

THE ASSOCIATION BETWEEN HIP MORPHOLOGY PARAMETERS AND 19-YEAR  
RISK OF END-STAGE OSTEOARTHRITIS IN THE HIP: A NESTED CASE-CONTROL  
STUDY

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## ABSTRACT

Subtle deformities of the hip joint are implicated in the aetiology of osteoarthritis (OA) of the hip. Parameters that quantify these deformities may aid understanding of these associations. This study examined relationships between such parameters and 19-year risk of total hip arthroplasty (THA) for end-stage OA.

A new software program designed for measuring morphological parameters around the hip was developed and validated in a reliability study. THA was the outcome measure for end-stage OA. A nested case-control study was used with individuals from a cohort of 1003 women who were recruited at year 1 in 1989 and followed to year 20 (The Chingford study). All hips with THA by year 20 and 243 randomly selected control hips were studied. Pelvis radiographs taken at year 2 were analyzed for variations in hip morphology. Measurements were compared between the THA case group and the control group.

THA cases had a higher prevalence of cam deformity (median alpha angle  $62.4^{\circ}$  versus  $45.8^{\circ}$ ,  $p=0.001$ ; mean modified triangular index 28.5mm versus 26.9mm,  $p=0.001$ ), and acetabular dysplasia (mean lateral centre edge angle (LCE)  $29.5^{\circ}$  versus  $34.3^{\circ}$ ,  $p=0.001$ ; median extrusion index 25.0% versus 18.5%,  $p=0.009$ ). Logistic regression analyses clustering by subject and adjusting for radiographic hip OA at year 2 showed that these morphological parameters were still significantly associated with THA by year 20. The alpha angle and LCE predicted the risk of THA independently when included in the same model.

This investigation describes measurements that predict the risk of THA for end-stage OA by year 20, independently of the presence of radiographic hip OA at year 2. These measurements can be made on an AP pelvis radiograph which is an inexpensive and commonly used clinical investigation.

## INTRODUCTION

Epidemiological studies indicate that osteoarthritis (OA) of the hip frequently occurs in the absence of OA in other large joints, suggesting that local factors are important in its pathogenesis<sup>1-5</sup>. Drawing on earlier published theories<sup>6,7</sup>, Harris<sup>8</sup> suggested that subclinical biomechanical factors may be important in the development of hip OA. He rebuked theories that the majority of hip OA cases were “primary”, or “idiopathic”, and hypothesised that abnormal hip morphology predates onset of OA and is not secondary to the arthritic process<sup>8</sup>. Several studies<sup>9-13</sup> have since provided evidence to support this hypothesis.

Specific abnormalities of hip morphology are now recognised as biomechanical risk factors for the development of OA of the hip<sup>8-11,14</sup>. The predominant mechanisms are acetabular dysplasia, whereby the shallow acetabulum results in focal loading of articular cartilage beyond its physiological tolerance<sup>10</sup>, and femoroacetabular impingement<sup>3,14</sup>, which occurs as a consequence of abnormal contact between the acetabular rim and femoral head-neck junction, resulting in damage to the chondral surface and labrum. Together with improved understanding of these deformities, parameters have been introduced to quantify them and enable classification of patients presenting with early hip disease<sup>6,15-19</sup>.

Whilst associations of abnormal morphology and OA are established<sup>13</sup>, prospective longitudinal data which may provide more convincing evidence of a causal relationship, particularly in relation to femoroacetabular impingement, is lacking. If subclinical deformities can be shown as effective predictors of OA in the general population, it may be possible to identify hips that are at risk before they progress to end-stage OA, necessitating total hip arthroplasty. In addition, clinical trials of both surgical<sup>20</sup> and medical treatments for at risk hips will mandate accurate morphological classification.

Anteroposterior (AP) pelvis radiographs are the most commonly used imaging modality for hip joints because they are inexpensive, readily accessible and available in large study cohorts<sup>21-25</sup>. Not only are they the OARSI recommended gold standard for assessment of progression of hip OA<sup>26</sup>, but they enable the recognition and quantification of deformities associated with dysplasia and femoroacetabular impingement<sup>1,8-11,14-16,23,27</sup>.

The present study validated a new software model for rapidly quantifying morphological parameters of the hip joint on an AP pelvis radiograph. This software was then used to analyse the AP pelvis radiographs of a healthy group of women, selected from the population using a random number generator. These same volunteers were then followed up for 19 years and records of any total hip arthroplasty (THA) performed for end-stage OA were gathered. The aim of the study was to identify any relationship between morphological parameters in the hip joint at baseline and risk of THA during the follow-up period.

## DATA AND STATISTICAL METHODS

### *Subjects*

In 1989, all women between 44 and 67 years of age who were registered at a London-based general practice were asked to take part (The Chingford study<sup>28,29</sup>). 1003 subjects participated in yearly clinic visits from year 1 to year 10 at which time morphometric, clinical, biological and radiological measurements were taken. Each woman had an anteroposterior (AP) pelvis radiograph taken at year 2. These radiographs were performed with the patient in the supine position and a small sand bag under the knees to minimize hip rotation. In subsequent years, clinic visits were less frequent, however telephone questionnaires were continued annually through to the present day (year 20). These included details of any operations undergone in the previous year. Validation of cases that had undergone THA for end-stage OA was done by contacting the patient's general practitioner and checking the medical records at the hospital at which the surgery was performed.

The present study selected all cases from the original cohort that had undergone THA between year 2 and 20 (40 hips in 31 individuals). A further 114 individuals who had not undergone THA were selected using a random number generator as the control group. Thus in total, 290 hips in 145 individuals were initially selected for study.

### *Exclusions*

Exclusion criteria were applied to ensure that year 2 radiographs were of a minimum acceptable quality standard to be included in the present study. From the starting cohort of 1003 individuals, 4 hip joints (2 individuals) were excluded due to poor radiograph quality. Poor radiograph quality was a subjective exclusion criteria applied by the principle investigator when a radiograph was either grossly over- or under-exposed to the extent that constituent anatomic landmarks were not visible for the purposes of analysis. 3 hip joints (2 individuals) were excluded because they already had a THA in situ. 1 hip joint was excluded because it had a dynamic hip screw (DHS) in situ, indicating previous femoral neck fracture. 24 hip joints (12 individuals) were excluded because they had excessive tilt,

measured by the distance between the sacrococcygeal joint and pubic symphysis<sup>30,31</sup>. In total 32 hips in 17 individuals were excluded. Of the 32 excluded hips, 22 happened to be in the selected THA and control cohorts, leaving 25 hips that had undergone THA and 243 hips that had not.

#### *Radiographic assessment of morphology*

Hip morphology was analysed using a Matlab based software package (Matlab R2009b, The MathWorks, Natick, MA, USA) called Hip Morf 2.0. A prototype (Hip Morf 1.0) has been used in previous cohort studies at our institution<sup>19,32</sup>. The software allowed the user to click on each of the constituent anatomical landmarks needed to measure several morphological parameters. Once all landmarks had been identified, the necessary angle, ratio and linear measurements were automatically calculated. We selected a large group of commonly used morphological parameters to be included in this process, all of which are listed in table 2. Each radiograph was anonymized and read independently by two investigators.

#### *Reliability study*

A formal reliability study was performed on anonymized AP pelvis radiographs. Intraobserver 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. Morphological measurements were compared using interclass correlation coefficients (ICC) for continuous data and Kappa analysis for the Triangular index which has a binary outcome.

#### *Statistical analysis*

For each morphological measurement, the mean measurement from the two investigators was calculated to reduce variability in the data. This was justified because the reliability study demonstrated good agreement (see results). Normally distributed variables were compared using the independent two tail t-test; non-normal variables by the Wilcoxon rank sum test and categorical data using Fisher's exact test. Where positive associations were identified with THA, logistic regression analysis was performed using THA as a binary outcome. The model adjusted for baseline height,

BMI, age, joint space narrowing and osteophyte grading. The Triangular index<sup>16</sup> is reported as a binary outcome. Therefore, in order to enable this variable to be included in regression analyses, a modification was used whereby the actual distance R was recorded as the Modified Triangular Index Height (MTIH, in mm, see figure 1). A long distance R implies a tendency to cam deformity.

Parameters that were statistically significant in the regression model were then combined in further multivariate analyses, using all of the same covariates, to assess whether they were independent predictors of THA. Logistic regression analyses was used with robust standard errors and clustering of hips by subject identifier code to account for the dependency of two hips from one subject. With 80% power at the 5% significance level, the present study was able to detect a percentage change of 8.8% in the extrusion index ratio measurements, 2.72° in the acetabular index (HTE), 1.69 in the modified triangular (Gosvig<sup>16</sup>) index (MTIH), 12.02° in alpha angle and 4.47° in Lateral Centre Edge (LCE) Angle.

Because both acetabular under-coverage (dysplasia) and over-coverage (pincer deformity) are implicated in the aetiology of OA, kernel density plots were produced for the LCE and acetabular index (HTE), in order to evaluate the distribution of data.

All statistical analysis was conducted using Stata SE v10, StataCorp, College Station, TX, USA and Matlab R2009b, The MathWorks, Natick, MA, USA.

## RESULTS

The baseline clinical characteristics of the subjects included in this study (n=135) were representative of the whole 'Chingford 1000 Women Study' (n=1003 subjects) as shown in table 1. The cases were significantly older and taller at baseline than the controls as shown in table 2. Cases also had a smaller JSW than controls.

A number of morphological variables were initially identified as being significantly associated with 19-year THA risk in univariate analyses (table 2). These included a number of proximal femur measures; the alpha angle, triangular index (and its modification, MTIH), and femoral neck width were all greater in cases whereas the femoral head to neck ratio was greater in controls. These results may be summarised as demonstrating a higher prevalence of cam deformity in the cases. In addition, a number of acetabular measures were significantly associated; the LCE and the HTE were smaller in cases whereas the extrusion index was greater in cases. These results may be summarised as demonstrating a tendency towards acetabular dysplasia in the cases. Potentially, a subgroup of the THA cases could have had acetabular over-coverage (pincer deformity) which would be offset by the remaining cases being dysplastic and obscured by calculation of the mean or median values. However, the kernel density plots (figure 2) do not demonstrate a clear bimodal distribution in the THA cases.

Multivariate analysis using logistic regression (table 3) revealed that the alpha angle, HTE, LCE and extrusion index remained significantly associated with THA after adjusting for age and BMI, whereas other morphology variables lost statistical significance. These morphological variables were then additionally adjusted for baseline radiographic OA evident at year 2 (osteophytes and joint space narrowing). There was little effect on the association of the alpha angle, LCE, or extrusion index; however the HTE became non-significant on adjusting for the presence of osteophytes. This indicates that the alpha angle, LCE, and extrusion index were independently associated with the development

of end-stage OA requiring THA by year 20, regardless of epidemiological variables or pre-existing OA at year 2.

In order to assess whether these morphological variables were independent of each other in predicting the need for THA, alpha angle and LCE were added in to the model. The addition of further variables would have resulted in over-fitting of the model and loss of statistical validity. Spearman correlation indicated a close association of extrusion index and LCE ( $r = -0.77$ ,  $p < 0.001$ ) as would be expected as they both measure acetabular coverage. Therefore extrusion index was dropped from the model. Based on 268 hips, for the alpha angle as an independent predictor of THA, the percentage increase in risk of THA per degree increase in alpha angle was 5.8% (95% CI 2.3% to 9.3%,  $p < 0.001$ ). For the LCE as an independent predictor of THA, the percentage increase in risk of THA per degree reduction in LCE was 10.5% (2.0% to 18.2%,  $p = 0.017$ ).

#### *Reliability study*

Table 4 demonstrates that the levels of agreement were good for the key morphological variables identified from table 2 and the subsequent regression analysis, supporting the reliability of measurements.

## DISCUSSION

This unique population-based study demonstrates that measures of hip joint morphology are associated with THA for end-stage OA over a follow up period of 19 years in middle-aged and elderly women. These measures predict THA independent of evidence of baseline radiographic OA and more importantly of each other. This suggests that it may be worth assessing these simple to measure variables on standard radiographs to assess a woman's risk of later need for THA.

Cam deformities may be assessed on an AP pelvis radiograph by the alpha angle<sup>18,33</sup> or triangular index<sup>16</sup>, which measure asphericity of the head, or the head-neck ratio which indicates offset at the head neck junction<sup>19</sup>. Because cam deformities involve the anterolateral aspect of the head-neck junction, the AP pelvis radiograph is not necessarily the optimum projection to visualise abnormality<sup>33</sup>. The triangular index was introduced as an alternative to measurement of the alpha angle from an AP pelvis radiograph, and is less sensitive to varying femoral rotation, although both are highly inter-related<sup>16</sup>. The results from the present study demonstrate that the alpha angle measured on an AP pelvis radiograph has a significant independent association to future risk of THA and thus is a useful clinical tool that can be used in assessing risk of THA for end-stage OA.

Historically, cam deformities have been termed 'pistol-grip'<sup>34</sup>, and 'head-tilt'<sup>35</sup>. Previous literature related to the importance of a cam deformity in relation to OA is limited in its quality. The majority of studies are based on selected cohorts of patients with known childhood hip disease, OA or hip pain, and usually do not have radiographs of the subjects involved before the development of symptoms or OA<sup>1,12,34-37</sup>. There are two large population-based studies, by Gosvig et al<sup>13</sup> and Doherty et al<sup>38</sup>, which have clearly associated the presence of cam deformity with OA. However, both studies are limited because of their cross-sectional nature, compared to ours with 19 year follow-up. Furthermore, the outcome measure for OA in the study by Gosvig et al<sup>13</sup> was joint space narrowing. In the context of the projected increase in burden of THA<sup>39</sup>, we consider THA to be a more clinically important surrogate marker of end-stage OA. Lynch et al<sup>40</sup> conducted a nested case-control study from a longitudinal cohort of elderly women (Study of Osteoporotic fractures) and examined associations of

incident hip OA with variations in proximal morphology, assessed by active shape modelling. They found no association of incident OA and 'pistol-grip' shaped hips. It should be noted that this cohort was rather older than ours at baseline (mean 71 years), and the follow-up was shorter (8 years). Interestingly, from an analysis of the same cohort, Javaid et al<sup>41</sup> noted that increased femoral neck width was associated with prevalent and incident OA. This finding is in keeping with our data.

Acetabular dysplasia has long been recognised as a risk factor for OA. The lateral centre edge (LCE) angle was first described by Wiberg<sup>6</sup> in 1939 as a quantitative measure of dysplasia and found to be associated with an increased risk of OA when the angle was <20 degrees. However, the evidence from subsequent case control<sup>42,43</sup> and cross-sectional population-based<sup>13,44-47</sup> studies is variable. Longitudinal studies in selected cohorts have also found conflicting evidence to support the use of parameters such as the CEA, HTE, and extrusion index<sup>10,48</sup>. One population-based study with 8 year follow-up found that the CEA was independently associated with the development of OA<sup>11</sup>. These data are in keeping with those of our study.

Acetabular over-coverage (pincer deformity<sup>23</sup>) has been linked to OA<sup>14</sup> and may also be described by the same parameters as dysplasia. This study demonstrated that LCE had a significant independent association to future risk of THA and was demonstrated as an inverse relationship, meaning that in this population it was subclinical dysplasia rather than pincer deformity that predicted THA. It is possible that a small proportion of the THA cases may have developed end-stage OA secondary to a pincer deformity. Potentially such cases with pincer deformity could have been obscured by the majority being dysplastic, however the kernel density plots did not show a bimodal distribution to support this contention. However, it is plausible that in larger cohorts such a relationship may become apparent.

There is an abundance of literature that links radiographic OA grade to risk of future THA<sup>5</sup>. The purpose of measuring baseline (year 2) radiographic OA in the present study was so that effect size of morphological parameters could be adjusted for baseline prevalence of OA in order to assess the independence of morphology on risk of THA. This is important because in early OA, secondary osteophyte formation at the femoral head-neck junction may be misinterpreted as a cam deformity. In late OA, femoral head collapse and osteophyte may produce a 'pistol-grip' appearance<sup>49</sup>. Therefore it is important to account for this potential source of error in the analysis. As demonstrated earlier, there was a higher baseline prevalence of radiographic OA in the case group than in the control group, which undoubtedly contributed to those individuals in the case group undergoing THA during the 19-year follow-up period. However, the effect size of the morphological variables remained significant even after the baseline OA was taken into account. Ideally, our baseline assessment of morphology in this cohort would have occurred at the onset of skeletal maturity. This would clarify the association of the cam deformity and OA, and potentially confirm a causal relationship. There are no studies that have tracked cases from the onset of skeletal maturity. Pollard et al<sup>32</sup>, in a sibling study of femoroacetabular impingement, noted that many siblings of patients treated for cam impingement also had cam deformities themselves, in the absence of degenerative change. This observation, together with the findings in the current study, suggests that a cam deformity may predate alterations in morphology due to OA. We are not aware of any other study that has demonstrated this independence of morphological variables to radiographic OA on the risk of THA. Furthermore, there are no previous data to indicate that these significant parameters are independent of each other. This study has clearly demonstrated that the alpha angle and LCE represent measurements that are important in predicting THA risk individually.

This study has a number of potential limitations. Although AP pelvis radiographs have obvious limitations over three-dimensional modalities when assessing joint morphology, they are inexpensive, easily accessible, and available in hundreds of thousands of patients worldwide, often taken for other reasons. In addition, pelvis radiographs are available in many other large cohort study populations.

The authors recognize that THA is a surrogate measure of end-stage OA in the hip. Other measures of OA include clinical severity scoring and radiographic grading, both of which may also be argued to be surrogate measures of disease state. THA is a surgical end-point that has been previously validated as an OA outcome measure<sup>50</sup> and is highly relevant to both patient and practitioner as it indicates progression to end-stage disease. It should be noted that the UK has a taxpayer-funded public health system, and thus all individuals in the present study may be considered to have equal access to THA with no personal expense. A limitation of this study was that our cohort consisted only of females, and therefore the results may not be applicable to males. The incidence of a cam deformity in the asymptomatic male population approaches 20%<sup>32</sup>, and it is currently not known why only a proportion of these individuals develop pain or OA. These findings therefore need to be reproduced in other populations.

In conclusion, a new software package called Hipmorf 2.0 was developed and validated. It measures 23 morphological parameters around the hip joint. Hipmorf 2.0 was used to investigate the relationship between variations in hip morphology and 19 year risk of THA for end-stage OA in the hip in a group of 145 women. THA was used as the only outcome measure in assessing whether an individual had developed end-stage OA. The present study found that the presence of a cam deformity, or acetabular dysplasia, as assessed by specific parameters, was significantly associated with future risk of THA, even after those parameters were adjusted for baseline height, age, BMI and radiographic OA. An increase in alpha angle of one degree independently equated to a 5.8% increase in 19-year risk of THA. Similarly, each one-degree reduction in LCE equated to a 10.5% increase in 19-year risk of THA. Each of these morphological parameters may be important predictors that can be simply used in an outpatient setting to assist in stratifying risk of future THA. These findings justify further investment in research investigating the role of early surgery which addresses such deformities and its efficacy in reducing the need for THA.

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## TABLES

Table 1. Baseline characteristics

Baseline characteristics	Full cohort (n=1003)	Subjects used in this analysis (n=135)	Subjects not used in this analysis (n=868)	Selection bias p-value
Age (years) median (IQR)	54 (49,60)	55 (50,60)	54 (49,59)	0.099
Height (m) mean (s.d.)	1.62 (0.059)	1.61 (0.057)	1.62 (0.060)	0.174
Weight (kg) median (IQR)	65 (58.5,73)	65.5 (59,71.8)	65 (58.4,73.4)	0.662
BMI (kg.m <sup>-2</sup> ) median (IQR)	24.86 (22.63,27.61)	24.83 (22.88,27.32)	24.87 (22.59,27.63)	0.870
Waist Circumference (cm) median (IQR)	77 (71,83.5), (n=992)	78 (71,84), (n=133)	76 (71,83), (n=859)	0.388
Hip Circumference (cm) median (IQR)	100 (95,106), (n=991)	100 (95,106), (n=133)	100 (95,106), (n=858)	0.755
Smoking Status (% current or ex-smoker)	46.2%	41.5%	46.9%	0.374
Physical Activity Score (3 (bad) to 12 (good)) median (IQR)	7 (6,8), (n=991)	7 (6,8), (n=134)	7 (6,8), (n=857)	0.438

[s.d.: standard deviation; IQR: interquartile range; \*p-value<0.05]

Selection bias (subjects used in this analysis versus subjects not used) is determined using the two-tail independent t-test for normally distributed data with mean(s.d.); for non-normal data with median (IQR) the Wilcoxon rank sum test is used; for categorical data expressed in percentages, the Chi-square test is used.

Table 2. Morphological predictors of THA.

Of the 290 hips (145 subjects) studied, 22 hips were removed due to an exclusion criteria. The remaining 268 hips (135 subjects) comprised of a case group with THA (n=25) and a control group without THA (n=243).

	Control group without THA (n=243 hips)	Case group with THA (n=25 hips)	p-value
<b>Characteristics</b>			
Age (years), median (IQR)	55 (49,59)	58 (54,61)	0.012*
Height (m), mean (s.d.)	1.61 (0.057)	1.64 (0.05)	0.015*
Weight (kg), median (IQR)	65.5 (58.7,71.8)	68 (61,80.2)	0.078
<b>Pelvis</b>			
Distance between centre of femoral heads (mm), median (IQR)	226.04 (217.97,232.56)	230.69 (225.63,240.97)	0.004**
Inter-acetabular width (mm), median (IQR)	153.52 (146.98, 158.85)	157.88 (154.20,162.88)	0.011*
<b>Acetabulum</b>			
Acetabular Width (mm), median (IQR)	61.3 (59.23,63.86)	62.45 (59.39,64.38)	0.401
Acetabular Depth (mm), mean (s.d.)	23.47 (3.53)	23.63 (3.32)	0.832
Acetabular Depth to Width (ratio), mean (s.d.)	0.381 (0.053)	0.380 (0.402)	0.937
Lateral Centre Edge Angle (degrees), mean (s.d.)	34.32 (6.77)	29.54 (7.68)	0.001**
Extrusion Index (ratio), median (IQR)	0.185 (12,25)	0.25 (17,34)	0.009**
Acetabular index (HTE) (degrees), median (IQR)	4.125 (2.4,6.39)	5.32 (2.74,10.83)	0.013*
Sharpe's Angle (degrees), median (IQR)	37.24 (34.62,39.53)	38.37 (35.58,39.68)	0.490
Acetabular Tilt (degrees), median (IQR)	55.25 (51.65,57.72)	56.08 (52.23,59.59)	0.218
<b>Proximal femur</b>			
Femoral head diameter, median (IQR)	54.99 (52.93,57.25)	55.54 (53.34,58.35)	0.217
Modified Triangular (Gosvig) Index – Height, mean (s.d.)	26.92 (2.22)	28.53 (2.94)	0.001**
Alpha Angle, median (IQR)	45.75 (43.29,53.95)	62.35 (46.52,83.6)	0.001**
Femoral neck width (min), median (IQR)	301.12 (287.86,317.94)	324.76 (310.61,381.25)	<0.0005***
Femoral neck length, median (IQR)	54.47 (49.50,57.68)	56.02 (52.47,59.92)	0.195
Femoral neck length to width ratio, median (IQR)	0.179 (0.161,0.198)	0.168 (0.147,0.190)	0.051
Femoral head to neck ratio, median (IQR)	0.183 (0.175,0.189)	0.172 (0.153,0.178)	<0.0005***
Femoral neck shaft angle (FNSA), median (IQR)	129.88 (126.06,133.89)	130.17 (126.95,134.68)	0.375
Modified proximal femoral angle (MPFA), median (IQR)	82.79 (78.53,85.88)	83.01 (80.75,86.97)	0.318
<b>Other</b>			
Minimum JSW, median (IQR)	3.85 (3.67,4.33)	3.60 (2.99,4.03)	0.026*
<b>Dichotomous variables</b>			
Protrusio acetabuli, %	0.82%	0.00%	0.822
Coxa Profunda, %	52.67%	48.99%	0.192
Crossover sign (acetabular retroversion), %	4.53%	0.00%	0.333
Triangular (Gosvig) Index, %	3.29%	32.00%	<0.0005***

The two tail independent t-test used for normally distributed data; the independent Wilcoxon rank sum test used for non-normal data; and the Fisher's exact test was used for categorical data; \*p-value<0.05, \*\*p<0.01, \*\*\*p-value<0.0005.

Table 3. Logistic regression analysis

The odds ratio's are calculated using THA by year 20 (outcome) and morphological parameters at year 2 (exposure); n=268 (hips)

Morphological parameter	No adjustment OR (p-value)	Adjusted by height OR (p-value)	Adjusted by bmi OR (p-value)	Adjusted by bmi and age OR (p-value)	Adjusted by age and JSN OR (p-value)	Adjusted by age and OP OR (p-value)
Extrusion Index, (ratio)	1.056 (0.002)**	1.056 (0.002)**	1.056 (0.002)**	1.061 (0.001)**	1.063 (0.007)**	1.064 (0.005)**
HTE, (degrees)	1.131 (0.021)*	1.144 (0.052)	1.137 (0.013)*	1.161 (<0.0005)***	1.151 (0.007)**	1.121 (0.093)
MTIH, (mm)	1.306 (0.011)**	1.242 (0.083)	1.302 (0.011)*	1.291 (0.011)*	1.296 (0.008)**	1.195 (0.114)
Alpha Angle, (degrees)	1.056 (<0.0005)***	1.052 (0.001)**	1.056 (<0.0005)***	1.057 (<0.0005)***	1.052 (0.001)**	1.0452 (0.006)**
LCE, (degrees)	0.906 (0.004)**	0.906 (0.004)**	0.903 (0.003)**	0.887 (0.002)**	0.880 (0.001)**	0.891 (0.004)**

HTE: Horizontal Toit Externe, synonomous with acetabular index; MTIH: Modified triangular index height; LCE: Lateral Centre Edge Angle; JSN: Baseline Joint Space Narrowing; OP: Baseline Osteophytes; OR: Odds Ratio, \*p-value<0.05, \*\*p<0.01, \*\*\*p-value<0.0005

Table 4. Inter-observer reproducibility and intra-observer repeatability

<i>Parameter</i>	<i>Coefficient</i>	<i>Inter-User Agreement</i> <i>(left hip, right hip)</i>	<i>Intra-User Agreement</i> <i>(left hip, right hip)</i>
Lateral centre edge angle	ICC <sup>†</sup>	0.86, 0.63	0.95, 0.97
Extrusion index	ICC <sup>†</sup>	0.89, 0.80	0.95, 0.98
HTE	ICC <sup>†</sup>	0.74, 0.61	0.96, 0.94
Triangular Index	Kappa <sup>‡</sup>	0.74, 0.74	0.74, 0.78
Alpha angle	ICC <sup>†</sup>	0.64, 0.52	0.77, 0.85

(<sup>†</sup>) inter-user agreement based on ten subjects, three raters; intra-user agreement based on ten subjects, one rater (three repeated measures)

(<sup>‡</sup>) inter-user agreement based on ten subjects, two raters; intra-user agreement based on ten subjects, one rater (two repeated measures)

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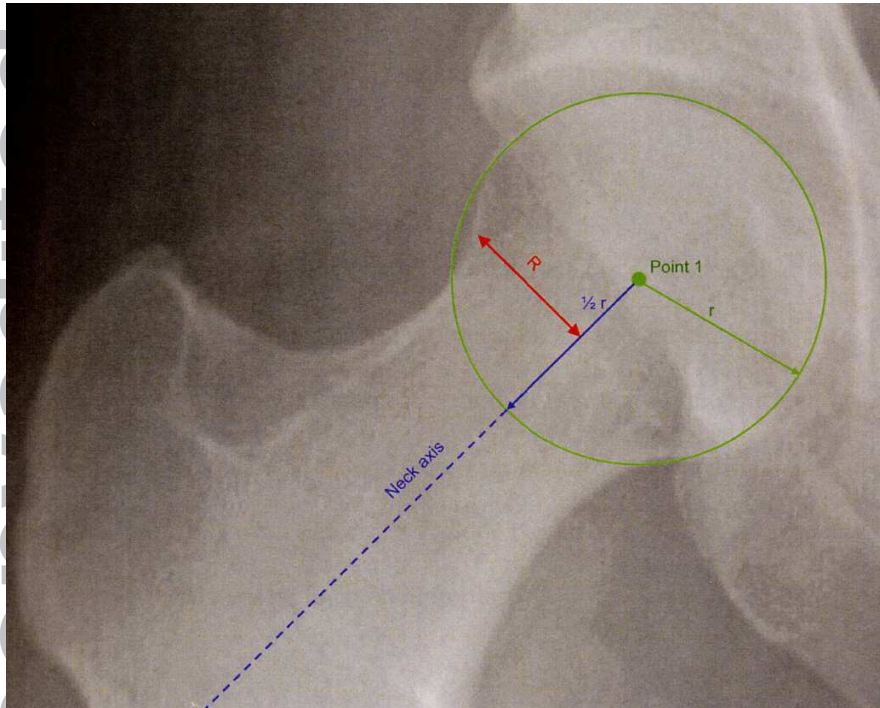


Figure 1. The Modified Triangular Index Height (MTIH) is the measurement  $R$ , recorded in mm.

In the original description of the Triangular Index<sup>16</sup>, if  $R > r + 2\text{mm}$ , a cam deformity is diagnosed.

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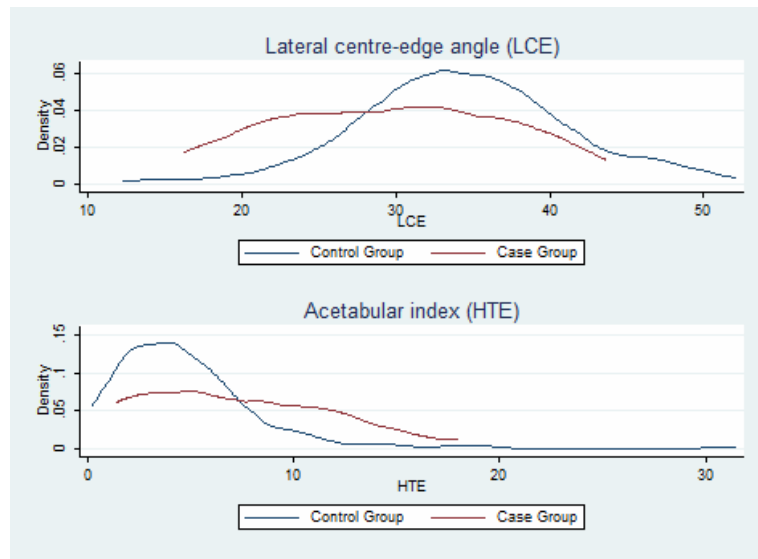


Figure 2. Kernel density plots of lateral centre-edge angle and acetabular index (HTE).