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## Population-based prevalence of multiple radiographically-defined hip morphologies: The Johnston County Osteoarthritis Project

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### Abstract

**Objective**—To provide the first prevalence estimates of different radiographic hip morphologies relevant to dysplasia and femoroacetabular impingement in a well-characterized U.S. population-based cohort.

**Methods**—Cross-sectional data were from the baseline examination (1991–1997) of a large population-based prospective longitudinal cohort study (The Johnston County Osteoarthritis

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### CONTRIBUTIONS

1. Conception and design: TAS, NKA, JMI, AEN; Acquisition of data: RR, JLS, JBR, NKA, JMI, AEN; Analysis and interpretation of data: RR, JLS, CA, JBR, TAS, NKA, JMI, AEN.
2. Drafting the article: RR, JLS, CA, TAS, AEN; Critical revisions for intellectual content: RR, JLS, CA, JBR, TAS, NKA, JMI, AEN.
3. Final approval of the version to be submitted: all authors.

### COMPETING INTERESTS:

The authors declare no conflicts of interest relevant to this work.

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Project). HipMorf software (Oxford, UK) was used to assess hip morphology on AP pelvis radiographs. Weighted, sex-stratified prevalence estimates and 95% confidence intervals for 4 key hip morphologies (AP alpha angle, triangular index sign, lateral center edge angle (LCEA), and protrusio acetabula) were derived and further stratified by age, race and BMI.

**Results**—A total of 5192 hips from 2596 individuals were included (31% African American, 43% male, mean age 63 years, mean BMI 29 kg/m<sup>2</sup>). Cam morphology was seen in more than 25% of men and 10% of women. Mild dysplasia was present in about 1/3 of men and women, while pincer morphology was identified in 7% of men and 10% of women. Femoral side (cam) morphologies were more common and more frequently bilateral among men, while pincer morphologies were more common in women; mixed morphologies were infrequent. African-Americans were more likely to have protrusio acetabula than whites.

**Conclusion**—We report the first population-based prevalence estimates of radiographic hip morphologies relevant to FAI and dysplasia in the U.S. These morphologies are very common, with ¼ men and 1/10 women having cam morphology, 1/3 of all adults having mild dysplasia, and 1/15 men and 1/10 women having pincer morphology in at least one hip.

### Keywords

Femoroacetabular impingement; cam/pincer morphology; radiography; epidemiology; osteoarthritis

## INTRODUCTION

Osteoarthritis (OA) is a major cause of disability in the US and is the most prevalent form of arthritis.[1] OA itself is the end-result of many potential risk factors.[2] Variation in hip morphologies is one risk factor that is of increasing interest due to risk of subsequent early-onset OA.[3] Some portion of what was previously thought to be primary hip OA may be secondary to morphologic abnormalities.[4]

Variations in hip morphologies can be associated with abnormal joint articulation and degradation of cartilage.[2, 3, 5] Hip dysplasia, in particular, is a known risk factor for the development of labral degeneration and early hip OA.[6] Other morphologies in the non-dysplastic hip have been identified as cam (abnormal femoral head and/or neck), pincer (acetabular overcoverage) or mixed morphologies.[5, 7–9] The mismatch between the femoral head and the acetabulum can lead to symptomatic impingement of the joint, known as femoroacetabular impingement (FAI) syndrome [9] and subsequent destruction of the articular cartilage of the femoral and acetabular surfaces.[7]

Evidence that these morphologies can be precursors to cartilage damage and resultant OA has been demonstrated by the distinct patterns of damage done by different morphologies.[2, 5, 8, 10, 11] The damage is secondary to the dynamic impingement process that results from the abnormal communication of the joint during movement.[11] It is still unclear how prevalent specific radiographic morphologies are, in the absence of OA or joint damage.[12]

Our current knowledge of hip morphologies comes primarily from the surgical literature, given the rise in procedures attempting to correct the structural abnormality.[13] Variations

in hip morphology have been studied amongst athletes, between genders, as well as in certain ethnic populations.[14–23] These studies, however, were limited to select populations such as symptomatic patients,[14, 15, 23] surgical patients,[17, 19, 23] women, [16, 21, 22] men,[24] convenience samples, [25–28] or were primarily white,[18] leaving a knowledge gap regarding hip morphologies in an unselected population of men and women. One study using a population-based birth cohort from Norway with a mean age of 18 years at the time of study reported a prevalence of cam morphology of 35% and 10%, and pincer morphology of 34% and 17%, in males and females respectively;[29] other truly population-based studies are lacking. Therefore, this study aims to provide prevalence estimates of radiographic hip morphologies in the U.S., using data from a well-characterized population-based cohort (which includes African-American and white men and women) with and without radiographic hip OA (rHOA).

## PARTICIPANTS AND METHODS

The Johnston County OA Project is population-based prospective longitudinal cohort study of OA and its risk factors based in Johnston County, NC, which is a rural area of 800 square miles with a population of 81,000 in 1990. Sampling methods have been previously described.[20, 30, 31] This cohort is representative of civilian, non-institutionalized African-American and white individuals 45 years or older. Briefly, the baseline sampling occurred from May 1991 through December 1997 and involved 2 steps: stratified simple random sampling of streets as primary sampling units and stratified subsampling of Caucasian women age 65 years or older. Sample weight calculation involved 3 steps, including raw weights from selection probability of streets, nonresponse adjustment from response propensity models, and post-stratification adjustment using strata defined by township, ethnic group, sex, and age group. In order to be considered for the project, participants had to be physically and mentally capable to follow the protocol and also be living in Johnston County for at least a year. The Johnston County OA Project has been continuously approved by the Institutional Review Boards of the University of North Carolina (UNC) and the Centers for Disease Control and Prevention; this radiographic analysis was addressed under the UNC IRB approval #11-1021.

The baseline protocol (1991–1997), from which these data are derived, entailed a home interview, one local clinic visit and a second home interview 2 weeks after the clinic visit. Age and race were self-reported. Height and weight were measured during the clinical visit and BMI was subsequently calculated from these values. Per protocol, all men had a supine anterior-posterior pelvic radiograph with feet in 15° internal rotation. Women younger than 50 years of age (of child-bearing potential) did not undergo pelvic radiography. Additionally, individuals weighing over 300lbs were excluded, due to radiography equipment limitations (Figure 1).

A single, experienced musculoskeletal radiologist (JBR) with high reliability (inter-reader [comparison with another expert reader]  $k$  0.859, intra-reader 0.886)[32] assessed all hips for Kellgren-Lawrence grade (KLG) without knowledge of any clinical or morphologic data. Radiographs were scored as KLG=0 in the absence of radiographic OA features; KLG=1 in the presence of a small osteophyte of doubtful significance; KLG=2 with an osteophyte but

no joint space narrowing; KLG=3 if there was moderate joint space narrowing; and KLG=4 if severe joint space narrowing was present, along with subchondral bone sclerosis.[33] Radiographic hip OA (rHOA) was defined as a KLG  $\geq 2$ ; individuals with one or both hips meeting this definition were defined as having rHOA for analyses (n=760).

OxMorf morphology software, which includes HipMorf, developed by the University of Oxford, was used to assess 23 aspects of hip morphology on the calibrated baseline hip films as we have previously reported.[20] HipMorf measurements have previously demonstrated high reproducibility and predictive validity for OA progression in other cohorts.[21, 22] We selected 4 key morphology features (Figure 2) to focus on for this analysis, including those associated with acetabular coverage (lateral center edge angle [LCEA], protrusio acetabula), and cam morphology (anteroposterior [AP] alpha angle, triangular index sign [34]). An AP alpha angle  $> 60^\circ$  [35] or the presence of a triangular index sign [34] were considered consistent with cam morphology. Dysplastic hips were defined when the lateral CEA was  $25^\circ$ , [15] with sensitivity analysis considering an alternate cut off of  $20^\circ$  (Supplemental Table D). Pincer morphologies were defined as lateral CEA  $> 40^\circ$  [15] or protrusio acetabula. Due to the possibility of position-related measurement error (even on standardized hip films [34]), prior to the final analysis, participants with hips with excessive tilt (sacrococcygeal [SC] joint to pubic symphysis distance  $> 50$  mm in men or  $> 80$  mm in women [36]) or pelvic rotation (obturator index  $< 0.6$  or  $> 1.4$  [34]) were identified and separately analyzed (n=338).[20]

### Statistical analysis

All analyses were performed using SAS-Callable SUDAAN (version 11.0.1) to produce population-weighted estimates and account for the complex survey design. The subset of interest (Figure 1) was analyzed as a subgroup of the initial n=3068 in the probability-based sample and all analyses were performed by combinations of excessive tilt or rotation, rHOA, and sex. We focused on and presented main results for the group (n=1,601) with normal pelvic alignment and no rHOA, by sex; the remaining groups' results (i.e. those with normal alignment and rHOA, n=657; those with tilt/rotation and no rHOA, n=235; those with tilt/rotation and rHOA, n=103) were produced and reviewed, though those data are not shown in full (see Supplemental Tables A–C). Unweighted and weighted baseline characteristics of the participants were evaluated and described. Analysis of hip morphology measurements was performed at the participant level, with additional consideration of unilateral and bilateral morphologies. Mixed morphology was defined in individuals who had both cam (either AP alpha angle  $> 60$  or presence of triangular index sign) and pincer (either LCEA  $> 40^\circ$  or protrusio acetabula) morphologic features. Weighted prevalence estimates and corresponding 95% confidence intervals for the selected hip morphologies were derived overall and stratified by age group, race and BMI group. These analyses are descriptive and comparisons are noted on a qualitative basis.

## RESULTS

A total of 5,192 hips from 2,596 participants were included in this analysis (Figure 1). The observed frequencies, as well as the weighted percentages with 95% confidence intervals for

demographic and clinical characteristics, are shown in Table 1. Overall, these individuals (31% African American, 43% male) had a mean age of  $63 \pm 10$  years, with a mean BMI of  $29 \pm 6$  kg/m<sup>2</sup>. Three-quarters of the included participants were overweight or obese, and two-thirds were between the ages of 55 and 74 years. Nearly 3/4 of the hips had a KLG of less than 2. Compared with women (n=1,483), men in the sample (n=1,113) were younger (mean age of 61 vs. 65 years), less frequently African American (27% vs. 34%), and had a slightly lower BMI (mean 27.9 vs. 29.3 kg/m<sup>2</sup>). Radiographically, men were more likely to have tilt/rotation of the pelvis and were somewhat less likely to have rHOA (Table 1). Additionally, those with rHOA were older, more often female and somewhat more likely to be African American, with no difference by BMI compared to those without rHOA; those with tilted/rotated pelvis were generally younger, more commonly African American, and more frequently male (Supplemental Table A).

The prevalence of femoral side (cam) morphologies (AP alpha angle  $>60^\circ$ , triangular index sign) are detailed in Table 2. A unilateral AP alpha angle greater than  $60^\circ$  was present in 18% of men and 7% of women, while the bilateral finding was seen in 9% of men and 3% of women. No consistent trends in prevalence were noted by race, age or BMI group. A unilateral triangular index sign was identified in 2% of men, but was infrequently bilateral in men (0.6%) and rare in women ( $<0.2\%$ ). The likelihood of having a triangular index sign declined with rising BMI in men, with no consistent trends by age, race, or among women (Table 2). Among individuals with rHOA, cam morphologies were more frequent, particularly in men (23% in men with rHOA vs. 18% in men without rHOA) and bilaterally (26.3% in men and 9.4% in women), and were more frequent among white compared with African American men [unilateral: 25% vs. 18%; bilateral: 28% vs. 21%], Supplemental Table B).

The prevalence of selected acetabular morphologies (dysplasia or pincer) are shown in Table 3. A unilateral LCEA suggestive of mild dysplasia (i.e.  $25^\circ$ ) was present in about 20% of the population, but was somewhat more frequent in men compared with women (22% vs. 18%), with no consistent trends by age, race, or BMI group. Bilateral dysplasia was also common, in 15% of both men and women. In those with rHOA (Supplemental Table C), dysplasia was less common among women (unilateral in 12% and bilateral in 7%). Additionally, in sensitivity analyses using a more stringent cut-off of  $20^\circ$  or less to define dysplasia, the prevalence of unilateral dysplasia was much lower, 8.5% in men and 5.8% in women; bilateral dysplasia by this definition was infrequent, affecting 1.6% of men and 3.1% of women (Supplemental Table D).

Pincer morphologies (acetabular overcoverage, e.g., LCEA  $>40^\circ$  and protrusio acetabula) were relatively infrequent overall ( $<6\%$  of the population). In contrast to the cam-type morphologies, these were more common in women, particularly for bilateral LCEA  $>40^\circ$  (4.4% in women vs. 2.2% in men) and protrusio; the latter also increased with age. Protrusio acetabula was present unilaterally in 6% of women, and bilaterally in 1.3%, compared with  $<0.5\%$  in men. Protrusio, alone among the studied morphologies, was more common in African Americans than whites, for both men and women (Table 3). Among individuals with rHOA, LCEA  $>40^\circ$  was more common overall, and seemed to increase with BMI; protrusio was also more common in women with rHOA vs. those without (Supplemental Table C).

Mixed morphology was relatively infrequent in the main analytic sample, affecting about 2% of men and women, and was somewhat more common (~3%) among obese men and women compared to the lower weight groups. Mixed morphology was more frequent with increasing age among women only (0.6%, 1.6%, 3.2%, and 4.3%, respectively for those aged 50–54, 55–64, 65–74, and 75 and older, Table 4).

## DISCUSSION

Hip morphologies and their role in FAI and OA have been of increasing interest over the last several years, demonstrated by the dramatic rise of papers on FAI in PubMed from less than 100 papers from 1996–2006 to more than 1500 papers from 2007 to present (PubMed). With the growing awareness of FAI, there has also been an increase in formal training and surgical management of these hip variations globally, but particularly in North America and Europe. [13] Notably, many of the authors of early papers on FAI were surgeons reporting on clinical series.[7, 10, 12, 18, 37] This concern for population bias has led to further studies of hip morphology in different populations,[14–23] but to our knowledge, this is the first U.S. population-based study to assess the prevalence of these radiographic morphologies in AA and white men and women. Prevalence estimates from our data suggest that these morphologies are overall very common in the population, such that one out of every four men and 1 in 10 women had cam morphology in at least one hip (AP alpha angle  $>60^\circ$ ), 1 in 3 adults (both men and women) had at least one hip with LCEA of  $25^\circ$  or less, and 1 in 15 men and 1 in 10 women had evidence of pincer morphology (LCEA over  $40^\circ$ ).

In accordance with previous studies, pincer morphologies were more common in women compared with men.[5, 7, 20] Acetabular rim degeneration is a common finding in aged hips, and could potentially be indicative of a nonpathological process.[5, 38] Interestingly, pincer morphology was not predictive for OA in the Chingford 1000 Women Study, a population-based study of women in the UK,[22] or in the CHECK study, a nationwide study in the Netherlands.[15] The CHECK study even suggested that pincer morphologies were protective against the development of OA,[15] in contrast to results in the Johnston County cohort, in which protrusio acetabula was associated with increased risk for rHOA. [20]

Also, as previously reported, cam morphologies were seen more frequently in men in all age groups studied.[5, 7, 20] These findings are of clinical interest as young men are more likely than older women to undergo surgical correction for FAI syndrome.[8, 23] In the CHECK study, it was noted that people with early OA were more likely to progress to end-stage OA if they had a severe cam morphology.[14] Likewise, the Chingford 1000 Women Study demonstrated that cam morphologies were predictive of OA.[22] These findings concur with prior results from our cohort, which also demonstrated an increased risk for rHOA with cam morphology [20].

Although previous reports focused on FAI estimate the prevalence of cam morphology ranging from 20–75%,[3, 10, 18] our findings suggest that cam morphologies (AP alpha angle  $>60^\circ$  and triangular index sign) are present in about 25% of men and 10% of women in the general population. Our results were similar to a population-based study from Norway

in younger individuals, which found cam morphology in 35% of men and 10% of women. [29] This difference among studies could be related to population differences as most papers that describe frequency of morphology include patients in surgical clinics (case series), not the total population.[7, 10, 12, 18, 37] Perhaps cam morphologies are more commonly associated with symptoms and therefore lead to more frequent medical evaluation and surgical interventions.[13, 21] Another possibility is that people with cam morphologies would have developed rHOA by the fourth decade of life, [20, 22] but were excluded from our primary analysis due to their already having rHOA; this is supported by the higher frequency of cam morphology among the subgroup of our cohort with prevalent rHOA.

Regardless, in an age of increasing surgical procedures to correct hip morphologies,[13, 21] it is worth noting that one in ten women and 1 in four men older than 45 years of age will have a cam morphology and not have rHOA. It is also notable that mild dysplasia (LCEA 25°) was present in about 1/3 of the population, again in the absence of rHOA, despite the reported increased risk of OA with this hip morphology.[39]

Limitations of the study include focusing on a primarily middle-aged adult population. In accordance with protocol, hip radiographs were not obtained in women younger than 50, as they were considered to be of potential child-bearing age. Exclusion of people >300 pounds may have also impacted our results. The use of AP pelvis x-rays to assess rHOA may have not been as sensitive as MRI or CT; however, this is the most common imaging modality applied in clinical care and cohort studies, and is the recommended initial imaging study for suspected FAI,[9] making radiographic prevalence data relevant for both clinical and research use. Another potential limitation of our study was the number of participants (n=338) with excessive tilt or rotation (initially excluded to improve accuracy and avoid potential errors related to positioning [34, 36]); however, those participants have been included in sensitivity analysis and the results did not change dramatically.

We have provided the first U.S. population-based prevalence estimates of radiographic hip morphologies relevant to FAI and dysplasia. We found a prevalence of mild dysplasia, cam morphology, and pincer morphology in 1 out of every 3, 4, and 15 men and 1 out of every 3, 10, and 10 women, respectively. Although we cannot infer causality from this cross-sectional work, the results suggest that a fairly large proportion of the population has radiographic evidence of these morphologies even in the absence of rHOA, across age, race, and BMI categories. Ongoing studies will assess symptoms associated with the different morphologies and whether these morphologic differences are clinically relevant in this population.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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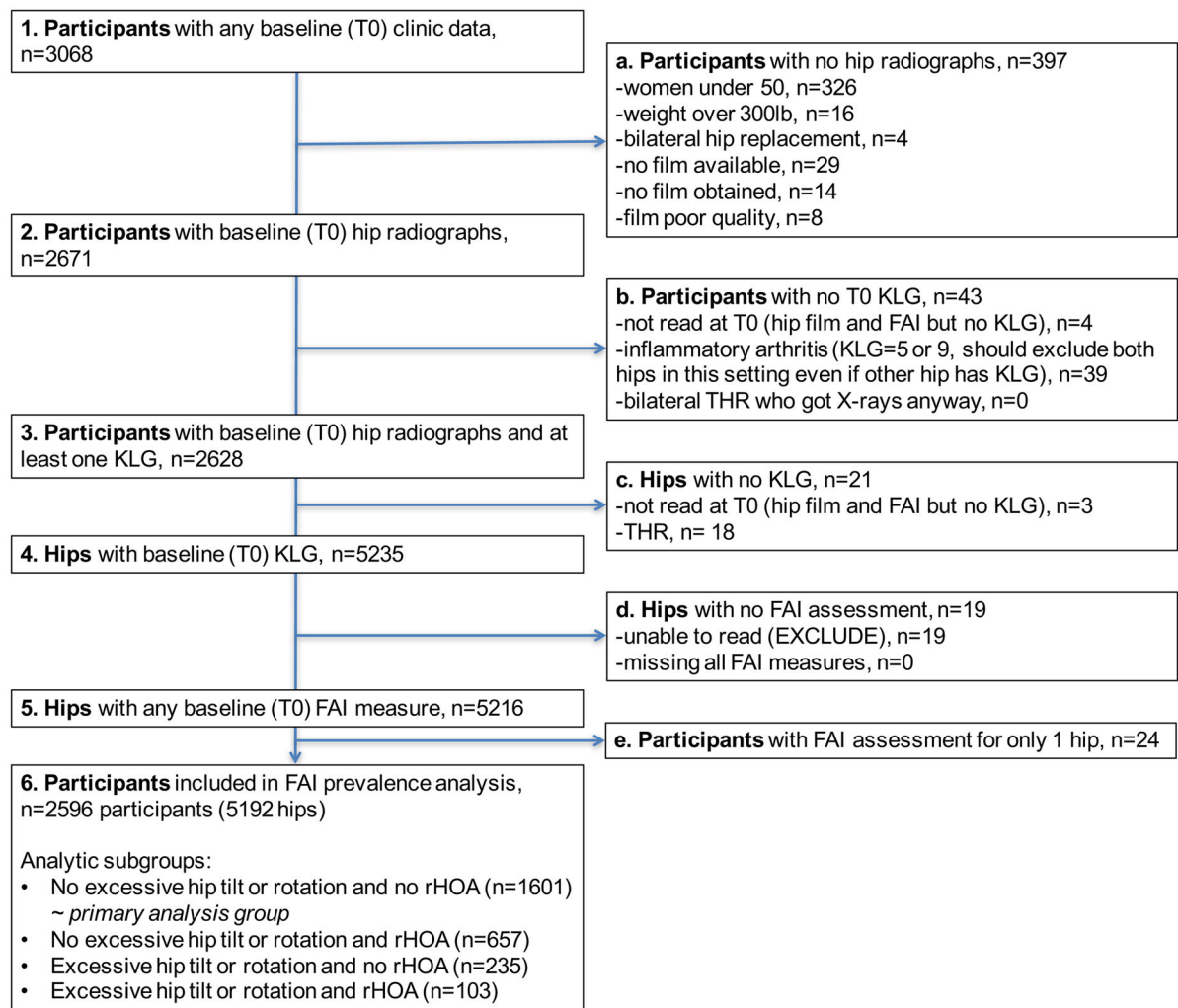
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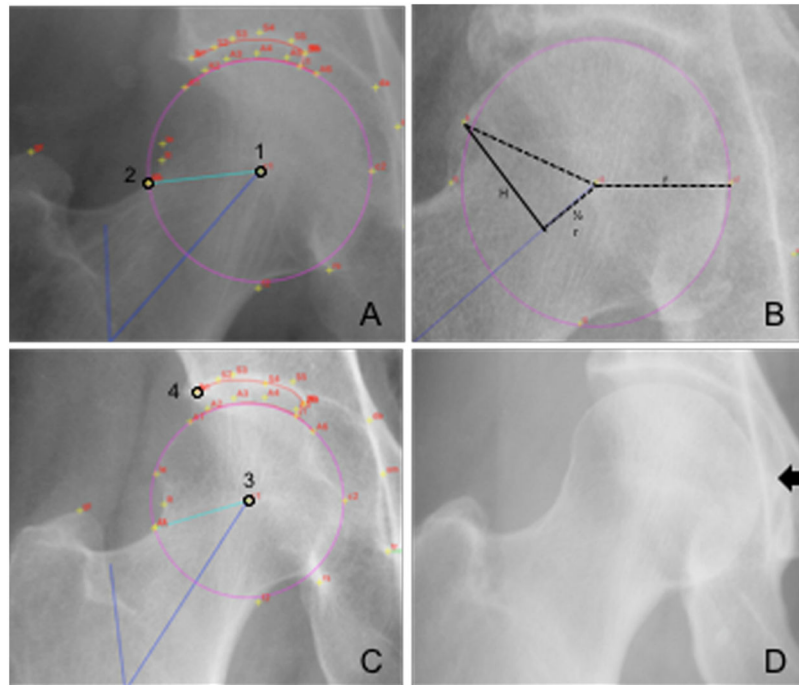
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**Figure 1.**  
Flowchart of participants and hips included in the analysis



**Figure 2. Assessment of hip morphologies in HipMorf**

**A) Alpha ( $\alpha$ ) Angle.** Point 1 is the center of the congruent circle placed over the femoral head. Point 2 is placed on the superior cortex of the femoral neck as it passes out of the circle placed over the femoral head. Alpha angle ( $\alpha$ ) is marked as the angle between the femoral neck axis and the line joining Point 1 and Point 2.

**B) Triangular (Gosvig) Index**

A line is drawn along the midline of the femoral neck axis. A distance equating to  $\frac{1}{2}$  the radius of the femoral head is measured (mm) along this axis from the femoral head centre, at which point a line is drawn at a perpendicular angle to this axis and which extends to the outer cortex of the femoral head. This line represents the triangular index as a binary outcome; present if  $R > r + 2\text{mm}$ , absent if  $R < r + 2\text{mm}$ .

**C) Lateral Center Edge Angle (LCEA)**

A vertical axis is drawn perpendicular to the inter-teardrop line. The lateral centre edge angle is measured between this vertical axis and a line drawn between the femoral head centre (point 3) and the lateral edge of the sourcil (point 4). This line was drawn to the native sourcil, excluding any osteophytes or overgrowth that may have been present.

**D) Protrusio Acetabuli**

The medial margin of the femoral head touches or overlaps the ilioischial line.

Observed frequencies and unweighted and weighted distributions of baseline demographic and clinical variables of study participants (n=2596), overall and stratified by sex \*

**Table 1**

| Characteristic                | All participants, stratified by sex |       |           |              |       |       |               |              |          |                 |       |              |          |
|-------------------------------|-------------------------------------|-------|-----------|--------------|-------|-------|---------------|--------------|----------|-----------------|-------|--------------|----------|
|                               | All participants (n=2596)           |       |           |              |       |       | Male (n=1113) |              |          | Female (n=1483) |       |              |          |
|                               | Count                               | %     | Weighted* | (95% CI)     | Count | %     | Observed      | Weighted*    | (95% CI) | Count           | %     | Weighted*    | (95% CI) |
| <b>Age (years)</b>            |                                     |       |           |              |       |       |               |              |          |                 |       |              |          |
| 45-54**                       | 645                                 | 24.8% | 27.3%     | (25.5, 29.1) | 365   | 32.8% | 37.7%         | (35.3, 40.3) | 280      | 18.9%           | 17.9% | (16.4, 19.5) |          |
| 55-64                         | 837                                 | 32.2% | 29.7%     | (28.2, 31.1) | 323   | 29.0% | 28.0%         | (26.1, 29.9) | 514      | 34.7%           | 31.2% | (29.2, 33.2) |          |
| 65-74                         | 760                                 | 29.3% | 29.6%     | (28.0, 31.2) | 314   | 28.2% | 25.6%         | (23.7, 27.6) | 446      | 30.1%           | 33.2% | (31.1, 35.3) |          |
| 75                            | 354                                 | 13.6% | 13.5%     | (12.2, 14.9) | 111   | 10.0% | 8.7%          | (7.8, 9.7)   | 243      | 16.4%           | 17.8% | (15.9, 19.9) |          |
| <b>Race</b>                   |                                     |       |           |              |       |       |               |              |          |                 |       |              |          |
| Caucasian                     | 1799                                | 69.3% | 82.4%     | (80.3, 84.4) | 818   | 73.5% | 83.4%         | (81.1, 85.4) | 981      | 66.1%           | 81.5% | (79.0, 83.8) |          |
| African-American              | 797                                 | 30.7% | 17.6%     | (15.6, 19.7) | 295   | 26.5% | 16.6%         | (14.6, 18.9) | 502      | 33.9%           | 18.5% | (16.2, 21.0) |          |
| <b>BMI (kg/m<sup>2</sup>)</b> |                                     |       |           |              |       |       |               |              |          |                 |       |              |          |
| Underweight: < 18.5           | 24                                  | 0.9%  | 0.8%      | (0.7, 1.1)   | 8     | 0.7%  | 0.6%          | (0.4, 1.0)   | 16       | 1.1%            | 1.0%  | (0.8, 1.4)   |          |
| Normal weight: 18.5 – 24.9    | 638                                 | 24.7% | 24.7%     | (23.3, 26.1) | 290   | 26.1% | 23.5%         | (21.9, 25.3) | 348      | 23.6%           | 25.8% | (23.5, 28.2) |          |
| Overweight: 25.0 – 29.9       | 1007                                | 38.9% | 40.7%     | (39.2, 42.2) | 489   | 44.1% | 45.9%         | (43.6, 48.1) | 518      | 35.1%           | 36.0% | (34.0, 38.1) |          |
| Obese: ≥ 30.0                 | 917                                 | 35.5% | 33.8%     | (32.3, 35.3) | 322   | 29.0% | 30.0%         | (28.0, 32.1) | 595      | 40.3%           | 37.2% | (34.9, 39.5) |          |
| <b>rHOA status</b>            |                                     |       |           |              |       |       |               |              |          |                 |       |              |          |
| Absent (KLG<2)                | 1836                                | 70.7% | 72.5%     | (71.2, 73.8) | 816   | 73.3% | 74.7%         | (72.8, 76.4) | 1020     | 68.8%           | 70.5% | (68.7, 72.3) |          |
| Present (KLG ≥ 2)             | 760                                 | 29.3% | 27.5%     | (26.2, 28.8) | 297   | 26.7% | 25.3%         | (23.6, 27.2) | 463      | 31.2%           | 29.5% | (27.7, 31.3) |          |

\* Weighted to the 1990 target population; Radiographic data were available for women only 50 years of age or older; BMI values for 10 participants are missing.

Weighted and sex-stratified prevalence estimates of cam morphologies among those with normal pelvic alignment and no rHOA (n=1601)\*

Table 2

| Demographic Subgroup                                | AP alpha angle > 60 degrees |              |           |              | Triangular index sign |            |           |            |
|---|-----------------------------|--------------|-----------|--------------|-----------------------|------------|-----------|------------|
|   | Unilateral                  |              | Bilateral |              | Unilateral            |            | Bilateral |            |
|   | %                           | 95% CI       | %         | 95% CI       | %                     | 95% CI     | %         | 95% CI     |
| Males Overall                                       | 18.4                        | (16.6, 20.3) | 9.3       | (8.0, 10.8)  | 2.1                   | (1.5, 3.0) | 0.6       | (0.3, 0.9) |
| Age group: 45-54 years                              | 19.0                        | (15.7, 22.7) | 6.7       | (4.8, 9.2)   | 1.8                   | (0.9, 3.6) | 0.5       | (0.2, 1.2) |
| Age group: 55-64 years                              | 21.6                        | (18.0, 25.8) | 9.4       | (7.1, 12.4)  | 2.7                   | (1.5, 4.7) | 0.0       |            |
| Age group: 65-74 years                              | 13.9                        | (10.9, 17.6) | 12.5      | (9.8, 15.8)  | 0.7                   | (0.3, 1.5) | 1.5       | (0.8, 2.8) |
| Age group: 75 years                                 | 17.2                        | (12.7, 23.0) | 10.9      | (6.7, 17.1)  | 5.5                   | (3.3, 9.1) | 0.0       |            |
| Race: Caucasian                                     | 18.7                        | (16.7, 20.8) | 9.4       | (8.0, 11.2)  | 2.2                   | (1.5, 3.1) | 0.6       | (0.3, 1.0) |
| Race: African-American                              | 16.5                        | (13.2, 20.4) | 8.4       | (6.0, 11.6)  | 2.0                   | (1.2, 3.3) | 0.4       | (0.2, 1.1) |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 34.5                        | (13.7, 63.7) | 38.9      | (11.6, 75.6) | 0.0                   |            | 0.0       |            |
| BMI group normal: 18.5 - 24.9 kg/m <sup>2</sup>     | 18.1                        | (14.6, 22.3) | 12.8      | (9.8, 16.5)  | 3.5                   | (2.5, 5.1) | 0.7       | (0.2, 2.2) |
| BMI group overweight: 25.0 - 29.9 kg/m <sup>2</sup> | 16.8                        | (14.2, 19.7) | 7.5       | (5.9, 9.6)   | 2.2                   | (1.3, 3.6) | 0.6       | (0.3, 1.1) |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 21.0                        | (17.1, 25.6) | 8.8       | (6.4, 11.9)  | 1.1                   | (0.3, 3.5) | 0.4       | (0.1, 1.0) |
| Females Overall                                     | 7.3                         | (6.2, 8.7)   | 2.5       | (2.0, 3.1)   | 0.1                   | (0.1, 0.2) | 0.2       | (0.0, 0.9) |
| Age group: 50-54 years                              | 6.8                         | (4.9, 9.3)   | 2.6       | (1.4, 4.8)   | 0.0                   |            | 1.0       | (0.2, 4.2) |
| Age group: 55-64 years                              | 6.8                         | (5.0, 9.0)   | 2.1       | (1.5, 2.9)   | 0.1                   | (0.0, 0.4) | 0.0       |            |
| Age group: 65-74 years                              | 8.2                         | (6.2, 10.7)  | 2.4       | (1.6, 3.4)   | 0.2                   | (0.1, 0.5) | 0.0       |            |
| Age group: 75 years                                 | 7.5                         | (4.6, 12.0)  | 3.6       | (2.2, 5.7)   | 0.0                   |            | 0.0       |            |
| Race: Caucasian                                     | 7.4                         | (6.0, 9.0)   | 2.2       | (1.7, 2.9)   | 0.1                   | (0.0, 0.2) | 0.2       | (0.1, 1.1) |
| Race: African-American                              | 7.2                         | (5.3, 9.7)   | 3.6       | (2.7, 4.9)   | 0.3                   | (0.1, 0.8) | 0.0       |            |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 16.1                        | (4.9, 41.5)  | 0.0       |              | 0.0                   |            | 0.0       |            |
| BMI group overweight: 25.0 - 29.9 kg/m <sup>2</sup> | 7.4                         | (5.6, 9.6)   | 2.9       | (2.1, 3.8)   | 0.1                   | (0.0, 0.4) | 0.0       |            |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 8.5                         | (6.6, 10.8)  | 2.2       | (1.5, 3.1)   | 0.2                   | (0.1, 0.4) | 0.0       |            |

\* Weighted to the 1990 target population; Radiographic data were available for women only 50 years of age or older; BMI values for 10 participants are missing; no data for AP alpha angle or triangular index in 4 participants

**Table 3**

Weighted and sex-stratified prevalence estimates of pincer morphologies among those with normal pelvic alignment and no rHOA (n=1601) \*

| Demographic Subgroup                                | LCEA = 25 degrees |              |           |              | LCEA > 40 degrees |             |           |            | Protrusio acetabula |             |           |            |
|---|-------------------|--------------|-----------|--------------|-------------------|-------------|-----------|------------|---------------------|-------------|-----------|------------|
|   | Unilateral        |              | Bilateral |              | Unilateral        |             | Bilateral |            | Unilateral          |             | Bilateral |            |
|   | %                 | 95% CI       | %         | 95% CI       | %                 | 95% CI      | %         | 95% CI     | %                   | 95% CI      | %         | 95% CI     |
| Males Overall                                       | 22.0              | (19.3, 24.9) | 15.4      | (13.6, 17.4) | 4.4               | (3.4, 5.6)  | 2.2       | (1.4, 3.4) | 0.3                 | (0.2, 0.6)  | 0.1       | (0.1, 0.3) |
| Age group: 45-54 years                              | 24.6              | (20.1, 29.7) | 19.9      | (16.1, 24.3) | 2.0               | (1.1, 3.8)  | 0.8       | (0.4, 1.9) | 0.0                 |             | 0.0       |            |
| Age group: 55-64 years                              | 19.0              | (14.8, 24.1) | 14.5      | (11.5, 18.3) | 4.9               | (3.3, 7.3)  | 2.8       | (1.3, 5.9) | 0.3                 | (0.1, 0.9)  | 0.0       |            |
| Age group: 65-74 years                              | 25.3              | (20.9, 30.3) | 9.9       | (7.2, 13.7)  | 6.0               | (4.1, 8.7)  | 4.4       | (2.8, 6.8) | 1.0                 | (0.5, 1.8)  | 0.4       | (0.1, 0.9) |
| Age group: 75 years                                 | 12.3              | (8.1, 18.3)  | 14.5      | (9.4, 21.8)  | 7.8               | (4.2, 14.0) | 0.0       |            | 0.0                 |             | 0.7       | (0.3, 1.5) |
| Race: Caucasian                                     | 22.6              | (19.6, 26.0) | 14.8      | (12.8, 17.1) | 4.5               | (3.4, 5.9)  | 2.3       | (1.4, 3.6) | 0.0                 |             | 0.0       |            |
| Race: African-American                              | 18.0              | (13.9, 22.9) | 19.3      | (15.5, 23.7) | 3.8               | (2.5, 5.8)  | 1.9       | (1.1, 3.4) | 2.2                 | (1.1, 4.3)  | 1.1       | (0.6, 1.9) |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 0.0               | (.,.)        | 34.5      | (13.7, 63.7) | 12.3              | (4.7, 28.4) | 0.0       |            | 0.0                 |             | 0.0       |            |
| BMI group normal: 18.5 - 24.9 kg/m <sup>2</sup>     | 21.0              | (17.1, 25.5) | 16.8      | (13.0, 21.5) | 8.2               | (5.3, 12.3) | 0.8       | (0.4, 1.4) | 0.7                 | (0.3, 1.6)  | 0.4       | (0.2, 0.9) |
| BMI group overweight: 25.0 - 29.9 kg/m <sup>2</sup> | 20.8              | (17.4, 24.8) | 17.2      | (14.3, 20.5) | 2.7               | (1.8, 4.1)  | 2.2       | (1.3, 3.8) | 0.3                 | (0.1, 1.0)  | 0.1       | (0.1, 0.3) |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 25.2              | (18.7, 33.0) | 10.9      | (7.9, 14.8)  | 4.1               | (2.5, 6.5)  | 3.4       | (1.6, 6.9) | 0.0                 |             | 0.0       |            |
| Females Overall                                     | 17.8              | (15.8, 19.9) | 14.6      | (13.1, 16.3) | 5.5               | (4.5, 6.7)  | 4.4       | (3.3, 5.9) | 6.0                 | (4.9, 7.3)  | 1.3       | (0.9, 1.9) |
| Age group: 50-54 years                              | 17.4              | (13.5, 22.0) | 23.6      | (19.5, 28.2) | 3.5               | (2.1, 6.0)  | 2.7       | (1.4, 5.2) | 3.7                 | (2.3, 5.9)  | 0.3       | (0.2, 0.7) |
| Age group: 55-64 years                              | 19.7              | (16.8, 23.1) | 16.3      | (13.7, 19.1) | 4.0               | (2.8, 5.7)  | 4.1       | (2.7, 6.2) | 4.8                 | (3.5, 6.4)  | 1.3       | (0.7, 2.5) |
| Age group: 65-74 years                              | 18.3              | (15.0, 22.1) | 9.4       | (7.1, 12.4)  | 6.9               | (5.1, 9.4)  | 6.0       | (3.6, 9.9) | 8.1                 | (5.8, 11.3) | 1.3       | (0.6, 2.8) |
| Age group: 75 years                                 | 12.4              | (8.4, 17.8)  | 9.9       | (6.6, 14.7)  | 8.6               | (5.9, 12.5) | 3.8       | (2.2, 6.4) | 7.0                 | (4.2, 11.3) | 2.9       | (1.8, 4.7) |
| Race: Caucasian                                     | 18.3              | (16.0, 20.8) | 14.5      | (12.8, 16.4) | 5.3               | (4.2, 6.6)  | 4.7       | (3.4, 6.4) | 4.8                 | (3.7, 6.2)  | 0.5       | (0.2, 1.1) |
| Race: African-American                              | 15.3              | (12.5, 18.6) | 15.2      | (12.6, 18.2) | 6.6               | (5.3, 8.2)  | 3.4       | (2.3, 5.0) | 11.4                | (9.1, 14.1) | 5.2       | (3.8, 7.2) |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 16.1              | (4.9, 41.5)  | 48.6      | (21.8, 76.2) | 25.7              | (8.7, 55.6) | 0.0       |            | 0.0                 |             | 0.0       |            |
| BMI group normal: 18.5 - 24.9 kg/m <sup>2</sup>     | 20.5              | (16.6, 25.2) | 17.6      | (14.1, 21.7) | 7.8               | (5.7, 10.7) | 3.7       | (2.2, 6.1) | 6.5                 | (4.4, 9.5)  | 1.4       | (0.9, 2.3) |
| BMI group overweight: 25.0 - 29.9 kg/m <sup>2</sup> | 17.9              | (15.3, 20.9) | 11.9      | (9.7, 14.5)  | 5.8               | (4.1, 8.2)  | 4.8       | (3.3, 7.1) | 5.4                 | (3.9, 7.4)  | 0.6       | (0.4, 0.9) |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 15.7              | (13.1, 18.7) | 14.8      | (12.4, 17.5) | 3.2               | (2.2, 4.7)  | 4.4       | (2.8, 6.7) | 6.1                 | (4.4, 8.4)  | 2.1       | (1.2, 3.7) |

\* Weighted to the 1990 target population; Radiographic data were available for women only 50 years of age or older; BMI values for 10 participants are missing; no data for LCEA in 1 participant, missing protusio for 15 participants

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Weighted and sex-stratified prevalence estimates of mixed cam and pincer morphologies among those with normal pelvic alignment and no rHOA (n=1601)\*

Table 4

| Demographic Subgroup                                | Cam and Pincer |            |
|---|----------------|------------|
|   | %              | 95% CI     |
| Males Overall                                       | 1.6            | (1.1, 2.2) |
| Age group: 45-54 years                              | 0.5            | (0.1, 1.6) |
| Age group: 55-64 years                              | 2.4            | (1.3, 4.3) |
| Age group: 65-74 years                              | 2.1            | (1.3, 3.4) |
| Age group: 75 years                                 | 1.8            | (0.6, 5.4) |
| Race: Caucasian                                     | 1.5            | (1.0, 2.3) |
| Race: African-American                              | 1.7            | (0.9, 3.2) |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 0.0            |            |
| BMI group normal: 18.5 – 24.9 kg/m <sup>2</sup>     | 0.5            | (0.3, 1.2) |
| BMI group overweight: 25.0 – 29.9 kg/m <sup>2</sup> | 1.4            | (0.9, 2.1) |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 2.7            | (1.4, 4.8) |
| Females Overall                                     | 2.3            | (1.6, 3.2) |
| Age group: 50-54 years                              | 0.6            | (0.3, 1.2) |
| Age group: 55-64 years                              | 1.6            | (0.9, 3.0) |
| Age group: 65-74 years                              | 3.2            | (1.8, 5.4) |
| Age group: 75 years                                 | 4.3            | (2.0, 8.7) |
| Race: Caucasian                                     | 2.1            | (1.4, 3.2) |
| Race: African-American                              | 3.1            | (1.8, 5.1) |
| BMI group underweight: < 18.5 kg/m <sup>2</sup>     | 0.0            |            |
| BMI group normal: 18.5 – 24.9 kg/m <sup>2</sup>     | 2.0            | (1.1, 3.7) |
| BMI group overweight: 25.0 – 29.9 kg/m <sup>2</sup> | 2.1            | (1.1, 4.2) |
| BMI group obese: ≥ 30.0 kg/m <sup>2</sup>           | 2.7            | (1.7, 4.4) |

\* Weighted to the 1990 target population; Radiographic data were available for women only 50 years of age or older; Values for 4 participants are missing; Mixed cam and pincer defined as any cam (either AP alpha angle greater than 60 degrees or presence of triangular index sign) and any pincer (either LCEA greater than 40 degrees or protrusio acetabuli)