The prevalence of cam and pincer morphology and its association with development of hip osteoarthritis

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Synopsis

Our understanding of femoroacetabular impingement (FAI) syndrome is slowly improving. The number of studies on all aspects (aetiology, prevalence, pathophysiology, natural history, treatment, and preventative measures) of FAI syndrome has grown exponentially over the past few years. This commentary provides the latest updates on the prevalence of cam and pincer hip morphology and its relationship with development of hip osteoarthritis (OA). Cam and pincer morphology is highly prevalent in the general population and in this paper is presented for different subgroups based on: age, sex, ethnicity, and athletic activity. Methodological issues in determining prevalence of abnormal hip morphology are also discussed. Cam morphology has been associated with development of hip OA while the association between pincer morphology and hip OA is much less clear. Results from reviewed studies as well as remaining gaps in literature on this topic are critically discussed and put into perspective for the clinician.

Key words: aetiology, cam, FAI syndrome, hip, impingement, pincer, osteoarthritis

Femoroacetabular impingement (FAI) syndrome has recently been defined by authors of an international consensus statement as "a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings".[26] They also described the most commonly seen symptoms and clinical signs. The primary symptom of FAI syndrome is motion-related or position-related pain in the hip or groin. Pain may also be felt in the back, buttock, or thigh. In addition to pain, patients may also describe clicking, catching, locking, stiffness, restricted range of motion, or giving way. Diagnosis of FAI syndrome does not depend on a single sign. The flexion, adduction, internal rotation (FADIR) test is most commonly used, and is sensitive but not specific. There is often limited hip motion, especially restricted internal rotation when in hip flexion.[26] Imaging findings, the focus of this manuscript, include the presence of cam and/or pincer hip morphology. Cam hip morphology is characterized by a nonspherical femoral head while pincer morphology is defined as overcoverage of the acetabulum relative to the femoral head, which can be either global (bony overgrowth of the acetabulum or a deep socket) or focal (acetabular retroversion). This manuscript provides an overview of studies that report on the prevalence of cam and pincer morphology, as well as studies investigating the relationship between cam and pincer morphology and hip osteoarthritis. Future research direction for FAI syndrome will be discussed.

Prevalence of cam morphology

A recent systematic review,[16] which included 30 studies, showed that the prevalence of cam morphology has yet to be defined in a truly overall population based cohort. The prevalence of cam morphology in this systematic review ranged from 5 to 75%. This high extent of prevalence variation among studies was based on population characteristics (age, sex, ethnicity, athletic activity, presence/absence of symptoms), the measures and concurrent threshold values used to quantify hip morphology, and the imaging technique.

Cam morphology: age

Cam morphology is less prevalent in adolescents than in adults and has been shown to gradually increase during skeletal growth.[1,3,55,56,63-65] Cam morphology can first be identified and starts to develop from the age of 12 years old[1,55,63], with prevalence increasing with age until the completion of growth.[3] In addition, the extent of athletic activity during skeletal growth may increase the risk of cam morphology development.[3,55,64] Cam morphology is therefore an acquired phenomenon during the second growth spurt and highly influenced by exercise related loads applied to the hip during this phase.

Cam morphology: sex

Cam morphology is probably more common in males. The prevalence of cam morphology in asymptomatic males ranges from 13.0 to 72.0% compared to 0 to 11.7% in asymptomatic women (**TABLE 1**).[30,32,39,57] Studies on symptomatic individuals are more inconsistent because of the selection bias related to symptomatic status. A study by Clohisy et al[14] showed an average prevalence of cam morphology of 47.6% in a symptomatic group of 1076 patients (55% women and 45% men) that underwent surgery for FAI syndrome. Symptomatology and functional limitations are pre-operatively significantly more severe in females compared with males.[29,51]

Cam morphology: ethnicity

Mosler et al[47] identified a significantly lower prevalence of cam morphology amongst young East Asian (19%) professional soccer players, when compared to other ethnicities including Arabic, Black, Persian, and Whites in whom the prevalence ranged between 58% and 72%. Similarly, cam morphology prevalence has been shown to be lower in asymptomatic Chinese men and women compared to Caucasians in another article.[68] However, in contrast, another prevalence study of asymptomatic higher aged individuals report that East Asian populations have a high prevalence of cam morphology (45.3% of 1178 hips).[44]

Cam morphology: athletic activity

In their systematic review and meta-analysis, Nepple et al[52] reported that professional athletes exhibit a higher prevalence of cam morphology relative to non-athletic individuals. The pooled prevalence of cam morphology in male athletes was 41% compared with 17% in male controls. In another systematic review[20], the authors reported prevalence of cam morphology in up to

55% of male athletes compared with 23% in the general population. In their systematic review, Dickenson et al[16] reported prevalence of cam morphology in athletes ranging from 48 to 75%.

Cam morphology: symptomatology

It is currently unknown whether or not the presence of cam morphology by itself is associated with symptoms. Only one prospective study is available, which investigated 200 asymptomatic volunteers over a period of 4.4 years and showed that the presence of cam morphology resulted in a relative risk of 4.3 (95% confidence interval (CI) 2.3, 7.8) of developing hip pain.[35] Similarly a cross-sectional study found an association between an increased alpha angle (indicative of cam morphology) and prior or current athletic-related groin pain in 125 collegiate national football league prospects.[37] This is consistent with the results of another study which showed a relationship between cam morphology based on higher alpha angles and hip symptoms.[8] However, Gosvig et al[24], studying a large non-athletic population consisting of 3202 individuals, showed no significant association between self-reported hip pain and cam morphology. Other studies also could not identify an association between symptoms and cam morphology.[9,33,48] When asymptomatic and symptomatic subgroups are compared, Mascarenhas et al[41] found a higher prevalence of cam morphology in symptomatic hips compared to asymptomatic hips. However, these studies consisted generally of less than 50 participants per subgroup.

Prevalence of pincer morphology

Pincer morphology is even more heterogeneously defined than cam morphology. However, similar to cam morphology, the prevalence of pincer morphology appears to vary across different subpopulations.

Pincer morphology: age

Only a few studies have been published on how the prevalence of pincer morphology changes with age. A study on an asymptomatic paediatric and adolescent population of a mean age of 10.4 years, identified the presence of pincer morphology starting at 12 years of age.[45] In adolescents with an average age of 14.4 years old, Li et al[40] reported a prevalence of pincer morphology of 32.4%. Laborie et al[36], in a study including 2081 young adults with an average age of 18.6 years, reported pincer morphology prevalence of 34.3% in men and 16.6% in women (**TABLE 2)**.

Pincer morphology: sex

Multiple studies have directly compared the incidence of pincer morphology between males and females, showing very little difference. Li et al[40] did not find a difference in prevalence of pincer morphology between asymptomatic males and females. Prevalences of 29.7% and 35.1% in males and females (P=.17) were presented. Other studies showed conflicting results. A higher prevalence of pincer morphology in males was observed in the study of 2081 individuals by Laborie et al[36] who reported a prevalence of pincer morphology of 34% in males, compared to 17% in females (P<.001). In contrast, coxa profunda was found to be significantly associated with female sex in 3 studies.[15,17,28] Two additional studies provided data on the prevalence of pincer morphology only in women, which ranged between 1 and 10%.[33,39] In comparison, the reported prevalence in males ranges between 3 and 66%.[32,47] There is also probably not a great difference in prevalence of pincer morphology between sexes in symptomatic individuals, based on a study by Nepple et al[51] who showed a prevalence of isolated pincer morphology in 56% of the males and 47% of females (P=.46) undergoing FAI surgery.

Pincer morphology: ethnicity

Less is known about the association between pincer morphology and ethnicity. The study of Mosler et al[47] compared the prevalence of pincer morphology (lateral center-edge angle (LCEA) >40º) between young soccer players with different ethnic backgrounds. No pincer morphology was found in white and East Asian soccer players. Arabic (3.6%), black (2.3%), and Persian soccer players (1.7%) showed also a low prevalence. Tannenbaum et al[66] did not find a difference in acetabular retroversion of pelvic specimens between African Americans and Caucasians. Several studies only investigated Asian persons, specifically Japanese, and found a prevalence of pincer morphology ranging from 7.4% to 37.4%.[7,21,44,46]

Pincer morphology: athletic activity

The prevalence of pincer morphology in athletes is highly variable. Harris et al[28] investigated a group of elite ballet dancers and found a prevalence of 74%. In studies, which investigated soccer/football players, prevalence of pincer morphology ranged from 3 to 66%.[22,32,47] A study which combined different type of athletes (volleyball, soccer, and track & field), found a pincer morphology prevalence of 1%.[33] In elite ice hockey players, Lerebours et al[38] found a prevalence of pincer morphology of 59.8%. Two systematic reviews, by Frank et al[20] and Mascarenhas et al[41] found a prevalence of pincer morphology in athletes of 49.5% and 51.2%, respectively.

Pincer morphology: symptomatology

Comparisons between symptomatic and asymptomatic subgroups were presented in a recent systematic review of Mascarenhas[41], which included 60 studies. Pincer morphology prevalence in the asymptomatic subgroup, reported in only 1 study, was 57%. In symptomatic individuals, prevalence of pincer morphology was on average 28.5% (standard deviation (SD) ± 19.2) across studies. The reported prevalence of pincer morphology in asymptomatic individuals in the systematic review by Frank[20] was 67% (range 61 – 76%). That systematic review which included 26 studies did not report on symptomatic individuals. These results are inconsistent with data from Gosvig et al[25] who reported lower prevalence of pincer morphology in men (15.2%) and women (19.4%) in a population-based study. A study by Ahn et al[7] showed pincer prevalence in asymptomatic males and females of 27% and 21%, respectively.

Relationship between cam morphology and hip osteoarthritis

In most studies, cam morphology has been associated with hip OA. The strength of association in several cross sectional and retrospective studies varied between odds ratio (OR)s of 2.2 (95% CI 1.7, 2.8) and 20.6 (95% CI 3.4, 34.8).[12,18,25] The number of well-designed epidemiological studies assessing the relationship between cam morphology and hip OA are limited. Three prospective cohort studies and 2 nested case control studies that included people without hip OA at baseline demonstrated an association between cam morphology and development of hip OA later in life (**TABLE 3**).[2,49,53,62,67] The strength of association varies between ORs of 2.1 (95% CI 1.6, 2.9) and 9.7 (95% CI 4.7, 19.8), primarily depending on the alpha angle threshold used for diagnosis. The positive predictive value (PPV) for developing end-stage OA within 5 years when having cam morphology was 10.9% for an alpha angle greater than 60° and 25.0% for an alpha angle greater than 83°.[2]

Relationship between pincer morphology and osteoarthritis

Pincer morphology does not appear to play a role in the development of hip OA. Three prospective cohort studies defined the presence of pincer morphology by a center-edge angle (CEA) of greater than 33.7° or 40°.[4,62,67] In the CHECK cohort[4], pincer morphology was measured both laterally (on anteroposterior (AP) pelvic radiographs) and anteriorly (on faux profile lateral radiographs). Neither anterior pincer morphology nor lateral pincer morphology was associated with development of hip OA within 5 years. Surprisingly, when pincer morphology was present both anteriorly and laterally, a significant protective effect for development of end-stage OA was found (OR 0.34, 95% CI 0.13, 0.87). This is consistent with the data from Chingford cohort[67] that did not identify an association between higher LCEA angles (only measured on AP radiographs) and development of hip OA. In this cohort, the continuous measure of the LCEA was divided into tertiles. Having an LCEA in the highest tertile (greater than 33.7°) was neither associated with development of radiographic hip OA, defined as a Kellgren & Lawrence[34] (K&L) grade greater than 2 (*P*=.64) nor with the need for total hip replacement (*P*=.67) 19 years later. Finally, results from the Rotterdam study[62] also failed to show an increased risk of developing hip OA at 10-year follow-up, with an OR of 1.24 (95% CI 0.93, 1.66) for pincer morphology.

Discussion

Cam and pincer morphology are common findings in the general population but the prevalence rate vary greatly among studied subpopulations. Cam morphology is associated with future development of hip OA while a link between pincer morphology and OA has never been identified in epidemiological studies. It is important to recognise that all studies on the prevalence and its association with OA investigated morphology only, which does not equate to FAI syndrome, which also includes the presence of symptoms and clinical findings.[26]

Differences and limitations in quantifying cam morphology

There is a large variation in the reported prevalence of cam and pincer morphology between subgroups, with some of that variation attributed to the variability in methodology used to determine the presence of cam and pincer morphology. In the literature, while the alpha angle is an accepted measure to define cam morphology[54], the angular thresholds that is used varies from 50 to 83°.[5,23,54] Furthermore, alpha angles can be measured by different imaging techniques, including radiographs, computed tomography (CT), and magnetic resonance imaging (MRI). Generally, using radial imaging with multiple measurement points (CT and MRI) around the femoral neck is more likely to detect the presence of cam morphology than 2-dimensional imaging (radiographs) and thus result in higher prevalence.[19] However, the use of multiple measurement points might increase the false positive rate.

Differences in cam morphology prevalence in subgroups

The differences in the prevalence of cam morphology between subgroups might provide some clues on aetiology. The greatest differences in prevalence are observed between athletes and non-athletes. The high prevalence of cam morphology observed in athletes might be due to repetitive axial loading, especially during skeletal maturation.[3,55,61,64] This might also partly explain the lower prevalence in females, as they mature earlier than males and probably have less exposure to repetitive axial loading during the second growth spurt, when cam morphology usually develops in males. Cam morphology is probably less frequent in the East Asian population, even in those with an athletic background. However, evidence is conflicting and no direct relationship between genetics and cam morphology has been established yet. Finally, whether the isolated presence of cam morphology is associated with, or predictive for symptoms and/or hip pain is unknown. But, we must be cautious in these interpretations, because although subgroups with a higher prevalence of cam morphology have been identified, it should be emphasized that most of these studies suffer from a high risk of bias.[16]

Differences and limitations in quantifying pincer morphology

The prevalence of pincer morphology is also highly dependent on how it is quantified and the imaging technique used.[4] Pincer morphology can be further defined as having focal or global (acetabular) overcoverage. Focal overcoverage has been defined by several indirect measures such as: the crossover sign, posterior wall sign, and ischial spine sign, which all have generally poor reliability and validity to define true retroversion / pincer morphology.[69] Global overcoverage can be defined by the presence of coxa profunda or protrusio acetabuli or the CEA.[10,50] Coxa profunda and protrusio acetabuli do not seem to be associated with the presence of pincer morphology.[50] Therefore, due to this heterogeneity in definition it is difficult to compare prevalence studies for pincer morphology.

Pincer morphology and hip OA

The prospective studies on the association between pincer morphology and hip OA all used the LCEA on AP radiographs and are therefore comparable.[4,49,53,62,67] However, none of these epidemiological studies could identify an association between pincer morphology and development of OA. It is also notable that 2 systematic reviews found a higher prevalence of pincer morphology in asymptomatic individuals than in symptomatic patients.[20,41] The reader should also bear in mind that although discussed separately, cam and pincer morphology are frequently found together, also known as a mixed type morphology.[42]

Cam morphology and hip OA

Despite the reported association between cam morphology and development of hip OA, one should keep in mind that the majority of people with cam morphology will not develop hip OA. Of the hips with cam morphology, between 6% and 25% will develop future OA within 5 to 19 years.[2,53] For cross-sectional and retrospectives studies, an important confounder is the fact that the radiographic appearance of OA might mimic cam morphology. For example the presence of osteophytes on the femoral head and/or flattening of the femoral head may be related to the OA process. This is hard to distinguish when OA and cam morphology are assessed on the same radiographs. This is less of an issue in a few well-designed prospective studies summarized in **TABLE 3**, but these studies have other methodological limitations such as the imaging modalities used and age of the participants.[2,4,49,53,62,67] All of these studies used AP pelvic radiographs and although this is the gold standard to quantify hip OA, it is suboptimal to define the presence of cam morphology. Only the more laterally located cams are seen on AP radiographs and the prevalence is therefore underestimated. The influence of this underestimation on the true association with hip OA is unknown. Further, the studies summarized only included middle aged to older people. The youngest participants included in the CHECK[2] and Chingford[67] cohorts were 45 years of age and the mean age was 55 and 54 years, respectively. The oldest people were included in the Rotterdam study[62], (minimum age 55 years, mean age 64 years) and in the Johnston county OA cohort study[49] (mean age 62 years). As cam morphology develops during skeletal growth in most cases, it is already present during early adulthood. Therefore, the relationship between cam morphology and hip degeneration between early adulthood and the age of 45 years is unknown. Some indications suggest that this relationship might be stronger in younger people than in middle aged to older people. First, the Rotterdam study showed a stronger relation between cam morphology and OA in people 65 years of age or younger (OR 3.1, 95% CI 2.1, 4.6) while the association disappeared in people greater than 65 years (OR 1.4, 95% CI 0.9, 2.2).[62] Second, features known to be associated with hip OA have been identified in younger populations[11,43,58] with the severity of cam morphology associated with the presence of labral tears and chondral defects.[58] A cross sectional study of asymptomatic participants with a mean age of 20 years showed a decreased in cartilage thickness in those with cam morphology.[60] Finally, from intraoperative findings it is known that severe cartilage damage can already exist in young people with cam morphology.[13,14] However, well-designed studies in young adults are lacking.

Future studies

Based on the results of this overview, there is a need for standardising criteria to determine the presence of cam and pincer morphology. For cam morphology the alpha angle is most often used and despite its limitations it is probably the best measure to date and future studies should therefore at least report the alpha angle. An alpha angle threshold of 60° has been proposed for AP radiographs[6], but there is no validated threshold for other radiographic views. To aid future comparison between studies it might be helpful to present results for different alpha angle threshold values. Many people with cam or pincer morphology will not develop any symptoms from this bony variant. Future studies should therefore also focus on characteristics that can differentiate persons with cam and pincer morphology that will become symptomatic and/or develop hip OA. Characteristics that may be worth considering include hip muscle strength, hip range of motion, gait pattern characteristics, the size of cam morphology, and type and amount of physical activities performed. This might lead to the identification of modifiable risk factors to prevent, stop, or slow down disease progression and also help avoid overtreatment. Future studies should also monitor whether treatment for FAI syndrome, nonsurgical or surgical, can stop or slow down the progression towards hip OA.

Conclusion

Cam and pincer morphology is highly prevalent in the general population. Cam morphology is linked to hip OA in the middle-aged population, but no data are available on its relationship among younger people. The association between pincer morphology and hip OA has not been demonstrated in the available prospective cohort studies. The presence of cam and/or pincer morphology does not always lead to FAI syndrome and subsequent hip OA and future research should focus on identifying factors that may predict who becomes symptomatic (FAI syndrome) in the presence of cam and/or pincer morphology and who subsequently will progress to have hip OA later in life.

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TABLE 1: Prevalence of cam morphology in asymptomatic individuals

Study	Group	Definition of cam morphology	No. of individuals (hips)	Mean (range or ± SD) age in years	Sex (Male/Female, %)	Imaging modality	Prevalence (Male/Female, %)
Agricola et al.[1]	Athletes: soccer	AA > 60º and/or VS: flattening or prominence	89 (178) cases, 92 (184) controls	14.8 (12-19) 13.8 (12-19)	All males	AP and FLL radiography	AA: 26, VS: 66 (cases) AA: 17, VS: 18 (controls) (PH)
Agricola et al.[3] **(FU 2y)**	Athletes: soccer	AA > 60º and/or VS: flattening or prominence	63 (126)	14.43 (12-19)	All males	AP and FLL radiography	AA: 38.9 VS: 69.0 (PH)
Anderson et al.[9]	Senior athletes	na	547 (1081)	67 ± 8	55/45	AP and FLL radiography	66.7 (PH)
Hack et al.[27]	Volunteers	AA > 50.5º	200 (400)	29.4 (21.4-50.6)	44/56	MRI	24.7/5.4 (PP)
Jung et al.[30]	Abdominal, pelvic or other medial issue	AA > 68º (men) AA > 50º (women)	380 (755)	60.4 (25-92)	28/72	Abdominal or pelvic AP scout CT	28.8/11.7 (PH)
Kang et al.[31]	Abdominal trauma or nonspecific abdominal pain	AA > 55º	50 (100)	na (15-40)	54/46	Abdominal CT	10.0 (PH)
Kapron et al.[32]	Athletes: collegiate football	AA >50º and/or HNO <8mm	67 (134)	21 ± 1.9	All male	AP and FLL radiography	AA: 72 HNO: 64 (PH)
Kapron et al.[33]	Athletes: collegiate	AA >50º and/or HNO <8mm	63 (126)	19.6 ± 1.4	All female	AP and FLL radiography	48 (PH) 60 (PP)

	volleyball, soccer, T&F						
Khanna et ‘ al.[35] (FU 4.4y)	Volunteers	AA > 50.5º and second analysis with AA > 60º	BL: 200 (400) FU: 170 (340)	FU: 29.5 (25.7-54.5)	45.3/54.7	MRI	FU: 25.9 (PH)
Laborie et al.[36]	Follow-up of initially newborns	Pistol-grip deformity, flattening and prominence	2.060 (4120)	18.6 (17.2-20.1)	42.1/57.9	AP and FLL radiography	35.0/10.2 (PP)
Larson et al.[37]	Athletes: collegiate football	AA > 55º	125 (239)	na	All male	AP and FLL radiography	65.3 (PH) 75.2 (PP)
Lerebours et al.[38]	Athletes: ice hockey	AA ≥ 55º	130 (260)	24.4 ± 4.3	na	AP and FLL radiography	69.4 (PH)
Leunig et al.[39]	Females from vocational/grammar school, males Swiss army	AA > 50.5º	324 (324)	20.0 ± 0.9 (male) 19.3 ± 1.3 (female)	75.3/24.7	MRI	24.0/0.0 (PP)
Li et al.[40]	Children with disorder unrelated to hip	AA ≥ 55º	558 (1116)	14.4 (10-18.2)	49.5/50.5	Pelvic CT	23.9/9.9 (PP)
Mineta et al.[44]	Disorder unrelated to hip (Japanese)	AA > 55° and/or FHNO ratio < 0.15	1178 (1178)	58.2 (20-89, ± 14.8)	59/41	Abdominal and pelvic CT	54.4/32.3 (PH)
Mosler et al.[47]	Athletes: soccer	AA > 60°	445 (890)	25 ± 4.9	All male	AP pelvic and Dunn view radiography	72 (PP)

Philippon et al.[56]	Athletes: ice hockey	AA ≥ 55°	61 (na) cases 27 (na) controls	14.5 (10-18, ± 2.7) 15.2 (10-18, ± 2.7)	All male	MRI	75 42 (PP)
Pollard et al.[57]	General population	AA > 62° and AOR < 0.14	83 (166)	47.5 (25-69) male 44.4 (22-67) female	47/53	Cross-table lateral radiography	13.0/7.0 (PP)
Reichenbach et al.[59]	Swiss army recruiters	2 = cam, AHNO<10mm, 3 = severe cam, AHNO>10mm	244 (244)	19.9 (18-24)	All male	MRI	24.0 (PP)
Van Houcke et al.[68]	Chinese and Belgian	AA > 55°	Chinese: 102 (204) Belgian: 99 (198)	na (18-40)	52.2/47.8	CT	31/17 41/39 (PH)

Abbreviations: AA, alpha angle; AHNO, anterior head-neck offset; AOR, anterior offset ratio; AP, anteroposterior; BL, baseline; CCD, caput-collum-diaphyseal; FHNO, femoral head-neck offset; FLL, frog-leg lateral; FU, follow-up; HNO, head-neck offset; na, not available; PH, per hip; PP, per person; T&F, track & field; VS, visual scoring; y, year

* If prevalence per gender is not specified, the overall prevalence is presented.

TABLE 2: Prevalence of pincer morphology in asymptomatic individuals

Study	Group	Definition of pincer morphology	No. of individuals (hips)	Mean (range or ± SD) age in years	Sex (Male/Female, %)	Imaging modality	Prevalence (Male/Female, %)
Ahn et al.[7]	Korean volunteers	COS, PWS or LCEA >40°	200 (400)	34.7 (21-49)	36.5/63.5	AP, Sugioka and 45° Dunn radiography	27/21 (PP)
De Bruin et al.[15]	Pelvic radiography patients	CEA >39°, AI <0°, CP, PA, AR	262 (522)	na	38/62	AP radiography	63.2 (PH)
Diesel et al.[17]	Volunteers	LCEA >40° AI <0° COS CP	226 (452)	36.5 (28-50)	46.3/53.7	AP radiography	10.9/10.9 30.3/41.2 10.9/16.7 60.5/92 (PH)
Gerhardt et al.[22]	Athletes: elite soccer	COS	95 (190)	25.4 (± 4.2)	79/21	AP pelvis and FLL radiography	26.7/10 (PP)
Harris et al.[28]	Athletes: elite ballet	PWS, COS, ISS, LCEA >40°, CP, PA	47 (94)	23.8 (± 5.4)	45/55	AP pelvis, false profile and Dunn 45° radiography	74 (PP)
Kang et al.[31]	Abdominal trauma or nonspecific abdominal pain	AV <15° COS AO/CP (CEA >40°)	50 (100)	na (15-40)	46/54	Abdominal CT	13/1 20 9/7 (PH)
Kapron et al.[32]	Athletes: collegiate football	LCEA >40°, AI <0° and/or COS	67 (134)	21 (± 1.9)	All males	AP pelvis and FLL radiography	52 (1 sign) 10 (2 signs) 4 (3 signs) (PH)

Kapron et al.[33]	Athletes: collegiate volleyball, soccer, T&F	LCEA >40° LCEA >40° and AI <0°	63 (126)	19.6 (± 1.4)	All females	AP pelvis and FLL radiography	1 (PH), 2 (PP) 1 (PH), 2 (PP)
Laborie et al.[36]	Follow-up of initially newborns	1 or more finding COS PWS AO	2060 (4120)	18.6 (17.2-20.1)	42.1/57.9	AP and FLL radiography	34.3/16.6 51.4/45.5 23.4/11 14.6/4.9 (PP)
Lerebours et al.[38]	Athletes: ice hockey	COS	130 (260)	24.4 ± 4.3	na	AP and FLL radiography	59.8 (PP)
Leunig et al.[39]	Females from vocational/grammar school, males Swiss army	AD ≤ 3mm	324 (324)	20.0 ± 0.9 (male) 19.3 ± 1.3 (female)	75.3/24.7	MRI	6/10 (PP)
Li et al.[40]	Children with disorder unrelated to hip	LCEA >40°	558 (1116)	14.4 (10-18.2)	49.5/50.5	Pelvic CT	29.7/35.1 (PP)
Mineta et al.[44]	Japanese population, reason unrelated to hip	LCEA >40°, AI <0°, COS	1178 (1178)	58.2 (20-89)	59/41	Pelvic CT	41.7/31.3 (PH)
Monazzam et al.[45]	Abdominal problems	LCEA ≥ 40°, TA ≤0°, AR (AV ≤0° and LCEA ≥40°)	225 (450)	10.4 (2-19)	45.8/54.2	Pelvic CT	5.8/2.0 4.4/5.3 6.8/4.1 (PH)
Mosler et al.[47]	Athletes: elite soccer	LCEA >40°	445 (890)	25 (± 4.9)	All males	AP and Dunn radiography	3.0 (PP)

Abbreviations: AD, acetabular depth; AI, acetabular index; AO, acetabular overcoverage; AR, acetabular retroversion; AV, acetabular version; CEA, center-edge angle; COS, cross-over sign; CP, coxa profunda; FLL, frog-leg lateral; ISS, ischial spine sign; LCEA, lateral center-edge angle; na, not available; PA, protrusion acetabulae; PH, per hip; PP, per person; PWS, posterior wall sign; TA, Tönnis angle

* If prevalence per gender is not specified, the overall prevalence is presented.

TABLE 3: Characteristics of multiple longitudinal studies on relationship between cam/pincer morphology and osteoarthritis, all based on AP radiographs

Study (FU, y)	No. of individuals (hips)	Mean (range or ± SD) age in years	Sex (Male/Female, %)	Definition cam* and pincer† morphology	Cam morphology prevalence (%)	Pincer morphology prevalence (%)	Definition of osteoarthritis	Odds ratio hip osteoarthritis [95% CI]
Agricola et al.[2] (FU 5y)	723 (1411)	55.9 (45-65, ± 5.2)	20/80	*AA >60º AA >83º AA >83º and IR ≤20º	11.1	na	End-stage OA: K&L ≥ 3 or THR	3.67 [1.68-8.01] 9.66 [4.72-19.78] 25.21 [7.89-80.58]
Agricola et al.[4] (FU 5y)	720 (1391)	55.9 (45-65, ± 5.2)	21/79	† LCEA >40º or ACEA >40º	na	54.6	End-stage OA: K&L ≥ 3 or THR	0.34 [0.13-0.87]
Nelson et al.[49] (FU 6y, 12.7y)	120 (239, CA: 71, CO: 168)	63 ± 8 (CA) 62 ± 9 (CO)	25/75	*AA >60º † LCEA >40º	Male: 59 (CA) 40 (CO) Female: 47 (CA) 18 (CO)	Male: 10 (CA) 6 (CO) Female: 24 (CA) 17 (CO)	OA: K&L ≥ 3 or THR	3.57 [1.17-10.90] in male 4.61 [2.09-10.16] in female NS in male NS in female
Nicholls et al.[53] (FU 19y)	135 (268, CA: 25, CO: 243)	55 (50-60)	All female	*AA † LCEA	na	na	End-stage OA: THR	1.052 per 1º increase NS
Saberi et al.[62] (FU 9.2y)	4438 (2960 RS-I, 1478 RS-II)	65.1 ± 6.4 (RS-I) 62.9 ± 6.4 (RS-II)	43/57 (RS-I) 44/56 (RS-II)	*AA >60º † CEA >40º	RS-I: 8.3 (L), 6.4 (R) RS-II: 7.2 (L), 7 (R)	RS-I: 10.9 (L), 8.9 (R) RS-II: 13.5 (L), 8.6 (R)	Incident OA: K&L ≥ 2 or THR	2.11 [1.55-2.87] NS
Thomas et al.[67] (FU 19y)	340 (634): OA group 734 (1466): THR group	54.2 (44-67)	All female	*AA >65º † LCEA >33.7º	na	na	OA: K&L ≥ 2 End-stage OA: THR	1.05 [1.01-1.09] for OA 1.04 [1.00-1.08] for THR NS for OA NS for THR

Abbreviations: AA, alpha angle; ACEA, anterior center-edge angle; CA, cases, center-edge angle; CI, confidence interval; CO, controls; FU, follow-up; IR, internal rotation; K&L, Kellgren & Lawrence; L, left; LCEA, lateral center-edge angle; na, not applicable; NS, not significant; OA, osteoarthritis; R, right; RS, Rotterdam study; THR, total hip replacement; y, year

[a] If odds ratio per gender is not specified, the overall odds ratio is presented.