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1 Title: The prevalence of cam hip morphology in a general 2 population sample

3 Introduction

4 Femoroacetabular impingement (FAI) syndrome is a motion related disorder of the hip that is
5 characterised by the symptomatic premature contact between the proximal femur and the
6 acetabulum.[1] This premature contact occurs as a result of certain hip shapes such as cam
7 and pincer morphology.[2] Cam morphology describes a flattening or convexity to the
8 femoral head neck junction, which during motion impinges against the acetabular rim.[2]
9 Pincer morphology describes a focal or global over coverage of the femoral head by the
10 acetabular rim, causing the rim to impinge on the femoral neck during motion.[2]

11 The presence of cam morphology has been associated with the development of hip
12 osteoarthritis (OA) since the 1960s. Murray and later Stulberg noted the high prevalence of
13 cam hip shapes in patient undergoing hip arthroplasty.[3, 4] In 2003 Ganz et al described FAI
14 as cause of hip OA, and in 2005 Beck et al hypothesised a mechanism by which FAI
15 syndrome causes hip OA.[2, 5] Since this description a number of cohort studies have shown
16 an increased risk of developing OA in subjects with cam morphology.[6-8] The same
17 association with OA has not been demonstrated with the presence of pincer morphology.[9]

18 Despite the increase in the recognition of cam morphology as a cause of hip OA the
19 epidemiology is poorly defined. A systematic review attempted to define the point prevalence
20 in the general population and reported a estimates from 5 to 75% of the population
21 affected.[10] This systematic review was unable to identify any truly general population
22 based studies. Meta-analysis was not possible due to the heterogeneity in study populations
23 and the variety of measures used to define cam morphology.[10] A recent consensus meeting
24 stated that hip morphology is best characterised with cross sectional imaging.[1] Only one
25 study, Sutter et al, has reported the diagnostic accuracy of measuring cam morphology. Sutter
26 et al defined the diagnostic accuracy of the most frequently used measure of cam
27 morphology; the alpha (α) angle.[11] They described that an α angles measured in the antero-
28 superior (1:30 o'clock) aspect of the femoral head neck junction had the best receiver
29 operator characteristics.[11] Sutter et al reported that a threshold value of 60° provided a

1 sensitivity of 80% and specificity of 73%, for the detection of cam morphology associated
2 with FAI syndrome.[11] No existing studies of the prevalence of cam morphology have
3 exclusively used this diagnostic criterion.

4 We aim to define the prevalence of cam morphology in the general population, using cross
5 sectional imaging and a measure with a pre defined diagnostic accuracy.

6 **Methods**

7 Institutional and NHS research ethics committee approval was given on 27th August 2014
8 (14/NI/1078). This manuscript is reported in accordance with the STROBE guidelines.[12]

9 **Population**

10 All patients who presented to University Hospitals of Coventry and Warwickshire (UHCW)
11 in 2015 and received a computed tomography (CT) scan following major trauma were
12 screened. Major trauma is defined as an injury severity score of greater than 15.[13] All
13 subjects between 16 and 65 years were deemed eligible. Subjects were excluded if they had
14 sustained a pelvic, acetabular or femoral fracture or were deceased.

15 Eligible participants were divided into male and female groups and different age groups, of 10
16 years: 16-25, 26-35, 36-45, 46-55 and 56-65. A sample of 20 eligible participants within each
17 group was randomly selected, using random number generation.

18 Included participants' date of birth, ethnicity (as coded on hospital records), postcode, and
19 digital communication in medicine (DICOM) files were recorded.

20 **Outcomes**

21 Each subjects postcode was used to calculate their index of multiple deprivation (IMD) from
22 the UK 2011 census data.[14] The IMD is the official measure of relative deprivation for
23 neighbourhoods in England.[15] The IMD is based on 7 domains: income, employment,
24 education, health, crime, barriers to housing and services, living environment. Areas are
25 ranked in deciles according to these measures.

1 DICOM files were imported into OsiriX viewer (Geneva, Switzerland) version 8.0.1.[16]
2 Multiplanar reconstruction of each hip were generated and α angles, as defined by Notzli et al,
3 were measured in the antero-superior (1:30 o'clock) aspect of the femoral head neck junction
4 relative to the long axis of the femur.[17] α angles are a widely used and easily reproducible
5 method for objectively detecting cam morphology.[17, 18] When measuring α angles a high
6 value, such as 70° indicates cam morphology, where hips with smaller value e.g. 45° are
7 regarded as normal. In this study hips where the α angle was greater than 60° , in the antero-
8 superior aspect of the femoral head neck junction, were defined as having cam
9 morphology.[11] The presence of hip osteophytes at the femoral head neck junction was
10 recorded.[19]

11 α angles were measured by ED, with repeat measures made one month later on a sample of
12 20 subjects to assess intra-observer reliability. PW made repeat measures on a sample of 20
13 subjects to assess inter-observer reliability.

14 **Statistical Analysis**

15 The inter- and intra-observer reliability of α angles was calculated by assessing the inter class
16 correlation coefficient for absolute agreement. Summary statistics were generated to report
17 the prevalence of cam morphology as a proportion of participants and hips affected, with
18 95% confidence intervals.[20] A secondary analysis excluding hips and subjects with head
19 neck osteophytes was also performed.

20 **Sample Size**

21 A sample size calculation was performed in order to establish the number of participants that
22 would be required to estimate the point prevalence with a power (β) of 0.8 and a confidence
23 (α) of 0.05. The study by Hack et al was used to estimate the constant proportion (the
24 anticipated prevalence of cam morphology- 34%) for the sample size calculation.[21]
25 Including 200 participants provided 80% power, for a confidence interval width of 0.1,
26 anticipating a prevalence of 0.35.[22] This sample size allowed 20 males and females in the 5
27 different age groups to be included.

1 **Results**

2 The 2015 UHCW major trauma database was screened over consecutive months. After nine
3 months, a sufficient number of subjects had been identified to allow random sampling of each
4 age and sex group. Figure 1 shows how the sample was identified.

5 <Insert Figure 1>

6 **Participant Characteristics**

7 ***Ethnicity***

8 Of the 200 participants included 181 had their ethnicity recorded. The majority of patients
9 (85.6%) were white. The ethnicity of the included subjects is compared to the UK general
10 population (2011 census data) in Table 1.[14]

11 < Insert table 1>

12 ***Index of Multiple Deprivation***

13 There was a broad representation in the sample from the most to the least deprived areas
14 based on the IMD; see Table 2.

15 <insert Table 2>

16 **Prevalence of Cam Morphology**

17 The inter- and intra-observer reliability of measuring α angles was 0.873 (95%CI 0.85-90)
18 and 0.903 (95%CI 0.87-0.93) respectively. The prevalence of cam morphology in the
19 population sampled was 47% (95%CI 42-51), with 56% of men and 37% of women affected
20 (see Table 3). The prevalence estimate of cam morphology at different ages and in men and
21 women is displayed in Table 3. The prevalence of cam morphology, excluding subjects with
22 osteophytes, was 45% (95%CI 37-52) (males 54% females 36%).

1 <Insert Table 3>

2 **Discussion**

3 In this study 47% of subjects' aged 16-65 (males 56% and females 37%) had cam
4 morphology. The sample was broadly representative of the UK general population including
5 similar proportions in terms of age, sex, ethnicity and social deprivation distribution. Cam
6 morphology was measured using cross sectional imaging, in keeping with recent
7 recommendations.[1] The measure of cam morphology used a measure with a pre-determined
8 diagnostic accuracy.[11]

9 A recent systematic review attempted to define the prevalence of cam morphology in the
10 general population.[10] This review reported that there were no general population based
11 studies, studies used a wide range of diagnostic criteria and were of a high risk of bias.[10]
12 Therefore the true prevalence could not be established.

13 Studies included in this systematic review that estimated the prevalence of cam morphology
14 using cross sectional imaging include Omoumi et al, Hack et al and Kang et al.[10] Omoumi
15 et al (n=77) report a prevalence of 61% when assessing α angles greater than 55° at 1:30
16 o'clock.[23] Hack et al (n=200) reported a prevalence of cam morphology of 34% using the
17 same criteria.[21] While Kang et al (n=50) report a prevalence of cam morphology of just
18 12% when measuring α angles greater than 55° at 3 o'clock.[24] Each of these studies were
19 rated as a high risk of bias due to the way in which their samples were derived and as a result
20 they lack external validity. These studies also failed to use a measure of cam morphology
21 with a pre-defined diagnostic utility.[10]

22 Our study sampled equal numbers of men and women of different ages and by reporting the
23 ethnicity and the IMD this sample was shown to be broadly representative of the general
24 population. The sampling frame was a clinical population which may have introduced bias in
25 the prevalence estimate.[25] The hospital where the sample was obtained is the second busiest
26 major trauma centre in the UK and receives patients from across the midlands region.[26]
27 Despite the perception that the occurrence of major trauma is random in nature, it is
28 recognised that young males are more frequently affected.[27] In our sampling of equal
29 numbers of males and female, of different ages we attempted to correct for this. This ensured

1 the sample reflected the general populations demographics and not the population who sustain
2 major trauma.

3 Strengths of this study are that the sampling frame included equal numbers of men and
4 women of different ages and that the definition of cam morphology had an established
5 diagnostic accuracy. The use of CT scanning also strengthens this study as it offers an
6 improved sensitivity compared to plain radiographs.

7 A potential source of bias from sampling major trauma patients could depend on the activity
8 level of patients. Increased levels of activity in adolescence are associated with the
9 development of cam morphology.[28] If those who have increased levels of activity are more
10 likely to suffer major trauma this could result in an over estimate of the prevalence of cam
11 morphology. The incidence of acetabular fractures (a group excluded in our study) and
12 posterior instability is reported to be higher amongst those with cam morphology; this is a
13 further potential source of bias, which may result in an under estimate of the true
14 prevalence.[29, 30] Any effect of this bias on the overall prevalence estimate is likely to very
15 small given the low incidence of these injuries.[31]

16 Due to the retrospective nature of the study design the authors were unable to collect data on
17 the presence of hip symptoms or examination signs. The presence of cam morphology alone
18 does not constitute a diagnosis of FAI syndrome. In order to be diagnosed with FAI syndrome
19 patients' must have hip symptoms, positive examination features and associated radiographic
20 signs (such as cam morphology).[1] Therefore we must be cautious when interpreting this
21 studies prevalence estimate in the context of FAI syndrome.

22 The number of patients assessed in this study is modest compared to other studies of cam
23 morphology.[6, 32, 33] The number of subjects assessed by Agricola et al, Gosvig et al and
24 Laborie et al was much greater, but these studies were limited by only assessing plain
25 radiographs. Sutter et al found that measuring in the anterosuperior aspect (1:30 o'clock) of
26 the head neck junction offered the best receiver operator characteristics.[11] Rakhra et al also
27 reported that measuring cam morphology on plain radiographs lacks sensitivity.[34] This
28 view was supported in a recent consensus meeting.[1] Despite the modest size of this study,
29 the sample size calculation showed that assessing 200 subjects could estimate the prevalence
30 to a confidence interval width of 0.1. Indeed the 95% confidence intervals for the prevalence
31 estimate in this study were 42-51%.

1 Given the relatively high prevalence reported in this study we should question whether the
2 specificity of the chosen measure (73%) was high enough.[11] Using a measure with a greater
3 specificity, and therefore higher α angle threshold, will have resulted in a lower prevalence
4 estimate. However this would reduce the sensitivity of the measure to detect cam morphology
5 associated with FAI syndrome. In their study determining the diagnostic utility of measuring
6 α angles on cross sectional imaging Sutter et al, gave equal emphasis to sensitivity and
7 specificity.[11] This is not unreasonable in a measure of this type, compared to, for example,
8 a cancer-screening tool where greater emphasis on sensitivity might be desirable.[35]

9 Different criteria for the presence of cam morphology were used in this study and those that
10 associate cam morphology and hip OA.[6, 7] Agricola et al and Nelson et al measured α
11 angles on antero-posterior radiographs (measuring 12 o'clock- superior aspect of head neck
12 junction) to determine the association between cam morphology and OA.[6, 7] In the study by
13 Agricola et al they found α angles greater than 83° , at 12 o'clock, had the greatest risk of
14 developing OA. It is plausible that different sizes of cam morphology (e.g. larger) may be
15 required to cause OA, while smaller cam morphology, and therefore lower α angles, may not
16 cause OA but are associated with FAI syndrome.

17 In this study different age groups up to 65 years were sampled. It was expected that some
18 subjects, particularly in the older age groups, would have evidence of hip osteoarthritis.[36]
19 In osteoarthritic hips, osteophytes form at the femoral head neck junction.[37] The presence
20 of osteophytes in participants would increase their α angles, potentially creating a false
21 positive result for the presence of cam morphology. A sub group prevalence estimate was
22 provided that excluded cases with radiographic OA. This reduced the prevalence estimate of
23 cam morphology to 45% of subjects (males 54% females 36%).In order to improve our
24 understanding of the epidemiology of FAI syndrome prospective studies that assess the
25 association between hip pain, clinical findings and hip morphology are required; this would
26 establish the prevalence of FAI syndrome in the population. Longitudinal studies are required
27 to determine the factors that associate cam morphology and the development of FAI
28 syndrome and hip OA.

29 **Conclusion**

30 In a sample broadly representative of the UK general population, using criteria with a known
31 diagnostic accuracy, cam morphology was identified in 47% of the participants aged between

1 16-65 (males 56% and females 37%). When excluding subjects with hip OA this estimate
2 reduced to 45% of subjects (males 54% females 36%).

3

1

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4 calculation.

5 **Contributions**

6

7 ED, PW, CH and DG all helped design the study, interpreted the data, drafted the manuscript
8 and approved the final version. ED collected and analysed the data.

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12 **Disclaimer**

13 The views expressed are those of the author(s) and not necessarily those of the NHS, the
14 NIHR or the Department of Health.

15 **Competing interests Statement**

16

17 The authors declare they have no conflicts of interest.

18

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