in the absence of supporting evidence to suggest that this technique results in improved diagnosis of cam-FAI.

We acknowledge the presence of study limitations, including the retrospective study design. Patient selection according to performance of MR arthrography introduces selection bias and may exclude advanced cases of cam-FAI that may have been diagnosed and undergone treatment on the basis of clinical examination and plain radiography alone. Using arthroscopic/open surgical femoral bony osteochondroplasty as the gold standard technique for determination of the presence or absence of cam-FAI is also subject to the performing surgeon's opinion, introducing a degree of unmeasurable uncertainty. Nonetheless, it must be assumed that femoral head–neck osteochondroplasty would only have been performed in patients in whom excessive tissue was directly visualized intra-operatively. It is noteworthy that a degree of standardization was introduced by the fact that each arthroscopic examination was performed by a single surgeon only, as was the case with each open surgical procedure. Furthermore, the fact that the results of both the clinical impingement test and MR arthrogram studies were known at the time of surgical intervention introduces bias inherent to the retrospective design of the study. It is possible that awareness of the results of these tests might have influenced the decision to intervene. Thus, the true predictive power of a positive clinical impingement test has been overestimated as a result herein.

In conclusion, we have shown that measurement of the α angle using the technique described by Nötzli is of no value in suggesting the presence of cam-FAI during MR arthrography, at least in our patient population. We suggest alternative arthrographic measures, one of which (the anterior femoral distance) outperforms the α angle measurement, though to an insufficient degree to suggest that it become part of the imaging standard. In our experience, a positive clinical impingement test remains potentially the most accurate means of predicting the presence of cam-FAI as diagnosed intra-operatively.

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