The alpha angle in cam-type femoroacetabular impingement

NEW REFERENCE INTERVALS BASED ON 2038 HEALTHY YOUNG ADULTS

L. B. Laborie,
T. G. Lehmann,
I. Ø. Engesæter,
F. Sera,
L. B. Engesæter,
K. Rosendahl

From Haukeland University Hospital and the University of Bergen, Bergen, Norway

■ L. B. Laborie, MD, PhD, Radiologist
Haukeland University Hospital, Department of Radiology, Jonas Lies vei 65, 5021, Bergen, Norway.

■ T. G. Lehmann, MD, PhD, Orthopaedic Surgeon
Haukeland University Hospital, Department of Orthopaedic Surgery, Jonas Lies vei 65, 5021, Bergen, Norway.

■ I. Ø. Engesæter, MD, PhD, Otorhinolaryngologist
Haukeland University Hospital, Department of Otorhinolaryngology, Jonas Lies vei 65, 5021, Bergen, Norway.

■ F. Sera, MSc, Statistician
UCL Institute of Child Health, Centre for Paediatric Epidemiology and Biostatistics, 30 Guilford Street, London WC1N 1EH, UK.

■ L. B. Engesæter, MD, PhD, Orthopaedic Surgeon, Professor
Haukeland University Hospital, Department of Orthopaedic Surgery, Jonas Lies vei 65, 5021, Bergen, Norway.

■ K. Rosendahl, MD, PhD, Radiologist, Professor
Haukeland University Hospital, Department of Radiology, Jonas Lies vei 65, 5021, Bergen, Norway.

Correspondence should be sent to Dr Med L. B. Laborie; e-mail: lene.bjerke.laborie@helse-bergen.no

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We report on gender-specific reference intervals of the alpha angle and its association with other qualitative cam-type findings in femoroacetabular impingement at the hip, according to a population-based cohort of 2038 19-year-olds, 1186 of which were women (58%). The alpha angle was measured on standardised frog-leg lateral and anteroposterior (AP) views using digital measurement software, and qualitative cam-type findings were assessed subjectively on both views by independent observers. In all, 2005 participants (837 men, 1168 women, mean age 18.6 years (17.2 to 20.1) were included in the analysis. For the frog-leg view, the mean alpha angle (right hip) was 47° (26 to 79) in men and 42° (29 to 76) in women, with 97.5 percentiles of 68° and 56°, respectively. For the AP view, the mean values were 62° (40 to 105) and 52° (36 to 103) for men and women, respectively, with 97.5 percentiles of 93° and 94°. Associations between higher alpha angles and all qualitative cam-type findings were seen for both genders on both views. The reference intervals presented for the alpha angle in this cross-sectional study are wide, especially for the AP view, with higher mean values for men than women on both views.

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Cam-type femoroacetabular impingement (FAI) is a recognised cause of hip pain in young adults and is considered to contribute to the development of osteoarthritis (OA).[1] Assessment of affected patients consists of a detailed clinical examination and imaging including plain radiographs, CT and MRI. The radiographs identify the anatomy of the femoral head–neck junction used to describe cam pathology, usually located on the anterosuperior aspect of the femoral neck.[2] Lateral views may include frog-leg, cross-lateral or Dunn views[3], and an anteroposterior (AP) view.[3-6] The alpha angle was first proposed by Nötzli et al[7] using MRI based on a pathological cut-off value of 50° (Fig. 1). Observations associated with cam-type pathology include any pistol grip deformity, focal femoral humps and a flattening of the lateral aspect of the femoral head.[1,2,8] Recent studies have confirmed that several of these radiological findings appear to be more common than first thought,[9-11] and we have previously shown that they are quite common in an unselected population of 2081 young adults, particularly in men.[10] In a subset of the same study, a positive anterior impingement test was reported in 7.3% of the men and 4.8% of the women.[12] Based on already reported cut-off values of ≥ 83° and ≥ 57° for men and women, respectively,[13] high alpha angles on the anteroposterior view were not in themselves associated with positive impingement tests.

Increased knowledge of the distribution of the alpha angle based on standardised pelvic radiographs in a large healthy population might help to clarify the diagnostic criteria for cam-type FAI. We measured gender-specific reference intervals for the alpha angle on the frog-leg and AP views in a population-based cohort of 2038 young adults, using a digital measurement methodology. We compared the alpha angle measurement with the qualitative assessment of cam-deformity on both radiological views.

Patients and Methods

From February 2007 to March 2009 we carried out a population-based cross-sectional study as a follow-up of the 1989 Bergen Birth Cohort (n = 4703). This comprises all babies born at the maternity unit of Haukeland University hospital in Bergen, Norway, during 1989, as part of a large randomised controlled trial designed to evaluate the effect of different screening strategies for developmental dysplasia of the hip (DDH) (Fig. 2).[14] A total of 3935 subjects from the 1989 cohort were invited to the follow-up study. A total of 2038 (51.8%), of whom 1186 (58.2%) were

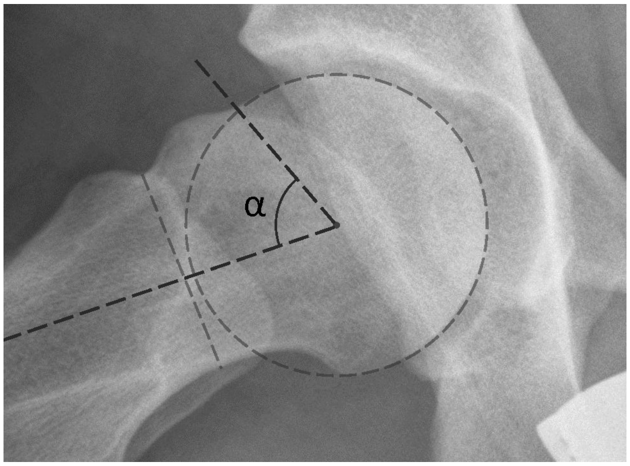

Fig. 1a

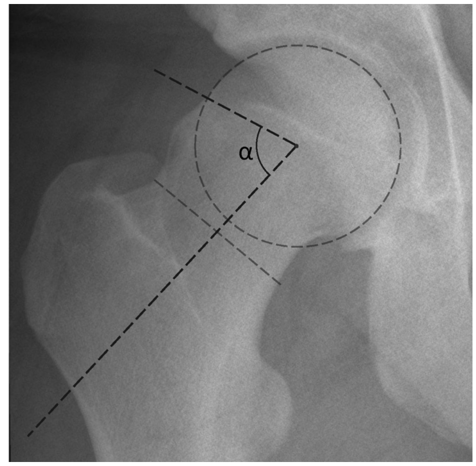

Fig. 1b

Radiographs demonstrating the alpha angle. a) The cam-deformity is assessed by the alpha angle (α) on the anterosuperior part of the head-neck junction on a frog-leg lateral view at 19 years of age. The longitudinal axis of the femoral neck is defined through its narrowest point and through the head centre. The alpha-point is placed where the radius of the curvature of the femoral head first exits the circle of best fit corresponding to a circular head. b) The cam-deformity is assessed by the alpha angle (α) on the superior part of the head–neck junction on an anteroposterior (AP) view at 19 years of age. As for the frog-leg view, a straight line is drawn from the alpha-point to the head centre, and this line, together with the longitudinal axis of the neck defines the alpha angle.

women and predominantly of Norwegian ethnicity, attended. Of the participants, 21 men and 81 women were treated for DDH as babies. There was no other hip pathology in this cohort.

Exclusion criteria after attendance were missing radiographs (owing to uncertain pregnancy status or radiographs not taken) or radiographs of suboptimal quality (excessive pelvic rotation as assessed by an obturator foramen index beyond a range of 0.6 to 1.8)[15] (Fig. 2). The overall study has previously been described in detail.[12] All participants gave written informed consent according to the Declaration of Helsinki. The study research protocol, including analyses of the non-responders, was approved by the Medical Research Ethics Committee of the Western region of Norway (No. 018.06).

Information regarding gender, age, birth-weight, weight and height at age seven years was collected from the community healthcare centres in Bergen and suburbs for those born in 1989 and whose information was available, including the non-responders. Analysis of these baseline characteristics showed similar values for birth-weight and for weight and height at age seven years for those who attended *versus* those who did not.[16] Only the gender distribution differed significantly ($p < 0.01$, chi squared test) between the two groups, as more girls than boys attended the follow-up study.

All radiographs were performed by a single trained radiographer, in the paediatric unit of the radiology department. A low-dose digital radiography technique (Direct Digital Radiography, Digital Diagnost System, version 1.5, Philips Medical Systems, Best, Netherlands) was used. Supine frog-leg and weight-bearing AP views were obtained according to a standardised protocol. The film-focus distance was 1.2 m and was centred 2 cm proximal to the symphysis for the AP view and at the symphysis for the frog-leg view. To standardise the frog-leg view, wedge-shaped pillows were placed underneath each thigh to secure approximately 45° of hip abduction. For the weight-bearing AP view, hips were kept in a neutral abduction–adduction position, with toes pointing forward. The radiographer took particular care with the posture during exposure in order to avoid excessive tilt or rotation. Gonadal shields were offered to men. The total mean radiation dose for the two radiographs together was 0.5 Gy/cm^2, with a corresponding effective dose of 0.15mSv (millisieverts).

The radiographs were stored in the Picture Archiving and Communications System (PACS) of the hospital, and also retrieved as Digital Imaging and Communications in Medicine (DICOM) files. A validated digital measurement program used for measurements related to hip dysplasia at skeletal maturity, 'Adult DDH' (University of Iowa Hospitals and Clinics, Iowa City, Iowa)[17] was extended to include the alpha angle on both the AP[12] and the frog-leg views. All alpha angles on both views were measured by the same observer (LBL). In the digital program, each hip is magnified to improve the manual placement of a cursor on four points corresponding to the circle of the femoral head, the lateral most point corresponding approximately to the point facing the lateral acetabular edge. None of the points are placed directly in the cam region. The four points allow the software to determine and draw a circle of best fit. The mid-axis of the femoral neck was found by placing one point on each side of the neck at its narrowest part and the software drew the mid-axis passing through the centre of the circle. The alpha point was placed where the anatomical bony curvature crosses outside the circle. The software

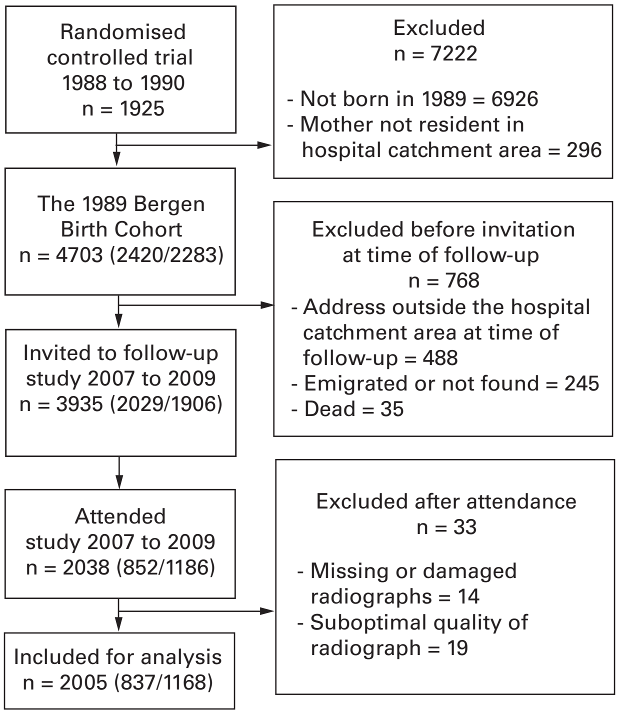

Fig. 2

Flow chart of participants (men/women) in the study.

calculated the angle between the mid-axis of the femoral neck and the alpha point, and transferred the result to an Excel spreadsheet (Microsoft, Redmond, Washington).

All radiographs were also assessed subjectively by an experienced paediatric musculoskeletal radiologist (KR) blinded to all other findings. Findings thought to be associated with cam-type FAI were noted on both views. A detailed description of these findings, together with their prevalences in this study population and inter- and intra-observer agreements, were reported previously.[10]

Reproducibility of measurements. A balanced set of 100 radiographs for both the frog-leg and the AP view including normal and pathological anatomy, were used to assess intra- and inter-observer and inter-method reproducibility. In all, ten frog-leg and ten AP radiographs were assessed for standardisation prior to and not included in the reproducibility analyses. One observer (LBL) measured all radiographs (both views) in the digital measurement software and manually in the IMPAX version 6.4 (Agfa HealthCare System, Mortsel, Belgium), using Mose's[18] templates to determine the circle of best fit around the femoral head and its centre. As in the digital measurement program, the mid-axis of the neck and the alpha point were identified. All digital and manual measurements were re-measured by the same observer after an interval of two months. In addition, another observer (KR) measured all the 100 radiographs (both views) once using the digital measurement software in order to perform the inter-observer study.

The 95% limits of agreement (LoA) method was used to examine the mean difference between two sets of readings performed by same observer (intra-observer), between a set of readings performed by two observers (inter-observer), and between a set of readings in the digital software and a set of manual readings (inter-method).[19,20] For the inter-method reproducibility we first calculated the mean for each method and on each subject and used these pairs of means to compare the two methods, as described in a previous paper presenting the 'Adult DDH' digital program.[17] The 95% LoA were estimated as mean difference between the two measurements (SD 1.96). The intra-and inter-observer reliabilities were also expressed by the intra-class correlation coefficient (ICC) using a one-way random effect analysis of variance (ANOVA) table (formula ICC [1]).[21] The inter-method reliability was expressed by ICC calculated using a two-way random effects ANOVA table (formula ICC [A,1]).[21]

Statistical analysis. Mean values, SDs, medians, ranges and empirical 97.5 percentiles with their corresponding 95% confidence intervals (CI) were calculated for both gender and sidedness separately for the alpha angle on the frog-leg and the AP views, respectively.[22] The binominal method was used to obtain the 95% CIs.[23] Repeated measures ANOVA was used to account for potential non-independence of radiological findings on right and left hips. In order to evaluate the effects of gender and side on the alpha angle values, subjects were considered as random-term, side as within-subject and gender as between-subject factors.

For the purpose of this study, a common qualitative dichotomised (yes/no) cam-type variable was created for each view, encompassing the qualitative cam-type findings reported previously.[10] In order to examine the association of high alpha angles with the subjective evaluation of the cam-type deformity for each of the two views, random effects models were fitted with alpha angle as outcome, the common qualitative cam-type variable as exposure, and side and gender as covariates. The random effects models take into account a possible non-independence of the alpha measurements, including a subject effect considered as a random variable.

All reported p-values are two-tailed. A p-value < 0.05 was considered statistically significant. No corrections for multiple comparisons were performed. Statistical testing was performed using the IBM SPSS version 20.0 statistical package (IBM, Armonk, New York), and in Stata Statistical Software, release 11 (StataCorp LP, College Station, Texas).

Results

A total of 2005 participants (837 men, 1168 women, mean age 18.6 years (17.2 to 20.1) had their two radiographs analysed (Fig. 2). The gender-specific reference intervals for the alpha angle, for both the frog-leg view and the AP view, are presented in Table I. All p-values for differences between gender and side were < 0.001 for both views. Higher mean values with wider 95% reference intervals

Table I. Gender-specific reference values (°) for the alpha angle measured on the frog-leg and anteroposterior views in 837 men and 1168 women aged 18 to 20 years, for right (R) and left (L) hips. Data are presented as mean, standard deviation (SD), median and range, with corresponding reference intervals based on 2.5 and 97.5 percentiles with 95% confidence intervals (CI) for each of the percentiles

	Side	Number*	Mean (°)	SD (°)	Median (°)	Range (°)	2.5 percentile (95% CI)	97.5 percentile (95% CI)
Frog-leg view								
Men	R	831	46.9	8.4	45.1	26.2 to 78.9	35.1 (33.7 to 36.0)	68.4 (66.1 to 70.9)
	L	829	45.9	7.7	44.4	30.5 to 80.4	35.1 (34.5 to 35.7)	66.9 (64.5 to 69.2)
Women	R	1168	42.3	5.7	41.5	29.3 to 75.6	33.8 (33.4 to 34.2)	56.4 (54.7 to 58.7)
	L	1168	41.6	5.4	41.0	21.0 to 66.8	33.3 (32.8 to 33.7)	54.4 (53.1 to 56.5)
Anteroposterior view								
Men	R	834	61.6	14.2	58.6	39.7 to 105.2	43.2 (42.3 to 43.7)	92.7 (90.8 to 93.5)
	L	834	60.6	12.4	57.6	38.6 to 95.8	43.7 (43.0 to 44.4)	89.1 (85.7 to 91.5)
Women	R	1168	51.9	14.1	46.8	36.4 to 103.4	39.3 (38.9 to 39.6)	93.7 (92.0 to 95.6)
	L	1168	50.7	11.4	47.1	37.0 to 102.3	39.4 (39.7 to 40.4)	87.6 (84.2 to 90.9)

*In subjects where radiation shields covered important anatomical landmarks on one side, only the contralateral side was included for analysis

Table II. Reproducibility studies for alpha angle (°) measurements on the frog-leg and anteroposterior views. Results are presented for the left hip

	First mean	Second mean	Mean difference (SD)	95% Limits of agreement	ICC
Frog-leg view					
Intra-observer (A) Digital 1- Digital 2	46.58	46.51	0.07 (2.68)	(-5.30; 5.44)	0.95 (0.93; 0.97)
Inter-method (A) Digital 1 - Manual 1	46.54	47.33	-0.77 (2.35)	(-6.70; 5.15)	0.94 (0.92; 0.96)
Intra-observer (A) Manual 1- Manual 2	47.16	47.50	-0.33 (1.90)	(-4.13; 3.46)	0.97 (0.96; 0.98)
Inter-observer (A+B) Digital A 2 - Digital B 1	46.51	44.81	1.70 (2.73)	(-3.76; 7.16)	0.92 (0.89; 0.95)
Anteroposterior view					
Intra-observer (A) Digital 1- Digital 2	58.03	57.60	0.43 (3.22)	(-6.01; 6.86)	0.96 (0.95; 0.98)
Inter-method (A) Digital - Manual	57.81	57.73	0.08 (3.18)	(-8.53; 7.76)	0.95 (0.93; 0.96)
Intra-observer (A) Manual 1- Manual 2	57.52	57.94	-0.42 (3.29)	(-6.99; 6.16)	0.96 (0.94; 0.98)
Inter-observer (A+B) Digital A 2 - Digital B 1	57.60	55.52	2.08 (5.13)	(-8.16; 12.34)	0.89 (0.85; 0.93)

Observer A (LBL); Observer B (KR); 1, first reading, 2, repeated reading, SD, standard deviation, ICC, Interclass correlation coeficient.

Table III. Associations between the alpha angle (°) and the qualitative radiographic cam type on both the frog-leg and the anteroposterior (AP) views, respectively. Results of random effects models, adjusted by gender and side, are shown for 2005 participants. The coefficient resulting from each model, adjusted by gender and side, indicates how many degrees higher the mean alpha angle is for the group with a positive subjective cam-type finding, compared with the group without

	Alpha angle (°) on frog-leg view			Alpha angle (°) on AP view		
Subjective assessment	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Cam-type	9.2	8.3 to 10.1	< 0.001	10.8	9.6 to 10.1	< 0.001

were seen for the AP view than the frog-leg view for both genders. None of the results were altered significantly when similar analyses were performed, excluding the 102 subjects who had received treatment for DDH as newborns.

The intra- and inter-observer reproducibilities for the alpha angle on the frog-leg and the AP views, together with the inter-method reproducibility for digital *versus* manual measurement techniques of the alpha angle on both views, are reported, expressed as 95% LoA and ICC (Table II). The LoAs were wider for all measurements on the AP view.

Associations between the alpha angle and qualitative radiographic findings. The random effects models, adjusted by gender and side, demonstrated significantly higher mean alpha values for those with qualitative cam-type findings than for those without, for both the frog-leg (9.2°, 95% CI 8.3 to 10.1) and the AP view (10.8°, 95% CI 9.6 to 10.1) (Table III).

Discussion

This population-based cross-sectional study presents gender-specific reference ranges for the angle in cam-type deformity. The mean alpha angle for the right hip on the frog-leg view was 47° in men and 42° in women, with 97.5 percentiles of 68° and 56°, respectively. For the AP view, mean values were 62° for men and 52° for women, with 97.5 percentiles of respectively 93° and 94° and wider intervals than the frog-leg values. Associations between higher alpha angles and the presence of qualitative cam-type findings were seen on both views.

We acknowledge several limitations to this study. The attendance rate of 52% for this cross-sectional analysis is moderate. Also, subjects with previous or ongoing hip problems might have been more encouraged to attend the study. However, comparisons of baseline growth characteristics at birth and at age seven years did not reveal any

Table IV. Mean, standard deviation (SD) and/or range for the alpha angle on different radiographic views, as reported in the literature. The three first studies report on normal hips without any sign of cam-type impingement, while the latter two include large population-based cohorts. In particular, the present study reports on results from a young population, among which there might be apparently normal hips that will develop cam-type pathology detected later (AP, anteroposterior; NA, not available)

Author, year	Population	View	Mean (SD)	Range	p-value for gender difference
Pollard et al[24] 2010	83 healthy adults with normal hip (43 males, 44 females, mean age 46 years [22 to 69])	Cross-table lateral, 15° internal rotation	Males:48° (SD 8°) Females: 47° (SD 8°)		NA
Toogood et al[32] 2009	375 normal femora of adult skeletons (188 males, 187 females, mean age 44 years [18 to 89])	Pelvic AP and a lateral view	AP (named gamma): 53.46° (SD 12.68°), Lateral (named alpha): 45.61° (SD 10.46°) Males lateral: 47.50° (SD 10.71°) Females lateral: 43.71° (SD 9.88°)	AP: 31.21° to 111.50° Lateral:16.87° to 78.57°	< 0.01 (lateral view)
Clohisy et al[4] 2007	24 normal subjects (24 hips, mean age 35 years [18 to 49]), 46% females	Frog-leg lateral, cross-table lateral, and AP	Frog-leg:43.7° (SD 12.1°), Cross-table lateral: 47.2° (SD 15.4°)AP: 51.2° (SD 15.7°),		NA
Gosvig et al[13] 2007	2803 healthy adults (1055 males, mean age 62 years [23 to 93], 1748 females, mean age 65 years [22 to 92])	Pelvic weight-bearing AP radiographs (left hips)	Males AP: 53.1° (SD 13.9°) Females AP: 45.5° (SD 5.1°)	Males AP: 30.0 to 94.0 Females AP: 32.0 to 108.0	< 0.0001
Current study	2005 healthy young adults (837 males, 1168 females, mean age 18.6 years [17.2 to 20.1])	Pelvic frog-leg lateral and weight-bearing AP (right hips)	Males frog-leg: 46.9° (SD 8.4°) Females frog-leg: 42.3° (SD 5.7°) Males AP: 61.6° (SD 14.2°) Females AP: 51.9° (SD 14.1°)	Males frog-leg: 26.2° to 78.9° Females frog-leg: 29.3 to 75.6 Males AP: 39.7 to 105.2 Females AP: 36.4 to 103.4	< 0.001 (frog-leg) < 0.001 (AP)

differences between the attenders and the non-attenders, except for the gender distribution.[16] The ethical aspects of a radiographic study in a population of healthy young adults need to be considered. The effective dose without gonadal shields was as low as 0.15 mSv for both radiographs together[16] and the use of gonadal shields in men reduces this number further. Finally, the results of this study might be age dependent, and are therefore valid for young adults only.

The strengths of this study include the large numbers and the homogenous age group, a standardised radiographic protocol and only one radiographer. All alpha angle measurements were performed by the same observer. The intra- and inter-reproducibility statistics for observers and for measurement technique when measuring the alpha angle compared well with those of other studies.[3,13,24] The use of a digital measurement program with automatic storage of results was time-saving with respect to both measuring and recording and avoided potential recording errors.

Consensus on the best way to define cam-type FAI is lacking. The anatomy of the femoral head–neck junction ranges from normal variants through borderline cases to pronounced pathology. An aspherical head–neck junction does not necessarily indicate a positive diagnosis of FAI, and a large proportion of subjects with radiographic cam-type FAI seem to be asymptomatic.[12] The alpha angle is often used as a quantitative measurement of cam deformity, although its accuracy and diagnostic value have been questioned.[25-27] Subjective assessment of alpha angles has been judged as suboptimal in one study, except where the observer was confident of a marked bony abnormality.[28]

The alpha angle was first proposed on MRI, with a pathological threshold value of 50° for both genders.[7] This measurement has been transferred to CT[29] and different lateral radiographs.[30] Threshold values for lateral views of all three modalities are commonly defined as 50° or 55°.[7,31] Recent studies of the alpha angle based on healthy populations indicate that these threshold values are set too low (Table IV).[32] Higher threshold values of 62° for both men and women were proposed based on the 97.5 percentile estimated from 83 individuals with normal hips.[24] Also, an increased cut-off value of 60° rather than 55° was recently proposed, in order to reduce false-positive results and still maintain an acceptable sensitivity.[27] Our results support the view that threshold values often used are set too low on lateral views.

The alpha angle is also reported on the AP view,[11,13] although the validity of this is debated. A Danish study suggested gender-specific threshold values of ? 83° and ? 57° for men and women, respectively, on a weight-bearing AP view with toes pointing forward.[13] The reference intervals for the AP view in our study are wide and suggest that the existing threshold values are set too low, especially in women.

We found that higher alpha angles were associated with the presence of qualitative cam-type findings on both views. We believe that it is beneficial to assess the cam-type deformity both quantitatively and qualitatively, as there is no consensus regarding the radiographic diagnostic criteria for cam-type FAI. The alpha angle is proposed in several radiographic views[30] and the frog-leg view is commonly preferred over the AP view,[4] although its accuracy in the diagnosis of cam deformity has been questioned.[33] However, both views, obtained in a standardised manner, should be assessed, as they provide images of different parts of the femoral head–neck junction. For example, in order to eliminate the normal anteversion of the femoral neck, the lower limb needs to be rotated internally.[30] Subsequently, the alpha angle will increase slightly in a 15° internally rotated AP view compared to the neutral view used in this study.[24]

The assessment of the alpha angle reflects difficulties in assessing three-dimensional (3D) anatomy from 2D images. In fact, some authors argue that radiographs are not accurate enough to identify cam deformity compared to CT and MRI, owing to the evaluation of the femoral head–neck offset.[34] The establishment of diagnostic criteria for FAI, and even new sets of measurements or methods, are needed.[35,36]

The radiological assessment should always be interpreted in light of the corresponding clinical information, including the presence of hip pain, restricted hip range of movement and a positive anterior impingement test.[12] In daily clinical practice values close to threshold values must also be interpreted in light of the variability of the alpha angle. This cross-sectional study presents wide reference intervals with higher mean alpha values in men than in women on both views. In particular, our results support the view that commonly used threshold values seem to be too low for the lateral view.

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