

Classifying Cam Morphology by the Alpha Angle

A Systematic Review on Threshold Values

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Background: The alpha angle is the most often used measure to classify cam morphology. There is currently no agreement on which alpha angle threshold value to use.

Purpose: To systematically investigate the different alpha angle threshold values used for defining cam morphology in studies aiming to identify this threshold and to determine whether data are consistent enough to suggest an alpha angle threshold to classify cam morphology.

Study Design: Systematic review; Level of evidence, 3.

Methods: The Embase, Medline (Ovid), Web of Science, Cochrane Central, and Google Scholar databases were searched from database inception to February 28, 2019. Studies aiming at identifying an alpha angle threshold to classify cam morphology were eligible for inclusion.

Results: We included 4 case-control studies, 10 cohort studies, and 1 finite-element study from 2437 identified publications. Studies ($n = 3$) using receiver operating characteristic (ROC) curve analysis to distinguish asymptomatic people from patients with femoroacetabular impingement syndrome consistently observed alpha angle thresholds between 57° and 60° . A 60° threshold was also found to best discriminate between hips with and without cam morphology in a large cohort study based on a bimodal distribution of the alpha angle. Studies ($n = 8$) using the upper limit of the 95% reference interval as threshold proposed a wide overall threshold range between 58° and 93° . When stratified by sex, thresholds between 63° and 93° in male patients and between 58° and 94° in female patients were reported.

Conclusion: Based on the available evidence, mostly based on studies using ROC curve analysis, an alpha angle threshold of $\geq 60^\circ$ is currently the most appropriate to classify cam morphology. Further research is required to fully validate this threshold.

Keywords: femoroacetabular impingement syndrome; cam morphology; hip; alpha angle; diagnosis

Femoroacetabular impingement syndrome (FAIS) is a motion-related disorder of the hip caused by a premature contact between the proximal femur and acetabulum.^{17,43} FAIS can be diagnosed by the presence of hip pain, a clinical sign suggestive of FAIS during hip examination, and imaging findings. Imaging findings include the presence of cam morphology, which is an asphericity of the femoral head. This extra bone formation is often located in the anterolateral head-neck junction and in most cases develops during skeletal growth.^{2,4,39,50}

The presence of cam morphology is a common imaging finding. The prevalence in the general population is

roughly 15%-25% in male patients and 5%-15% in female patients.^{16,18,41} The significance of cam morphology in isolation, without the presence of symptoms and clinical signs, is unknown. Although its presence is associated with limited range of motion^{6,22,34} and the future development of osteoarthritis (OA),^{3,35,37,42,47,49} the association with hip pain is conflicting.^{24,48}

Cam morphology can be quantified by various means. Measures that have been described include the head-neck ratio,²⁹ triangular index,¹⁵ beta angle,⁸ and the alpha angle.³⁸ To date, the alpha angle is the measure most often used to quantify cam morphology, and it has been used in various imaging modalities and views. The alpha angle, always measured in a 2-dimensional (2D) plane, quantifies the sphericity of the femoral head-neck junction on a location depending on the radiographic view. For example, on

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an anteroposterior (AP) view, the alpha angle quantifies the lateral head-neck junction, whereas on a frog-leg lateral or Dunn view, the alpha angle quantifies the anterolateral head-neck junction. The advantage of 3-dimensional (3D) imaging is that the alpha angle can be measured at multiple locations around the head-neck junction. Some analyze the alpha angle as a continuous variable,³⁷ whereas others³⁵ use threshold values to binary classify the presence and absence of cam morphology. As the alpha angle per definition is a 2D measurement, it might be applied to all imaging modalities such as radiographs and 3D planes. However, the reported alpha angle threshold values to identify or diagnose cam morphology have been inconsistent. Threshold values used range from 50° to 83°.^{13,15,38,40}

Because of the inconsistencies in alpha angle threshold values prevalence data and associations between cam morphology and hip pain or pathology are difficult to interpret. Nötzli et al³⁸ first described the alpha angle and suggested a 55° threshold, although a 50° threshold has frequently been used by others.^{18,21,23,24,27} By an advanced understanding of cam morphology prevalence and its association with pathology, some authors^{2-4,35,42,50} have suggested a higher alpha angle threshold to classify cam morphology. A recent scoping review³⁰ suggested that a threshold around 60° would be more appropriate to classify cam morphology. In a recent consensus statement on FAIS and on the classification of hip-related pain, the authors acknowledged importance of the use of a consistent alpha angle threshold.¹⁷ Particularly for research purposes, future studies are warranted to study a homogenous population and to classify the presence of cam morphology consistently. However, no exact alpha angle threshold value could be advised because of the lack of a systematic synthesis of this data.¹⁷

Therefore, the aims of this systematic review were to (1) appraise studies investigating alpha angle threshold values for cam morphology and (2) determine whether data are consistent enough to suggest an alpha angle threshold to classify cam morphology.

METHODS

Protocol and Registration

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed during the search and reporting phase.⁴⁶ This review was registered in PROSPERO after a pilot search and before the updated search and extraction of the data. Protocol details

can be accessed via the online PROSPERO database (registration No. CRD42019126021).

Identification and Selection of the Literature

The study protocol, with a PICO (patient-intervention-comparison-outcome) framework and eligibility criteria for the reports, was composed before the search was performed. We included (1) studies aiming at identifying an alpha angle threshold value based on imaging (eg, radiographs, magnetic resonance imaging [MRI], computed tomography [CT], or ultrasound) to distinguish between hips with and without cam morphology. We considered (2) all types of methodology to identify a threshold value, including, for example, reference intervals and confidence intervals based on the alpha angle distribution, receiver operating characteristic (ROC) curve analyses or associations between alpha angle thresholds, and certain outcomes. For studies using ROC curve analyses or association studies, we included the ones that explained threshold values in relation to symptoms, range of motion, intra-articular hip pathology (labral tears/chondropathy), hip OA, and/or total hip replacement (THR). (3) Studies that primarily investigated the association between cam morphology and symptoms, intra-articular hip pathology, hip OA, and/or THR and used predefined threshold values to quantify cam morphology were only included when they studied ≥ 3 alpha angle threshold values. The exclusion criteria were (1) studies including a group of patients with hip diseases such as dysplasia, Perthes, and slipped capital femoral epiphysis; (2) animal studies; (3) studies using 1 or 2 predefined alpha angle thresholds for cam morphology to study the association with hip symptoms, intra-articular hip pathology, hip OA, and/or THR; and (4) systematic reviews, meta-analyses, case series with fewer than 10 participants, and congress abstracts. No restrictions for publication language or publication period were used.

Literature Search Strategy and Information Sources

A sensitive literature search strategy was conducted for several online databases, with the assistance of a medical librarian. The following databases were searched from inception until February 28, 2019 (date last searched): Embase.com, Medline (Ovid), Web of Science Core Collections, Cochrane Library Central Registry of Trials (Wiley), and Google Scholar. The searches combined terms for hip with alpha angle. The complete search strategy for each database can be found in the Appendix.

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Selection of Studies

The titles, abstracts, and full texts of all studies found using our search strategy were scored independently by 2 different raters (P.K., R.A.) to determine whether they met the inclusion criteria, resulting in an equal judgment between the raters. Disagreements were resolved by a consensus meeting. A third reviewer (M.R.) was involved for determination of full-text inclusion regarding 1 article because of failure to achieve consensus between the 2 main reviewers. Reference screening of included articles was also performed. The interrater reliability for final inclusion after full-text screening was 1.00 (100% agreement).

Data Extraction

The data extraction was performed by the 2 reviewers. Data that could answer the primary question were extracted, such as alpha angle thresholds for cam morphology (including alpha angle upper limits, 95% CI, etc) and the imaging modality used. The 2 reviewers extracted the data independently, with disagreements resolved through a consensus meeting.

Risk of Bias (Quality) Assessment

The risk of bias of the included studies was scored by the Cochrane Risk of Bias Tool (2.0)¹⁹ for randomized controlled trials (RCTs), the MINORS (Methodological Index for Non-Randomized Studies) scale⁴⁴ for non-RCTs, and the Newcastle-Ottawa Scale (NOS)⁵¹ for case-control and cohort studies, as described in the PROSPERO protocol. Ultimately, only case-control and cohort studies were included in this systematic review, meaning that only the NOS assessment was performed. This tool focuses on 3 areas: the selection of groups, comparability of groups, and ascertainment of outcome. This tool results in a total score from 0 to 9, with 9 indicating the highest study quality. The 2 reviewers independently performed the risk of bias assessment, and discrepancies between the reviewers were resolved by a consensus meeting. The interrater reliability for the NOS score was 0.93 (95% CI, 0.81-0.98).

Synthesis of the Data

A meta-analysis was not performed because of significant methodological and clinical heterogeneity among included studies. Heterogeneity was primarily found in participant characteristics, imaging technique, exposures and outcomes, study designs, and risk of bias per study.

RESULTS

Selection of Studies

We identified 2437 titles after the initial review, of which 15 studies qualified for inclusion in the quality assessment and analysis (Figure 1).

Characteristics of the Included Studies

In this systematic review, 4 case-control studies,^{7,11,31,45} 10 cohort studies,^{5,9,12-15,25,26,32,40} and 1 finite-element study²⁸ were included. All the findings are summarized in Tables 1 and 2.

Population Characteristics

The sample size of the studies ranged from 1²⁸ to 3226¹² (median, 197), with the number of hips ranging between 1²⁸ and 4004²⁵ (median, 339). The mean age of all study populations ranged from 18.6²⁵ to 55.9⁵ years (median, 38). In 4 studies,^{7,11,26,45} more male than female participants were included; in 8 studies,^{5,12,14,15,25,28,32,40} more women than men were included; in 1 study,⁹ participant sex was not specified; and in 2 studies,^{13,31} the sex distribution was equal. Of the 4 case-control studies, 3^{7,31,45} included patients with FAIS, while 1 study¹¹ defined patients with hip pain as cases without specifying whether they fulfilled the FAIS criteria. All control participants were asymptomatic. In the 10 cohort studies, 5 studies^{9,14,26,32,40} specifically described their population as asymptomatic, 1 study⁵ had both symptomatic and asymptomatic participants, and the remaining 4 studies^{12,13,15,25} did not further specify this. The finite-element study²⁸ also did not specify this.

Risk of Bias Within Studies

After inclusion, the interrater reliability for NOS scores suggested a moderate agreement ($\kappa = 0.69$). According to the results of the NOS tool and the predefined criteria, 9 studies (3 case-control^{11,31,45} and 6 cohort^{5,12,15,25,26,32}) scored 5 points or higher (Table 3).

Results of Individual Studies

Imaging Modality

Various imaging modalities were utilized in the 15 studies, including radiographs,^{5,9,11,13,15,25,40} CT,^{7,26,28,32} and MRI.^{12,14,31,45} Radiographic views included the AP,^{5,13,15,25} cross-table lateral,^{9,40} and frog-leg lateral.^{11,13,25} CTs were performed in several planes, such as an oblique axial plane,^{7,26} of which 1 was reconstructed,⁷ double-oblique plane,²⁶ coronal plane,²⁸ and alpha angle measured at 9 different positions around the femoral head-neck junction.³² The MRIs were performed in an oblique axial plane and radial view (1 study¹⁴), a coronal plane (1 study¹²), and a transverse-oblique plane parallel to the femoral neck axis (1 study⁴⁵); 1 study³¹ did not specify the plane.

Symptoms, Intra-articular Pathology, OA, and THR

Six studies^{5,7,11,28,31,45} reported symptoms, intra-articular pathology, hip OA, and/or THR. One study⁵ showed that an alpha angle of 78° gave the maximum area under the ROC curve, which was 0.69 (95% CI, 0.62-0.75), for end-stage OA.

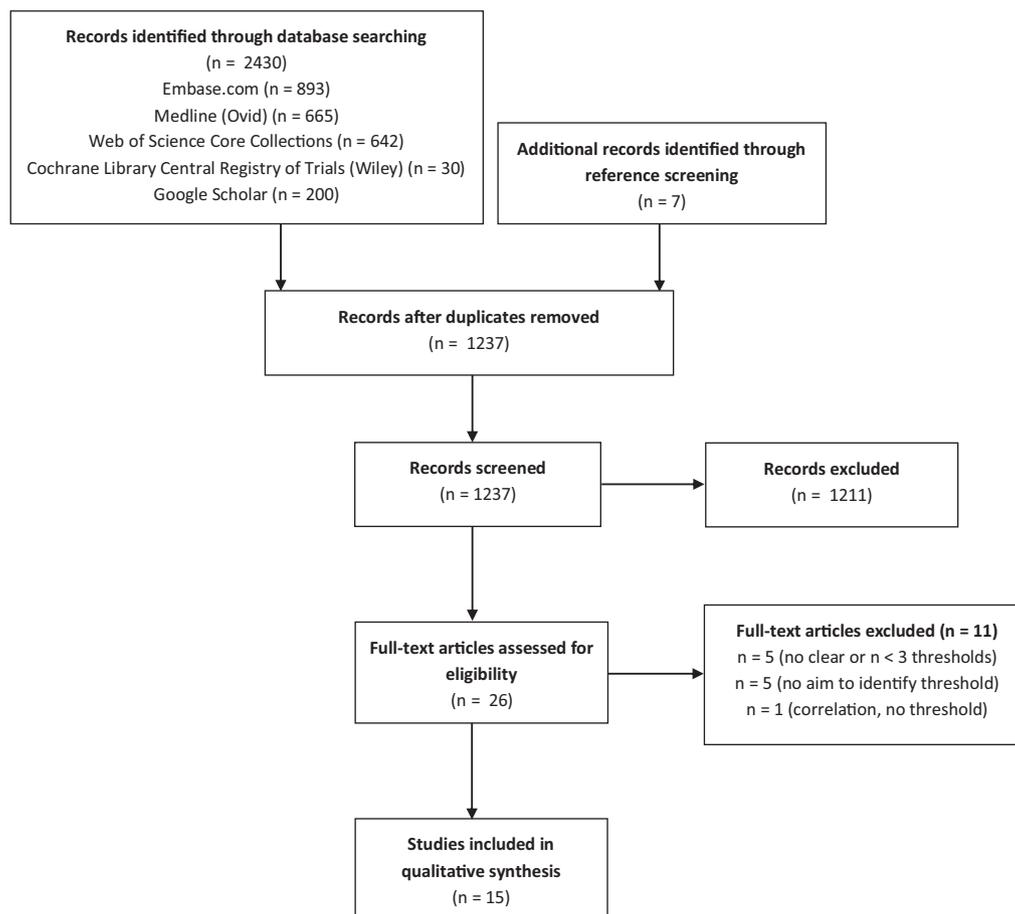


Figure 1. Flow diagram of the selection process, following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2009 guidelines.

TABLE 1
Case-Control Studies^a

Authors, Year	Study Design	Cases				Controls				Imaging Modality Used?		Symptoms, Intra-Articular Pathology, OA, THR?	Methodology for Determining Threshold	Suggested Threshold Value	Confounders
		No. of Cases (Hips)	Mean Age (Measure of Variation)	Sex (% Male/Female)	(A)symptomatic	N (Hips)	Mean Age (Measure of Variation)	Sex (% Male/Female)	(A)symptomatic	Type	Plane				
Barrientos, 2016 ⁶	Case-control	38 (38)	36.1 ± 11.8	55/45	Symptomatic	101 (202)	36.8 ± 14.4	41/59	Asymptomatic	CT	Oblique axial, anterolateral 1:30-o'clock	Cases: symptomatic FAI, undergoing hip arthroscopy controls: asymptomatic	ROC	57°	No differences in sex or age
Espie, 2014 ¹¹	Case-control	75 (96)	38 (95% CI, 36-40)	77/23	Both	50 (100)	36.2 (95% CI, 34-38.4)	54/46	Asymptomatic	Radiograph	Frog-leg lateral	Cases: (a)symptomatic FAI controls: asymptomatic	95% reference interval	Male: 63° Female: 58° (total: 60°)	No significant difference in age and height
Mascarenhas, 2018 ³¹	Case-control	176 (176)	35.6 ± 9	50/50	Symptomatic	372 (372)	33.9 ± 8	50/50	Asymptomatic	MRI	360° clockwise, radial (NFS)	Cases: symptomatic FAI undergoing hip surgery Controls: asymptomatic	ROC	58°-60°	Weight, age, sex matched
Sutter, 2012 ⁴⁵	Case-control	53 (NFS)	35.6 (range, 20-50)	62/38	Symptomatic	53 (NFS)	34.5 (range, 23-50)	58/42	Asymptomatic	MRI	Transverse-oblique: AI, anterior, AS, superior, PS	Cases: symptomatic FAI with cam morphology. Controls: asymptomatic	ROC	60°	Age and sex matched

^aAI, anteroinferior; AS, anterosuperior; CT, computed tomography; FAI, femoroacetabular impingement; MRI, magnetic resonance imaging; NFS, not further specified; OA, osteoarthritis; PS, posterosuperior; ROC, receiver operating characteristic; THR, total hip replacement.

TABLE 2
Cohort Studies (and 1 Finite-Element Study)^a

Authors, Year	Study Design	Cohort Characteristics				Imaging Modality Used?		Symptoms, Intra-Articular Pathology, OA, THR?	Methodology of Determining Threshold Value	Suggested Threshold Value	Confounders
		No. of Cases (Hips)	Mean Age (Measure of Variation)	Sex (% Male/Female)	(A)symptomatic	Type	Plane				
Agricola, 2014 ⁵	Prospective cohort	1457 (2879)	CHECK: mean 55.9 (range, 45-65) Chingford: mean 54.2 (range, 44-67)	CHECK: Both 20/80 Chingford: 0/100	Both	Radiograph	AP/coronal	Pathological cam: end-stage OA within 5-19 years (n = 105) versus no end-stage OA (n = 2774)	Cam morphology: based on bimodal alpha angle distribution, pathological cam morphology: ROC	cam: 60° pathological cam: 78°	Separate male and female, uni/bilateral, no correction for age
Bouma, 2014 ⁶	Cross-sectional cohort	83 (155)	N/A	NFS	Asymptomatic	Radiograph	Cross-table lateral		95% reference interval	66° (anatomic method) 58° (3-point method)	No significant difference in alpha angle in male/female
Fischer, 2018 ¹²	Cross-sectional cohort	3226 (NFS)	53 ± 14 (range, 21-90)	49/51	NFS	MRI (whole body)	AP/coronal		95% reference interval	71°	Significant association between age, weight, waist, BMI, height, and alpha angle
Fraitzl, 2013 ¹³	Retrospective cohort	339 (339)	Male: 47 ± 17, female: 55 ± 19	50/50	NFS	Radiograph	AP/coronal and FLL		95% reference interval	Male (AP/FLL): 70°/70° Female (AP/FLL): 61°/66°	No correlation between age and alpha angle
Golfam, 2017 ¹⁴	Cross-sectional cohort	197 (394)	29.4 (range, 21.4-50.6)	44/56	Asymptomatic	MRI	Oblique axial, radial, 1:30-o'clock		95% reference interval	Axial: 63° Radial: 66°	Insignificant relation between age and alpha angle, significant relation between sex and alpha angle
Gosvig, 2007 ¹⁵	Cross-sectional cohort	2803 (NFS)	NFS	38/62	NFS	Radiograph	AP/coronal		cam morphology: mean ± 1SD Pathological cam morphology: mean ± 2SD	Male: 69° (borderline), 83° (pathological) Female: 51° (borderline), 57° (pathological)	Specified for sex
Laborie, 2014 ²⁵	Cross-sectional cohort	2005 (FLL: 3996, AP: 4004)	18.6 (95% CI, 17.2-20.1)	42/58	NFS	Radiograph	AP/coronal (weightbearing) and FLL		97.5% percentile	Male (AP/FLL): 93°/68° Female (AP/FLL): 94°/56°	Specified for sex and side
Lepage-Saucier, 2014 ²⁶	Cross-sectional cohort	94 (188)	49 ± 16.6	52/48	Asymptomatic	CT	Oblique axial (90°) and double oblique (45°)		95% reference interval	Male (45°/90°): 93°/68° Female (45°/90°): 84°/69°	Specified for sex and side
Liu, 2017 ²⁸	Experimental finite-element study	1 (1) multiple modeled hips	35	0/100	NFS	CT	AP/coronal	Peak acetabulum pressure: 60° = 6.295, 70° = 7.291, 80° = 10.620, 90° = 11.460	Peak pressure forces between various threshold values and motions	80°	N/A
Mascarenhas, 2018 ³²	Cross-sectional cohort	590 (1111)	33 ± 8	46/54	Asymptomatic	CT	Pelvis: 9 positions around head-neck		95% reference interval	65°-70° for 12.00/3.00-o'clock 60° for 1- to 1.30-o'clock	Age, side, limb dominance, and sex
Pollard, 2010 ⁴⁰	Cross-sectional cohort	83 (166)	46 (range, 22-69)	47/53	Asymptomatic	Radiograph	Cross-table lateral		95% reference interval	62°	No significant difference between sex

^aAP, anteroposterior; BMI, body mass index; CHECK, Cohort Hip & Cohort Knee; CT, computed tomography; FLL, frog-leg lateral; MRI, magnetic resonance imaging; N/A, not available; NFS, not further specified; OA, osteoarthritis; ROC, receiver operating characteristic; THR, total hip replacement.

A second study²⁸ investigated the alpha angle in relation to peak pressure in the acetabulum and showed that if the alpha angle increased, the peak pressure increased as well. All 4 case-control studies, of which 3 used the ROC,^{7,31,45} reported their diagnostic alpha angle threshold for their patients with FAIS as compared with their asymptomatic controls.

Method of Determining Alpha Angle Threshold

Several methods of determining the alpha angle threshold were used in the studies. In 8^{9,11-14,26,32,40} of the 15 studies, the 95% reference interval was used. This was measured as the mean ± 1.96 SD, and the upper limit was chosen as the threshold. In 1 study,²⁵ the 97.5% percentile was used, and in 1 study¹⁵ the mean ± 1SD for cam morphology and the mean ± 2SD for pathological cam were used. In 4 studies,^{5,7,31,45} ROC curve analysis was used to assess the alpha

angle threshold, which best distinguished the presence and absence of FAIS^{7,31,45} or end-stage OA.⁵ One study⁵ based their cam morphology threshold on the bimodal distribution of the alpha angle. The finite-element study²⁸ measured peak contract pressure on the acetabular cartilage between various thresholds and motions.

Alpha Angle Threshold

Measurement Methods. Four studies^{5,7,31,45} reported an alpha angle threshold for cam morphology by ROC curve analysis or by using the bimodal distribution. Three of these studies^{7,31,45} studied FAIS versus asymptomatic participants and suggested that alpha angle thresholds ranged between 57° and 60°. The 8 studies^{9,11-14,26,32,40} that reported alpha angle threshold values by using the 95% reference interval reported a range from 58° to 93°. In the 3

TABLE 3
The Newcastle-Ottawa Scale Scores per Study^a

Authors, Year	Study Design	NOS Score		
		Selection	Comparability	Outcome
Agricola, 2014 ⁵	Prospective cohort	★ ★ ★	★	★ ★ ★
Barrientos, 2016 ⁷	Case-control	★ ★ ★		★
Bouma, 2014 ⁹	Cross-sectional cohort	★ ★		★
Espie, 2014 ¹¹	Case-control	★ ★ ★ ★	★ ★	★
Fischer, 2018 ¹²	Cross-sectional cohort	★ ★ ★	★ ★	★
Fraitzl, 2013 ¹³	Retrospective cohort	★ ★		★
Golfam, 2017 ¹⁴	Cross-sectional cohort	★ ★ ★		★
Gosvig, 2007 ¹⁵	Cross-sectional cohort	★ ★ ★	★	★
Laborie, 2014 ²⁵	Cross-sectional cohort	★ ★ ★	★ ★	★
Lepage-Saucier, 2014 ²⁶	Cross-sectional cohort	★ ★	★ ★	★
Liu, 2017 ²⁸	Experimental finite-element study	★		★
Mascarenhas, 2018 ³¹	Case-control	★ ★ ★	★ ★	★ ★ ★
Mascarenhas, 2018 ³²	Cross-sectional cohort	★ ★ ★	★ ★	★
Pollard, 2010 ⁴⁰	Cross-sectional cohort	★ ★ ★		★
Sutter, 2012 ⁴⁵	Case-control	★ ★ ★	★ ★	★ ★

^aThe NOS score is a total score of 3 different domains: “selection” (maximum 4 stars), “comparability” (maximum 2 stars) and “outcome” (maximum 3 stars), with a maximum score of 9. Both cohort and case-control studies are presented. A blank cell indicates the lowest score (0 stars). NOS, Newcastle-Ottawa Scale.

remaining studies, the study¹⁵ reporting the mean \pm 1SD for cam morphology determined a suggested alpha angle threshold of 51° and 69° for female and male patients, respectively, and the study²⁵ reporting the 97.5% percentile determined a suggested threshold for frog-leg lateral and AP views between 56° and 94° for female patients and 68° and 93° for male patients. The finite-element study²⁸ suggested a threshold of 80° (Figure 2).

Sex-Based Differences. Six studies,^{11-13,15,25,26} all using the 95% reference interval, mean \pm 1SD or 2SD, or the 97.5th percentile, suggested different thresholds for male and female patients, with alpha angle thresholds ranging from 63° to 93° in men and 58° to 94° in women.

DISCUSSION

We found 15 studies aimed at determining an alpha angle threshold to distinguish between hips with and without cam morphology. Most studies proposed an alpha angle threshold based on the upper limit of the 95% reference interval, and 3 studies^{7,31,45} were based on ROC curve analyses as 1 study⁵ was based on a bimodal distribution. Although a definite threshold value remains subjective, we suggest to report a threshold value of $\geq 60^\circ$ to classify cam morphology based on the currently available literature.

Most studies (12 of 15) used the upper limit of the 95% reference interval or comparable methods such as the +1SD, +2SD, or 97.5% percentile as the cutoff value to define the presence of cam morphology. While reference values in an asymptomatic population might give an indication, it might for several reasons not be the optimal approach for quantifying cam morphology. The assumption that only the upper 2.5% of an asymptomatic population has cam morphology is probably incorrect, given the high prevalence of this abnormality in the asymptomatic population.³³ Cam morphology might be more prevalent in male than in female patients, resulting in higher mean alpha angles in men than in women when a given population is being studied.^{20,21,27,40} Higher prevalence of mixed-type morphology is also observed in male compared with female patients.^{10,36} However, this does not imply that the alpha angle threshold should automatically be lower in female than in male patients, something that was proposed by 3 studies^{13,15,25} included in this systematic review. This is one of the reasons for the wide range of proposed alpha angle threshold values—between 51° and 94°—in studies using this methodology.

One study⁵ used the distribution of the alpha angle to propose a threshold value. This study combined data of 2 large cohorts that both independently showed a bimodal distribution of the alpha angle. Combining these alpha angle data resulted in a non-sex specific threshold of 60°

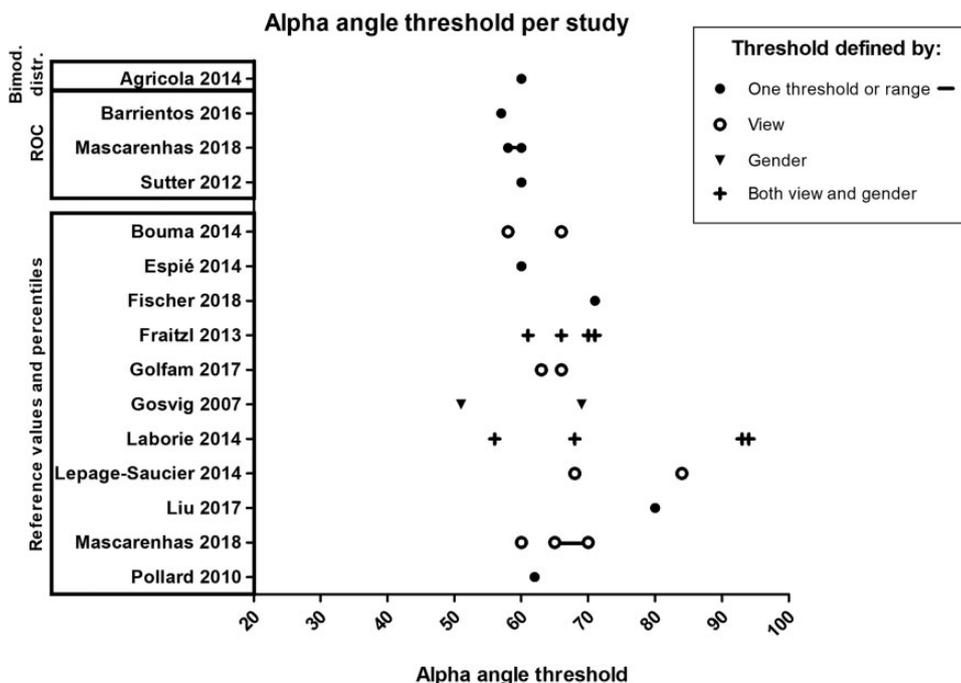


Figure 2. The alpha angle thresholds summarized across all included studies. ROC, receiver operating characteristic.

to discriminate between hips with and without cam morphology. Interestingly, a bimodal distribution naturally shows a distinction between normal and abnormal alpha angles and is therefore optimal to determine cutoff values. Three studies^{7,31,45} used ROC analysis to distinguish asymptomatic people from patients with FAIS, which is clinically a much more relevant method, as cam morphology can be highly prevalent in asymptomatic people. These studies showed consistent threshold values ranging between 57° and 60°.

Utilizing a consistent alpha angle threshold and imaging modality to classify cam morphology is important to study etiology, compare prevalence numbers, and study associations with concurrent pathology. Based on the above-mentioned current literature arguments, we feel that an alpha angle threshold of $\geq 60^\circ$ to quantify cam morphology would currently be the most appropriate value. This threshold was also found to be most appropriate by a recent scoping review.³⁰ However, we also acknowledge that it remains subjective as to where to draw the threshold line. There might also be reasons for not dichotomizing the alpha angle and studying it as a continuous variable, for example in prognostic studies. Further research is required to determine this.

It is important to note that the $\geq 60^\circ$ threshold is proposed as a classification criterion for cam morphology, which is different from a diagnostic criterion. Classification criteria intend to create a relatively homogeneous well-defined cohort for clinical research and do not intend to capture the more heterogeneous population of FAIS patients.¹ In order to use cam morphology for the clinical diagnosis of FAIS, more anatomic variables should be considered, such as the femoral torsion, neck-shaft angle, and acetabular morphology, as well as clinical findings and

patient symptoms. We therefore do not suggest using this threshold value in isolation for clinical decision making. It should be kept in mind that, although studies^{7,31,45} using ROC curve analysis generally showed that a 60° threshold could best distinguish patients with FAIS from asymptomatic people, there was still an overlap of these groups around the 60° threshold.

A wide range of imaging modalities and views were used in the included studies. For the purpose of the current systematic review, we described all outcomes of suggested alpha angle threshold values irrespective of the imaging modality or view used. Owing to study heterogeneity, it was not possible to pool studies based on the imaging modality or view used. Most studies used AP radiographs or 3D imaging reformatted as an AP view/coronal plane. Studies using ROC analyses, on which we mostly based our conclusions, also used different planes such as the coronal, oblique axial, clockwise radial (2-o'clock), and transverse-oblique planes. In these studies, a threshold of $\geq 60^\circ$ was suggested utilizing these planes as well. Thus, despite heterogeneity in modalities and views, the studies concluded the same thresholds to distinguish between hips with and without cam morphology. Still, radiographs (2D view) are limited by the fact that positional differences can limit reproducibility, and only certain locations of the head-neck junction—depending on the type of view—can be studied, which might result in underestimation of cam morphology. Most included studies that used 3D imaging also reduced the analysis to 2 or 3 planes, thereby also suffering from potential cam morphology underestimation. Only the 2 studies by Mascarenhas et al^{31,32} used radial formatted reconstructions around the femoral head-neck junction and measured the alpha angle on multiple locations around the

femoral neck. One of these studies,³² using the 95% reference interval to determine an alpha angle threshold value, suggested a 60° threshold for the 1- to 1:30-o'clock position and 65° and 70° for the 12-o'clock and 3-o'clock positions, respectively. Future studies should evaluate whether the suggested threshold of $\geq 60^\circ$ is applicable for all imaging modalities and/or views before diagnostic criteria can be introduced.

Limitations

There are limitations related to the included studies, which need to be addressed. First, although some large studies with up to 3226 participants were included, 9 of the 15 studies had less than 200 participants. There were also studies with a high risk of bias. Most studies (11 of 15) scored high (at least 3 of 4 points) on the NOS item "selection," as we considered most participants representative of people that can have cam morphology. However, only 2 studies scored 3 (of 3) points on the item "outcome." As mentioned before, there was large heterogeneity in multiple factors, such as age, imaging modality and view used, sex, and the methodology used to study threshold values.

CONCLUSION

Based on the available literature on alpha angle threshold values, we suggest reporting a non-sex specific threshold of $\geq 60^\circ$ to classify cam morphology.

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APPENDIX

Search Strategy

EMBASE

(‘hip disease’/exp OR ‘hip’/exp OR ‘hip arthroscopy’/de OR ‘hip radiography’/de OR ‘cam type femoroacetabular impingement’/de OR (femoroacetabul OR femor*-acetabular* OR femoracetabul* OR cam OR hip OR hips OR cox OR coxae):ab, ti) AND (‘alpha angle’/de OR ‘notzli alpha angle’/de OR ‘dunn 45 alpha angle’/de OR ‘dunn 90 alpha angle’/de OR ‘alpha angle measurement’/de OR ‘alpha angle threshold value’/de OR ‘alpha angle of femur’/de OR ‘reverse alpha angle’/de OR (((alpha OR a OR dunn OR notzli) NEAR/3 (angle* OR degree*)):ab, ti)*

MEDLINE Ovid

(Hip Injuries/ OR exp Hip/ OR (femoroacetabul OR femor*-acetabular* OR femoracetabul* OR cam OR hip OR hips OR cox OR coxae).ab, ti.) AND (((alpha OR dunn OR notzli) NEAR/3 (angle* OR degree*))).ab, ti.)*

Web of Science

TS=(((femoroacetabul OR (femor* next acetabular*) OR femoroacetabul* OR cam OR hip OR hips OR cox OR coxae)) AND (((alpha OR a OR dunn OR notzli) NEAR/2 (angle* OR degree*))))*

Cochrane CENTRAL

((femoroacetabul OR (femor* next acetabular*) OR femoracetabul* OR cam OR hip OR hips OR cox OR coxae):ab, ti) AND (((alpha OR a OR dunn OR notzli) NEAR/3 (angle* OR degree*)):ab, ti)*

Google Scholar

femoroacetabulal|“femoral|femoroacetabular”|femoracetabular|“cam impingement|deformity|morphology|lesion|type”|hip|hips|cox|coxae "alpha|a|dunn|notzli angle| angles|degree|degrees"|“angle alpha”