Cam impingement: defining the presence of a cam deformity by the alpha angle

Data from the CHECK cohort and Chingford cohort

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Abstract

Introduction: Cam impingement is characterized by abnormal contact between the proximal femur and acetabulum caused by a non-spherical femoral head, known as a cam deformity. A cam deformity is usually quantified by the alpha angle; greater alpha angles substantially increase the risk for osteoarthritis (OA). However, there is no consensus on which alpha angle threshold to use to define the presence of a cam deformity.

Aim: To determine alpha angle thresholds to define the presence of a cam deformity and to define a pathological cam deformity based on development of OA.

Methods: Data from both the prospective CHECK cohort of 1002 individuals (45-65 years) and the prospective population-based Chingford cohort of 1003 women (45-64 years) were combined. The alpha angle was measured at baseline on anteroposterior radiographs, from which a threshold for the presence of a cam deformity was determined based on its distribution. Further, a pathological alpha angle threshold was determined based on the highest discriminative ability for development of end-stage OA at follow-up.

Results: A definite bimodal distribution of the alpha angle was found in both cohorts with a normal distribution up to 60°, indicating a clear distinction between normal and abnormal alpha angles. A pathological threshold of 78° resulted in the maximum area under the ROC curve.

Conclusion: Epidemiological data of two large cohorts shows a bimodal distribution of the alpha angle. Alpha angle thresholds of 60° to define the presence of a cam deformity and 78° for a pathological cam deformity are proposed.

Introduction

Historically, the cause of most hip osteoarthritis (OA) has been defined as ‘idiopathic’, but recent evidence suggests that development of hip OA is largely influenced by the presence of a cam deformity.(1-4)

A Cam deformity is characterized by extra bone formation at the anterolateral head-neck junction resulting in a non-spherical Cam-shaped deformity.(5) It is forced into the acetabulum during flexion and internal rotation of the hip, a process referred to as cam impingement.(6) In time and with repeated movement, the cam deformity might damage the soft tissue structures of the hip, leading to pain, decreased function, and subsequently osteoarthritis (OA) of the hip.(2-3, 7)

The presence of a radiographic cam deformity is a common finding with prevalence numbers of roughly 15-25% in males and 5-15% in females.(8-10) The wide range of prevalence reported is mainly due to the inconsistency in the definition of what is a cam deformity. A cam deformity is commonly assessed by the alpha angle, which measures the extent to which the femoral head deviates from spherical.(11) Greater alpha angles increase the risk for development of OA substantially.(2-3, 12-14) However, there is neither a validated alpha angle threshold value to define the presence of a cam deformity, nor a pathological threshold that indicates an increased risk for development of OA. As a consequence, threshold values ranging from 50° to 83° have been used in literature, which makes prevalence numbers and associations with subsequent pathology difficult to compare and interpret. (11, 15)

In order to determine alpha angle thresholds, large cohort studies are needed. For that reason, we combined data of the CHECK cohort and Chingford cohort, both with prospective follow-up. Using these data, the aim of this article is to determine an alpha angle threshold for defining the presence of a cam-type deformity, and to determine a pathological alpha angle threshold based on development of OA at follow-up.

Methods

Study population

The alpha angle threshold values were determined in the CHECK cohort with a current follow-up of 5 years, and in the Chingford study with a follow-up of 19 years.

CHECK is a nationwide multicenter prospective cohort study of 1002 individuals aged 45-65 years (mean 55.9 years) with early symptomatic OA (pain) of the hip or knee. They had not yet consulted their general practitioner for these symptoms, or the first consultation was within 6 months before entry. Participants with any other pathologic condition that could explain the symptoms were excluded (for hip: other rheumatic disease, previous THR or K&L grade 4, trauma, dysplasia, Perthes disease, subluxation, osteochondritis dissecans, fracture, septic arthritis, bursitis, tendinitis, or previous hip surgery).(16)

The Chingford cohort is a population-based cohort of 1003 asymptomatic women aged 44-67 years (mean 54.2 years). These women were registered at a general practice in London and were invited to participate in a study assessing musculoskeletal disease in the population. Yearly clinic visits were performed, which included; morphometric, clinical, biologic, and radiographic measurements.

Radiographs

In the CHECK study, weight-bearing Anterio-Posterior (AP) pelvis radiographs were obtained from the 11 participating research centers according to a standardised protocol. Feet were positioned such that the medial side of the distal part of the first phalanx touched and a wedge was used to assure 15° internal rotation. In the Chingford Cohort, each woman had a standardised supine AP pelvis radiograph, taken at years 2, 8 and 20. A small sand bag under the knees was used to minimize hip rotation.

In both the CHECK and Chingford cohorts, AP pelvis radiographs were scored atlas based and ‘blind’ to clinical details according to the method of Kellgren and Lawrence (K&L) at baseline, and at 5 year follow-up in the CHECK cohort and at year 20 in the Chingford cohort.(17-18). End-stage OA was defined by K&L grade 3, 4, or total hip arthroplasty (THA) at follow-up.

Alpha angle

The alpha angle measures the extent to which the femoral head deviates from spherical. It is measured by first drawing the best fitting circle around the femoral head, then a line through the centre of the neck and the centre of the head. From the centre of the femoral head, a second line is drawn to the point where the superior surface of the head-neck junction first departs from the circle. The angle between these two lines is the alpha angle (Figure 1).(11)

In both cohorts, the alpha angle was semi-automatically calculated. In the CHECK study, the shape of the proximal femur was outlined by a set of points that were positioned on anatomical landmarks using statistical shape modeling (SSM) software (ASM tool kit, Manchester University, Manchester, UK). From this points set, the alpha angle was calculated using Matlab (V.7.1.0).(2, 19) In the Chingford cohort, the alpha angle was also measured using a validated Matlab based (Matlab R2009b; MathWorks) software package called Hip Morf 2.0.

Reliability of the alpha angle was examined in both cohorts and between both techniques. In the CHECK cohort, interobserver reproducibility was examined by positioning the point set twice in 25 randomly selected hips by three investigators. Intra-observer repeatability was tested for each investigator in 10 randomly selected radiographs. In the Chingford cohort, intra-observer repeatability was assessed by 1 investigator reading 10 randomly selected blinded radiographs on 3 occasions. Interobserver reproducibility was assessed by 2 further observers reading the same 10 radiographs.(3) Finally, in order to examine interobserver reliability between both techniques, the alpha angle was calculated in 30 randomly selected hips using SSM software and Hipmorf 2.0 (14 hips of the CHECK cohort and 16 hips of the Chingford cohort).

Statistics

Reliability of the alpha angle as a continuous measure was assessed using intraclass correlation coefficient (ICC) and Cohen's kappa indicating agreement for whether a hip was classified as having or not having a cam deformity. A Bland-Altman plot was used to visualize agreement in the alpha angle measurements between the two techniques (SSM and Hipmorf).(20)

Explorative analysis showed a bimodal distribution of the alpha angle in both cohorts, indicating two different populations, one without cam deformity and one with cam deformity. To determine the presence of a cam deformity, the optimal threshold that distinguishes between both distributions was assessed. The alpha angle data of both cohorts were combined and an optimal fit through the data was determined based on a mixture of normal distributions using matlab (V7.1.0). The alpha angle corresponding with the minimum of the fit was used as a threshold to define the presence of a cam deformity. Difference in alpha angle between men and women below the found threshold was calculated using generalized estimating equations.

To define a pathological threshold, end-stage OA at follow-up was used as an outcome. The maximum area under the receiver operating characteristic (ROC) curve was calculated for each possible alpha angle threshold. The maximum area under the ROC curve corresponds with the threshold having the highest sum of sensitivity and specificity for development of OA, which indicates the optimal alpha angle threshold to distuingish between hips with and without end-stage OA at follow-up.

Results

Participants CHECK and Chingford

Of the 1002 individuals in the CHECK cohort, 89 were lost to follow-up, 16 were not able to visit the hospital during the five year follow-up, 32 refused to undergo radiographs or had missing radiographs, and 124 were excluded because this first cluster of participants had AP hip radiographs (instead of AP pelvic radiographs) obtained at baseline. Of the remaining 741 individuals (1482 hips), another 71 hips (with a total of 18 subjects because of bilateral involvement) were excluded because the radiographs were of insufficient quality to reliably position the SSM points, leaving 1411 hips in 723 individuals for inclusion with 80% (n=575) being women. Of the included hips, 76% had no signs of radiographic hip OA (K&L=0) and 24% had doubtful radiographic hip OA (K&L=1).

From the initial Chingford cohort of 1,003 individuals, 795 individuals had AP pelvis radiographs obtained at year 2. Of those, 20 individuals were excluded due to poor radiograph quality. Five hip joints were excluded because they had a metalwork in situ, indicating previous femoral neck fracture. Seventy-two hip joints were excluded due to excessive tilt. A total of 119 hips in 61 individuals were excluded, leaving 1468 hips in 734 individuals for inclusion at baseline. At baseline, 80% had a K&L score of 0, 6% had a K&L score of 1 and 14% had a K&L score of ≥2.

Reliability and reproducibility of the alpha angle

In the CHECK cohort, the ICC score for interobserver reliability was 0.73 and the ICC score ranged from 0.85 to 0.99 for intra-observer reliability. In the Chingford cohort, the ICC score for interobserver reliability were 0.89 and the ICC score ranged from 0.79 to 0.95 for intra-observer reliability ICC scores.

The ICC score for interobserver reliability using both techniques was 0.66. When the alpha angle was analyzed as a dichotomous measure based on the presence or absence of a cam deformity, a Cohen's kappa of 0.85 was found when both techniques were compared. The Bland-Altman plot is shown in figure 2 and illustrates two outliers; no systematic differences between the measurements were identified.

Threshold for defining the presence of a cam deformity

In both the CHECK cohort and the Chingford cohort, a definite bimodal distribution of the alpha angle was found (figure 3a-b). The optimal fit through the combined data showed a minimum at an alpha angle of 62.7° (figure 3c). Figure 3d-e depicts the distribution of the alpha angle in men and women separately in the CHECK cohort. A corresponding bimodal distribution of the alpha angle was found in both men and women and the higher prevalence of cam deformities in men than in women is clearly illustrated. When analyzing the hips with an alpha angle less than 62.7 degrees in the CHECK cohort, the mean (SD) alpha angle in men 45.0 (± 4.15) was significantly higher than in women 42.7 (± 3.9), $p<0.001$.

Pathological threshold

In the CHECK cohort, 2.76% (39 hips) developed end-stage OA within five years follow up. THA patients did not have other hip pathology than OA nor other hip surgery during follow-up. In the Chingford cohort, 7.05% (66 hips) had developed end-stage OA at Year 20.

A pathological threshold was determined based on the hips with cam deformity that developed end-stage OA at follow-up. An alpha angle threshold of 78° resulted in the maximum area under the ROC curve, which was 0.69 for end-stage OA (figure 4). It is illustrated by figure 5 that the majority of hips with a cam deformity that developed OA had an alpha angle greater than 78°.

Discussion

In the present study that combined data of two large prospective cohorts, comprising almost 3000 hips, an alpha angle threshold for defining the presence of a cam deformity was determined based on the bimodal distribution of the alpha angle. Also, a pathological threshold value was determined based on development of end-stage OA at follow-up.

Previously, threshold values based on the distribution of the alpha angle in a certain population have been proposed, and ranged from 50° to 83°.(11, 15, 21-22) These studies defined the presence of a cam-type deformity either by the upper limit of the 95% reference interval, or by the +1 standard deviation of the mean. Although these values might give an indication, the reference interval or standard deviation might for several reasons not be optimal to define an alpha angle threshold. First, the assumption that only the upper 5% of a given population has an abnormal alpha angle is incorrect. Many studies showed a prevalence higher than 5% in asymptomatic individuals with various threshold values for the alpha angle.(8, 23-26) Secondly, reference intervals assume a normal distribution of the alpha angle, which was clearly not the case in our cohorts. Also, different threshold values for men and women have been proposed based on significant differences in mean alpha angle between men and women.(15, 22) However, as the prevalence of cam deformities is higher in men than in women, a greater mean alpha angle in men can be expected, but this does not imply that the alpha angle cut-off in women should be lower. Figure 3 d-e clearly illustrates that the higher mean alpha angle in men is actually influenced by outliers, which are in fact the hips with a cam deformity.

To define the presence of a cam deformity, we propose a threshold of 60°. The threshold of 62.7° was based on the minimum of the optimal fit through the combined alpha angle data. However, the optimal fit actually consisted of three distributions, as the distribution of the alpha angles <60° was slightly skewed to the right. When we forced a fit of two distributions through the data, the minimum was found at an alpha angle of 56.7°, which was clearly too low. The benefit of a bimodal distribution is that there are only a few cases in between those alpha angle thresholds, assuring that separation in cam versus non cam cases is not too sensitive to small differences in threshold value (Figure 3). We therefore regard a non gender specific threshold of 60° to be optimal to distinguish between normal hips and hips with cam deformity.

When comparing the distribution of the alpha angle in the CHECK cohort with the distribution in the Chingford cohort, a higher prevalence of cam deformities in the Chingford cohort was found. As no systematic differences in measurement between both techniques were found, this might be due to the differences of inclusion. The Chingford cohort is a population based cohort, where individuals might have had hip complaints for a longer time. In contrast, an inclusion criterion of the CHECK cohort was that individuals consulted the GP for the first time because of hip or knee pain. Individuals suffering from pain because of cam impingement are likely to present with complaints at a younger age than 45 years, which means that they were not included in the CHECK cohort.

As higher alpha angles are associated with more severe cartilage damage and OA, Gosvig et al. proposed a pathological threshold based on the +2 standard deviations of the mean which resulted in pathological thresholds of 83° for men and 57° for women.(15) However, in our opinion a pathological threshold value should rather be based on 'true' pathology. Still, as opposed to the threshold based on the bimodal distribution of the alpha angle, the definition of a pathological threshold value might be more subjective. We determined a pathological threshold value based on the highest discriminative ability for development of end-stage OA during the follow-up period, using the maximum area under the receiver operating characteristic (ROC) curve. Using this method, we propose a non gender specific threshold of 78°. It can also be visualized in figure 5 that most hips with cam deformity that developed end-stage OA had an alpha angle higher than 78°.

For upcoming clinical trials it is important to avoid misclassification of the radiographic presence of a cam deformity. An alpha angle below 60° is often used to quantify a cam deformity, but below this value we could not discriminate between hips with and without a cam deformity. This might also explain why a value of 60° has previously been shown to be optimal to discriminate between symptomatic and asymptomatic cam deformities.(27-28) However, a cam deformity is highly prevalent in the general population and is only a prerequisite for cam impingement. Whether someone with a cam deformity will become symptomatic and develops cartilage damage depends on many other factors such as the orientation of the acetabulum, the frequency of impingement events represented by for example sporting activities, genetics, and the vulnerability of the soft tissue structures within the hip joint. The presence of a radiographic cam deformity alone is therefore not suitable for the diagnosis of cam impingement.

Although the alpha angle has been shown to be associated with decreased function and to be highly predictive for development of OA, concern might rise about the reported wide range of reliability.(29-30) In our cohorts, bias in measuring the alpha angle was limited by two factors. First, observers were blinded for clinical status and did not know which hips were going to develop OA at follow-up. Second, the alpha angle was semi-automatically calculated from a point set which was positioned on the contour of the bone. When the alpha angle is drawn manually, the observer might be influenced by the visual appearance of the head-neck junction. ICC scores as examined in our cohorts were in between previously reported values and showed strong agreement. The greatest differences in alpha angle occurred when both methods were compared, as illustrated by an ICC of 0.66. This was caused by two outliers (figure 2). Using the SSM-technique, an alpha angle of 39° and 44° for these outliers was measured. However, a very small part of the femoral head was outside the circle using Hipmorf, which is why an alpha angle of 86° and 90° was measured. Excluding these two hips increased the ICC between the two techniques from 0.66 to 0.89. Except for these outliers, there was agreement in categorizing hips with or without cam deformity in all hips. It appears that drawing a best fitting circle is crucial for reliably determining the alpha angle.

Several measures to quantify the cam deformity besides the alpha angle have been proposed, such as the head-neck ratio, anterior offset ratio, and triangular index.(15) All those measures quantify the loss of concavity of the head-neck junction and show good reproducibility. However, a nonspherical, flattened femoral head might have a normal concavity of the head-neck junction. Such an abnormal morphology might lead to impingement but is not captured by above mentioned measured, except for the alpha angle. Further, in both the CHECK and Chingford cohort, the alpha angle was most predictive for OA.(2-3)

This study has some limitations. First, the use of AP radiographs might not be optimal for quantifying a cam deformity. Although the exact amount of cam deformities missed on AP radiographs varies in different reports, we acknowledge that the prevalence of cam deformities is underestimated.(15, 31-32) Though, when only AP radiographs are used, the alpha angle is still highly predictive for OA. Second, it is unknown whether the proposed thresholds are applicable for other radiographic views, or in other planes when 3D imaging techniques are used. The proposed thresholds should therefore be validated in large cohorts using CT or MRI.

In conclusion, the alpha angle in this study of combined epidemiological data showed a bimodal distribution, indicating a clear distinction between hips with and without cam deformity. An alpha angle threshold of 60 degrees is proposed for defining the presence of a cam deformity. In addition, a pathological threshold of 78 degrees is proposed based on development of OA at follow-up.

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Figure 1. The alpha angle quantifies the asphericity of the femoral head.

A. a normal alpha angle of 41° is shown representing a spherical femoral head.

B. an abnormal alpha angle of 98° is shown representing a cam deformity.

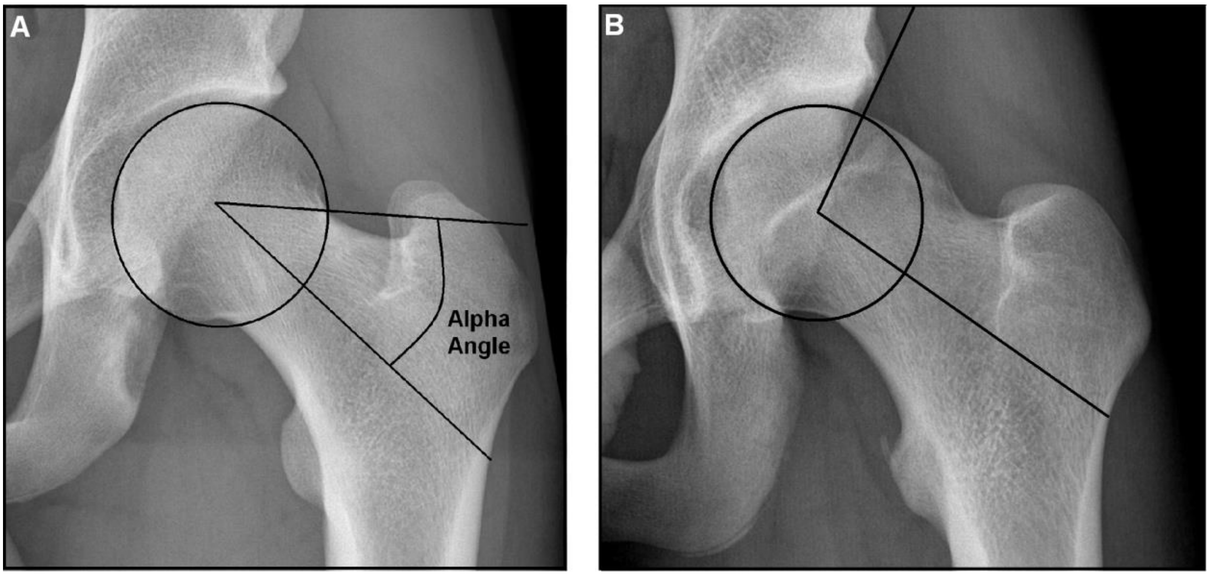


Figure 2. Bland Altman plot of the difference versus average alpha angle showing the agreement in alpha angle measurement of 30 hips between the SSM point set and Hipmorf technique.

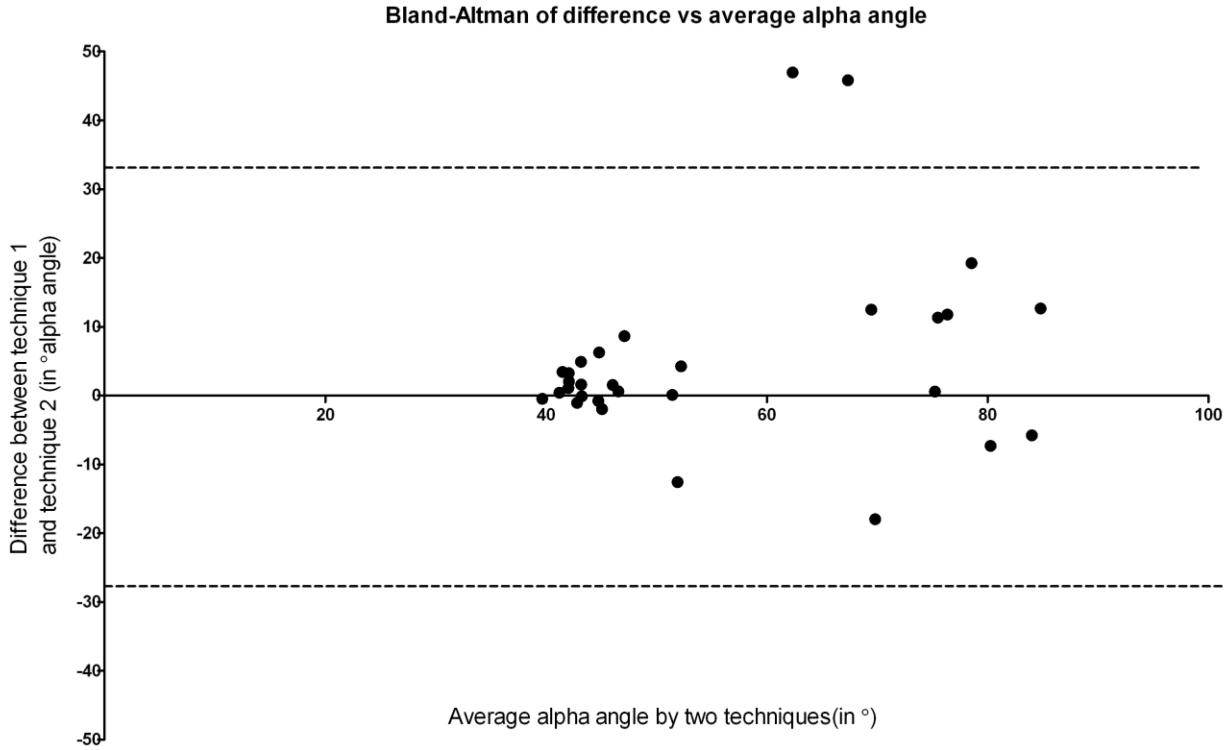


Figure 3. Presence of cam deformity: 60 degrees

Histograms of the alpha angle as measured on anteroposterior radiographs with kernel density plot show a clear bimodal distribution in the CHECK cohort **(A),** the Chingford cohort **(B)**, and the combined data of both cohorts **(C).** A corresponding normal distribution of the alpha angle until a value of 60° is shown in both men **(D)** and women **(E)** in the CHECK cohort. These histograms also illustrate the higher prevalence of cam deformity in men than in women.

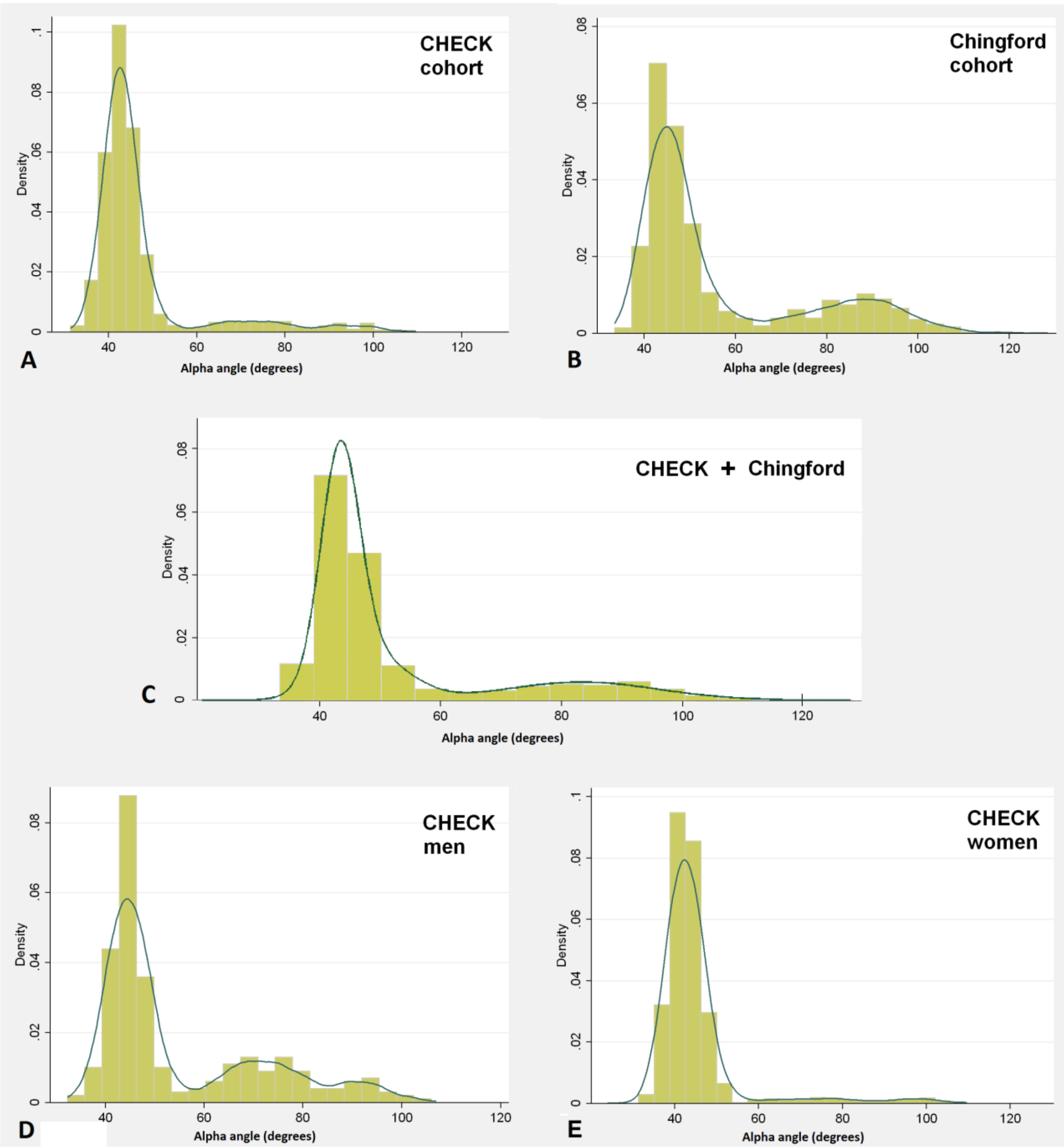
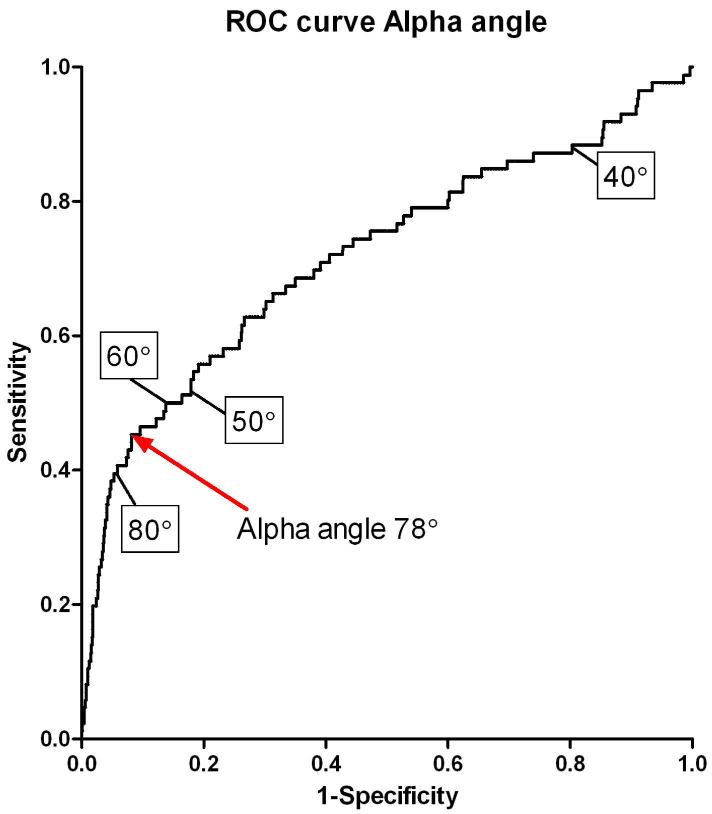


Figure 4. ROC cure

A. the ROC curve of the alpha angle as a continuous measure for end-stage OA is shown, with the pathological threshold of 78° indicated. B The area under the ROC curve for each alpha angle threshold is shown.



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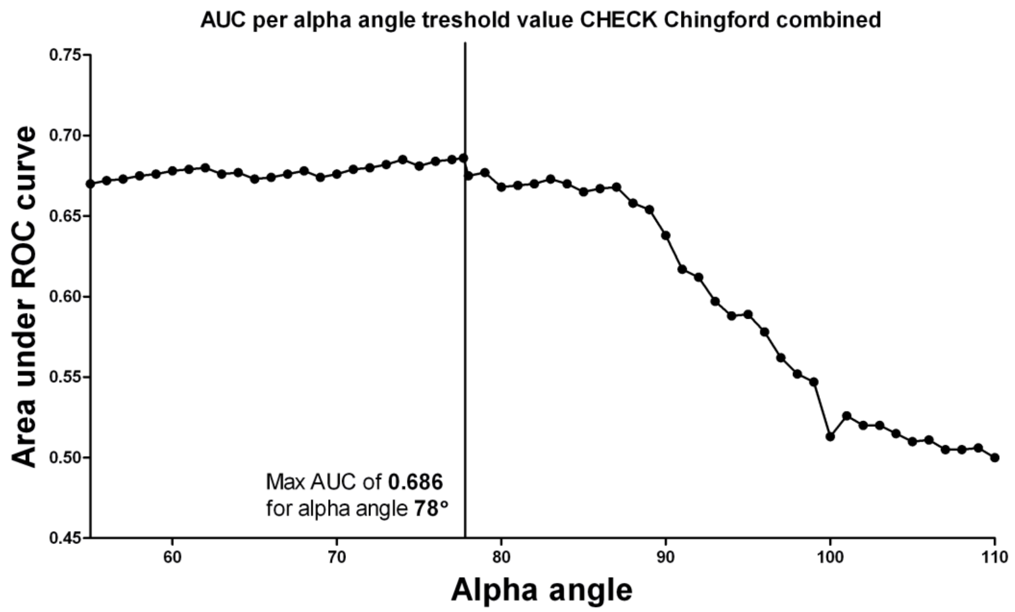

B

Figure 5. Pathological alpha angle threshold: 78 degrees

Scatterplot showing the alpha angle on the X-axis and a random variable on the Y-axis. The dots represent the combined hips of the CHECK cohort (green) and Chingford cohort (blue) at baseline with a cam-deformity that developed end-stage OA (K&L 3, 4, or THA). The pathological threshold of 78 degrees is indicated.