A new radiological index for assessing asphericity of the femoral head in cam impingement

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Femoroacetabular cam impingement is thought to be a cause of premature osteoarthritis of the hip.

The presence of cam malformation was determined in 2803 standardised anteroposterior (AP) pelvic radiographs from the Copenhagen Osteoarthritis Study by measuring the alpha (α) angle and the triangular index, a new measure of asphericity of the femoral head. In addition, the α-angle and the triangular index were assessed on the AP and lateral hip radiographs of 82 men and 82 women randomly selected from patients scheduled for total hip replacement (THR). The influence of varying femoral rotation on the α-angle and the triangular index was also determined in femoral specimens under experimental conditions.

From the 2803 radiographs the mean AP α-angle was 55˚ (30˚ to 100˚) in men and 45˚ (34˚ to 108˚) in women. Approximately 6% of men and 2% of women had cam malformation. The α-angle and triangular index were highly inter-related. Of those patients scheduled for THR, 36 men (44%) and 28 women (35%) had cam malformation identifiable on the AP radiographs. The triangular index proved to be more reliable in detecting cam malformation when the hip was held in varying degrees of rotation.

The combination of the α-angle and the triangular index will allow examination of historical radiographs for epidemiological purposes in following the natural history of the cam deformity.

The pathogenesis of osteoarthritis (OA) is complex with many risk factors, such as age, gender, race, ligamentous instability, obesity, inheritance, joint incongruity, childhood joint disorders and exposure to repeated daily lifting associated with its development. Over the past decade, extensive research into the importance of femoroacetabular abnormalities has been conducted. The concept of femoroacetabular impingement has been recognised. Magnetic resonance imaging, arthroscopic and finite-element studies have shown that cam, pincer or sliding impingement between the femoral head or the head-neck junction and the acetabular labrum can result in hypertrophy, fraying and detachment of the labrum thereby exposing the junction of the cartilaginous and bony acetabulum.1-5 It is assumed that this precipitates the degenerative process.6 The underlying anatomical malformations are subclinical asphericity of the femoral head,7,8 which occurs mainly in men in cam impingement, coxa profunda and/or a retroverted acetabulum.1,5 It is assumed that this precipitates the degenerative process.6 The underlying anatomical malformations are subclinical asphericity of the femoral head,7,8 which occurs mainly in men in cam impingement, coxa profunda and/or a retroverted acetabulum in pincer impingement and acetabular dysplasia in sliding or subluxing impingement.9-19

While the mechanics of femoroacetabular impingement and OA have been extensively elucidated in the literature, other important aspects of femoroacetabular impingement have not. The epidemiology of cam or pincer impingement and their influence on the development of OA compared with other risk factors have not been described. Ideally, in order to answer these questions, unlimited access to MR or CT scans of the hips of randomly selected symptomatic and asymptomatic subjects from all age groups would be required, combined with an extensive knowledge of all the other previously identified risk factors. Such an investigation is not feasible. An alternative is to examine the historical radiographs of patients, applying the generally accepted geometrical discriminators of femoral head-neck radiographs and to correlate the results with epidemiological data. This approach has been used to establish the relationship between acetabular dysplasia and OA.15,16

In cam impingement, the anatomical deformity is characterised by a lateral increase in the radius of the femoral head caused by a slight
varus deformity of the head-neck junction in the anteroposterior plane (AP) (Fig. 1), combined with a posterior displacement, resulting in the characteristic hump deformity of the anterolateral portion of the head-neck junction.

Usually, the alpha (α) angle of Notzli et al., which was originally developed for analysing the coronal view of the hip on MRI, is used to determine the degree of malformation (Figs 2 and 3).

We have examined the distribution of the AP α angle in standardised, weight-bearing AP pelvic radiographs of 2803 subjects of the Copenhagen Osteoarthritis Study and the distribution of the lateral and AP α angle in 164 patients scheduled for total hip replacement (THR). In addition, we have studied how the α angle varied in radiographs of ten femoral specimens (aspherical and normal) taken in increments of 5˚ of axial rotation of the femur. Finally, we have attempted to determine if there was a more accurate geometrical index of asphericity of the femoral head than the α angle, whereby the cam or hump deformity could be detected with an acceptable degree of certainty on AP radiographs.

**Patients and Methods**

**Standardised radiological material of the Copenhagen Osteoarthritis Study.** This is a sub-study of the Copenhagen City Heart Study, which is a longitudinal survey of an adult, almost entirely Caucasian population selected from the citizens of the county of Østerbro in Copenhagen using a random social-security-number algorithm. The survey has recorded life-style factors, cardiopulmonary disease and musculoskeletal disease between 1976 and April 2002. Between 1991 and 1994, AP radiographs of the pelvis were recorded in 4151 participants, 1533 men with a mean age of 62 years (23 to 93) and 2618 women with a mean age of 65 years (22 to 92). Radiographs were obtained in the standing position with the feet pointing straight forward determined by markers in the floor and the legs positioned in neutral abduction-adduction along the functional axis. The x-ray beam was centered two finger breadths above the symphysis pubis in the vertical midline with a source-to-film distance of 120 cm in all cases. Two radiographers obtained all the radiographs and attempted to have every exposure in neutral pelvic rotation. In all the pelvic radiographs, the width of the hip joint space was assessed at three standard locations of the weight-bearing area. The minimum width of the three measurements was selected for further analysis. Furthermore, the centre-edge angle (CEA), the acetabular depth-to-width ratio and the femoral head extrusion index was determined. Finally, the diameter of the femoral head was measured. The Tönnis obturator foramen index, which is obtained by dividing the largest horizontal diameter of the obturator foramen on the right side by that on the left, was measured. Deviation of this index from 1.0 indicated rotation of the pelvis relative to the x-ray beam which in excess may affect the measurements. A detailed description of the radiological protocol has been reported previously.
The following exclusion criteria were applied: a residual joint space of $\geq 2$ mm which was applied as a radiological discriminator of OA; CEA $\geq 20^\circ$ in both hips; a Tönnis obturator foramen index of $\geq 0.8$ and $\leq 1.2$; previous surgical procedures on either hip; a history of childhood hip or knee disease; and evidence of Perthes’ disease. Applying these criteria to the gross material there remained 2803 radiographs of 1055 men and 1748 women on which further analysis could be performed. The centre of the femoral head was identified using Mose’s circles which consist of a transparent sheet of plastic with concentric circular markings 1 mm apart. The longitudinal axis of the femoral head was identified by connecting the centre of the femoral head to the midpoint of the narrowest place on the femoral neck (Figs 1 and 2), usually bisecting a line drawn from the tip of the greater trochanter to the apex of the lesser trochanter.

The neutral radius of the femoral head, usually the horizontal, was measured (there was no variation of magnification), and the AP adaptation of the $\alpha$ angle was assessed at the point at which the radius of the femoral head increased and left the head at the head-neck junction. If the resultant radius R at the point 0.5 $r$ along the axis of the femoral head, at the head-neck junction, exceeds the natural radius of the femoral head by 2 mm on a radiograph with 1.2 magnification, then a hump malformation is present (R $\geq r + 2$ mm). This method provides a simple and accurate description of the hump malformation in both lateral and AP radiographs. The greater R is at the femoral head-neck junction, compared with the natural head radius r, the more pronounced is the hump malformation (Figs 2 and 3). One observer (KKG) performed all the measurements using a 0.1 mm scaled magnifying glass (Peak, Tokyo, Japan). The intra- and interobserver reliability coefficients of the $\alpha$ angle and triangular index were calculated (KKG, HP).

Standardised radiological material of patients scheduled for uncemented total hip replacement. To determine the relationship between the radiological indices of hump malformation in the AP and lateral planes, the radiographs of 164 randomly selected patients (82 men and 82 women), scheduled for THR were analysed. The mean age of the men was 59 years (30 to 82) and of the women 61 years (34 to 81). The radiographs were obtained with the patients supine, positioned with the patellae pointing straight upwards and the feet mounted in holders. For the lateral recordings, the x-ray beam was centered at the ilio-inguinal skin fold at 45° to the groin and parallel to the examination axis.

Diagram showing the triangular index for assessment of the asphericity of the femoral head and hump malformation. The radius (r) of the femoral head is measured. Then $1/2$ r and the corresponding perpendicular height (H) to the cortex are measured. The pathologically increased radius (R) is found by applying the Pythagorean law for triangular figures ($a^2 + b^2 = c^2$). If $R \geq r + 2$ mm on a radiograph, with 1.2 magnification asphericity is for all practical purposes demonstrated.
The radiographs were stored digitally. Using the associated geometrical modalities in the Image Management and Applications-Radiology Information Service (IMPAX-RIS) system (Agfa, Köln, Germany), the centres of the femoral head, the longitudinal axis of the neck, the radius of the femoral head and the $\alpha$ angle and triangular index were assessed in both radiological planes by the same observer (KKG).

Geometrical analysis of femora subjected to radiological exposure with incremental rotation of 5°. To determine the influence of varying rotation on the geometrical indices of the hump malformation, ten femoral specimens were securely mounted in a wooden frame on a baseplate, which allowed for stepwise rotation around the longitudinal axis (Fig. 4). Two specimens had apparent hump malformation at the femoral head-neck junction, and eight were normal in all regards. The gender of the specimens was not known. The starting position was defined with the posterior condylar line parallel to the back edge of the baseplate. The tube-to-femur distance was 83 cm and specimen-to-film distance 17 cm. The radiographs were recorded at increments of 5° from the starting point to 35° of external rotation and to 35° of internal rotation. These radiographs were also stored digitally and the geometrical indices measured accordingly in each radiograph (KKG, EM).

Reliability. Intra- and interobserver reproducibility was obtained by the serial measurement of 30 patient-specific radiographs from the specimen series and 70 from the Copenhagen Osteoarthritis Study material. The sets were switched between two authors (KKG HP) and re-measured after an interval of four weeks.

Statistical analysis. Most distributions and calculations of gender-specific differences were determined by independent samples $t$-tests. Odds ratios (OR) were calculated by the chi-squared test. Intra- and interobserver reproducibility of continuous variables such as the $\alpha$ angle and the triangular index was assessed by intraclass coefficients. All the statistical calculations were performed using the SPSS version 13.0 statistical software (SPSS Inc., Chicago, Illinois) and statistical significance was ascribed when the p-value was < 0.05.

Results

Radiological material of Copenhagen Osteoarthritis Study. The distribution, gender-related differences and suggested normal, borderline and pathological threshold values of the AP $\alpha$ angle are summarised in Tables I and II. There was a highly significant gender-specific difference in the $\alpha$ angle.

<table>
<thead>
<tr>
<th>Table I. The distribution, gender-related differences and suggested pathological threshold limits of the femoral head-neck junction $\alpha$ angle (°) assessed in 2803 standardised anteroposterior pelvic radiographs</th>
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<tbody>
<tr>
<td><strong>Men</strong></td>
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<tr>
<td><strong>Right hip</strong></td>
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<tr>
<td>Mean $\alpha$ angle (°)</td>
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<tr>
<td>Minimum</td>
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<td>Maximum</td>
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<td>SD</td>
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* p-value, independent samples $t$-tests
† 95% CI, 95% confidence interval

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<th>Table II. Suggested normal, borderline and pathological threshold values (°) of the femoral head-neck junction anteroposterior $\alpha$ angle</th>
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<tr>
<td><strong>Normal</strong></td>
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<td><strong>Borderline</strong></td>
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<td><strong>Pathological</strong></td>
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<th>Table III. The distribution of gender-related differences and inter-relationships of hump malformation in 2803 standardised, anteroposterior pelvic radiographs according to the $\alpha$ angle (°), and the triangular index (TI)</th>
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<tr>
<td><strong>Men (n = 1055)</strong></td>
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<tr>
<td>Right hip hump $\alpha$ angle</td>
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<tr>
<td>Left hip hump $\alpha$ angle</td>
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<tr>
<td>Right hip hump TI</td>
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<tr>
<td>Left hip hump TI</td>
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* p-value, independent samples $t$-test
† OR, odds ratio
‡ 95% CI, 95% confidence interval
This reflected clinical experience and the underlying notion of a subclinical epiphyseal slip which occurs most commonly in boys. The widespread standard deviation (SD) of the male AP $\alpha$ angle, although it was calculated from 2110 hips, again reflected that hump malformation is principally a male condition. The SD of the female AP $\alpha$ angle was nar-
However, applying these SDs and noting that the $\alpha$ angles were strictly distributed according to the normal Gaussian distribution, the normal threshold is the mean plus 1 SD and the borderline range is between the normal plus two SDs. Any value in excess of this is analogous to the CE angle of Wiberg, where most authors consider a CE angle $\leq 20^\circ$ to be definitely pathological, between $20^\circ$ and $25^\circ$ as possibly dysplastic and $\geq 25^\circ$ as normal.

The results of applying these predefined limits for a pathological AP $\alpha$ angle and the calculation of the proposed triangular index on the radiological material are summarised in Tables III and IV. There were no inherent properties of borderline malformation in the concept of the triangular index. Either the radius of the femoral head increases laterally and is therefore aspherical at a predefined distance along the axis of the femoral neck from the centre of the femoral head ($1/2 r$) with enlargement of more than 2 mm, or this deformity is absent. When applying the triangular index, the incidence of hump malformation in this selected material occurred in approximately 40% of these patients had hump malformations to a varying degree.

In Table VI the AP and lateral inter-relationships of the $\alpha$ angle, and the triangular index are presented. From the AP radiographs the incidence of false-negative hump malformation ranged between 3% and 10%.

We found that hump malformation was present in 42% of the radiographs of patients scheduled for THR. The majority of the hump malformations were clearly assessed on the AP radiographs alone; in 3.1% (2) of the hump cases in men, and in 5.4% (4) of these cases in women, malformation was only present on the lateral projection.

Geometrical analysis of femoral specimens subjected to stepwise radiological measurement. The relationship between the axial rotation of two femoral specimens with typical anterolateral hump malformation and the resulting change in the $\alpha$ angle and triangular index is presented in Figure 5. Because of the complex three-dimensional (3D) properties of the hump, the $\alpha$ angle lost its ability to detect asphericity of the femoral head in the AP plane with both increasing external and internal rotation of the femur from the starting position. However, the triangular index remained relatively unaltered between $20^\circ$ of internal rotation and $20^\circ$ of external rotation.

In Figure 6, the relationship between the axial rotation of four of the normal femoral specimens and the resulting changes in the $\alpha$ angle and triangular index is presented. Again, the $\alpha$ angle is variable while the triangular index does not present false-positive results.

Reliability. The interclass coefficient for the triangular index was 0.95 and for the $\alpha$ angle 0.83. The intraclass coefficient for the triangular index varied between 0.97 and
between the two observers (KKG and HP), and between 0.90 and 0.96 for the $\alpha$ angle.

Discussion

We believe that our results show that the hump malformation of the femoral head-neck junction which causes cam impingement, is detectable to an acceptable level on standardised AP pelvic radiographs in which excessive malrotation of the pelvis and the hip is avoided, especially when applying the triangular index radiological index for asphericity of the femoral head.

Generally, the $\alpha$ angle, originally developed to describe the hump malformation in coronal MR slices, is used in the current literature on this subject.20,23 In the study of Notzli et al.,20 normal and pathological limits of the $\alpha$ angle were obtained by investigating the MR images of 35 asymptomatic subjects with negative impingement tests and no history of hip symptoms, and defined a threshold of approximately 65°. However, the genders were pooled. By modifying the $\alpha$ angle to the AP plane, we have demonstrated that there are significant gender-related differences in the assessment of the $\alpha$ angle. Since the underlying condition of hump malformation is believed to be a partial epiphyseal slip, such a difference should be expected as cam impingement is much more prevalent in men, both clinically and radiologically. However, precise delineation of the pathological and normal situations has not been described in the literature because the SD of a large representative cohort
of randomly selected symptomatic and asymptomatic subjects has not been estimated. To evaluate the absolute and relative importance of cam malformation for premature development of OA against other known risk factors, it is pertinent that asphericity of the femoral head can be determined in large collections of historical radiographs.

The \( \alpha \) angle can be under-estimated in AP radiographs of the hip when the rotation is not controlled. The triangular index can be used as another geometrical discriminator for hump malformation and asphericity of the femoral head. We believe that it offers the benefit of being purely geometrical using fixed reference points, while the \( \alpha \) angle is difficult to pinpoint. The exact site at which the radius of the aspherical femoral head leaves the inherent radius and increases laterally on a curved surface is not easy to define. There is no notion of intermediate or borderline pathology in regard to the triangular index, and it has slightly better intra- and interobserver reproducibility than the \( \alpha \) angle. It displays the same gender-specific differences as the \( \alpha \) angle.

In our study of 164 patients (164 hips) scheduled for THR and with standardised lateral and AP radiographs, we found that 42% of the 164 hips had hump malformation. There was good agreement between the lateral and the AP radiographs and only 3% of humps in men and 5.5% of those in women could not be detected in the AP radiographs using the \( \alpha \) angle. In other words, the proportion of false-negative assessments of hump malformation, when studying well-positioned AP radiographs alone was acceptable. The results, when applying the triangular index, were comparable.

In the study on the femoral specimens we demonstrated that the normal hip does not become abnormal during rotation using the triangular index while the \( \alpha \) angle was more variable. In the two abnormal specimens, the triangular index did not become normal within 20˚ of internal rotation and 20˚ external rotation while the \( \alpha \) angle was variable.

In summary, we believe that most hump malformations at the femoral head-neck junction are readily identifiable on AP pelvic radiographs provided that these are recorded under standardised conditions, especially if supported by the triangular index. This should make it feasible to study the epidemiology of cam impingement in appropriate historical radiographs.

We gratefully acknowledge the painstaking work of radiographers J. Madelung and H. Ipsen in recording the radiological substrate of this and all our other studies.

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References