Does the Type of Sport Influence Morphology of the Hip?

A Systematic Review

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Background: Femoroacetabular impingement (FAI) has been extensively investigated and is strongly associated with athletic participation.

Purpose: To assess (1) the prevalence of cam-type FAI across various sports; (2) whether kinematic variation among sports influences hip morphology; and (3) whether performance level, duration, and frequency of participation or other factors influence hip morphology in a sporting population.

Study Design: Systematic review; Level of evidence, 4.

Methods: A systematic search of Embase, PubMed, and the Cochrane Library was undertaken following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Prospective and retrospective case series, case reports, and review articles published after 1999 were screened, and those that met the inclusion criteria decided a priori were included for analysis.

Results: The literature search identified 58 relevant articles involving 5683 participants. A total of 49 articles described a higher prevalence of FAI across various ''hip-heavy'' sports, including soccer, basketball, baseball, ice hockey, skiing, golf, and ballet. In studies including nonathlete controls, a greater prevalence of FAI was reported in 66.7% of studies (n = 8/12). The highest alpha angle was identified at the 1-o'clock position (n = 9/9) in football, skiing, golf, ice hockey, and basketball. The maximum alpha angle was located in a more lateral position in goalkeepers versus positional players in ice hockey (1 vs 1:45 o'clock). A positive correlation was also identified between the alpha angle and both age and activity level (n = 5/8 and n = 2/3, respectively) and between prevalence of FAI and both age and activity level (n = 2/2 and n = 4/5).

Conclusion: Hip-heavy sports show an increased prevalence of FAI, with specific sporting activities influencing hip morphology. There is some evidence to suggest that a longer duration and higher level of training also result in an increased prevalence of FAI.

Registration: CRD4202018001 (PROSPERO).

Keywords: hip; femoroacetabular impingement; athletic training; anatomy; young adult

Femoroacetabular impingement (FAI) is a common cause of intra-articular hip pain and is a precursor to the development of idiopathic osteoarthritis of the hip.[22] There are 3 types of FAI: cam, pincer, and a mixed type with features of cam and pincer. Cam-type FAI describes an abnormality of the femoral head-neck junction with a decreased head-neck offset that generates excess shear forces on the acetabulum.[22] Pincer type is conversely due to acetabular overcoverage, which leads to damage of the labrum secondary to repeated linear contact in hip flexion, thereby leading to calcific changes in the labrum.[22]

Cam FAI has an increased prevalence in the athletic population, where repetitive impact and increased stress on the physis may cause the development of abnormal joint morphology. From a young age, the frequency and intensity of training in this population are far greater than in recreational athletes or the general population.[43] High levels of athletic activity at a young age have been proposed to lead to developmental abnormalities in growth from the proximal femoral physis, resulting in the development of cam morphology; it has also been proposed that different movement patterns can lead to sport-specific variations in cam morphology.[8,51] Sporting activities can be broadly

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TABLE 1
Sports Categories

Cutting	Flexibility	Contact	Impingement	Asymmetric	Endurance
Soccer	Dance	American football	Ice hockey	Baseball	Track and field
Basketball	Mixed martial arts	Rugby	Rowing	Golf	Swimming (other than breaststroke)
			Baseball catcher	Volleyball	
			Breaststroke swimming		

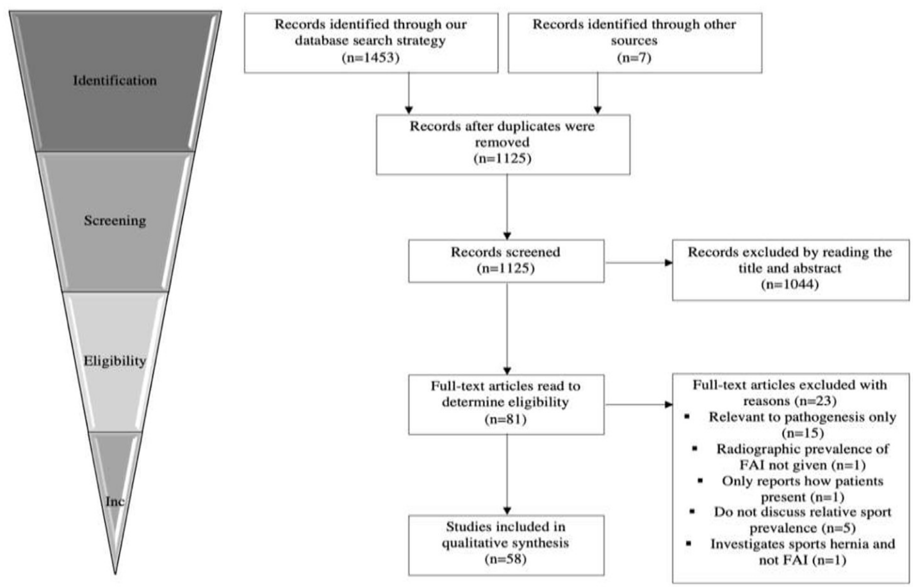

Figure 1. Search process. FAI, femoroacetabular impingement.

divided into categories depending on the type of movement, as shown in Table 1.[43]

The aim of this systematic review therefore is to assess (1) the prevalence of cam-type FAI across various sports; (2) whether kinematic variation among sports influences hip morphology; and (3) whether performance level, duration, and frequency of participation or other factors influence hip morphology in a sporting population.

METHODS

Our systematic review and meta-analyses were conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The study protocol is registered with PROSPERO (CRD4202018001).

Search Strategy

The search process is displayed in Figure 1 and the search strategy in Appendix A (available in the online version of this article). Inclusion criteria were studies in the English language in which cam FAI was measured via the alpha angle in patients aged ≤30 years and those investigating an association between cam and sporting activities. Articles were excluded if they were nonoriginal, technical notes, editorials, commentaries, or conference abstracts or they were published before 1999. Two reviewers (C.D., M.P.) independently screened titles and abstracts. Full texts were

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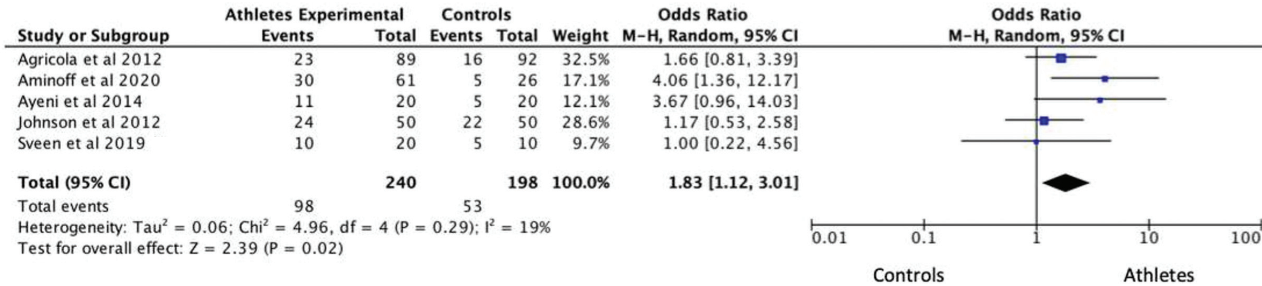

Figure 2. Prevalence of cam-type FAI per individual in athletes vs controls. The term *events* here refers to the occurrence of cam morphology in athletes and controls. For example, in the 2012 study by Agricola et al,[1] 23 experimental events implies that 23 athletes were reported to have cam morphology out of the 89 athletes studied. Of the 92 controls assessed, 16 had cam-type FAI. FAI, femoroacetabular impingement; M-H, Mantel-Haenszel.

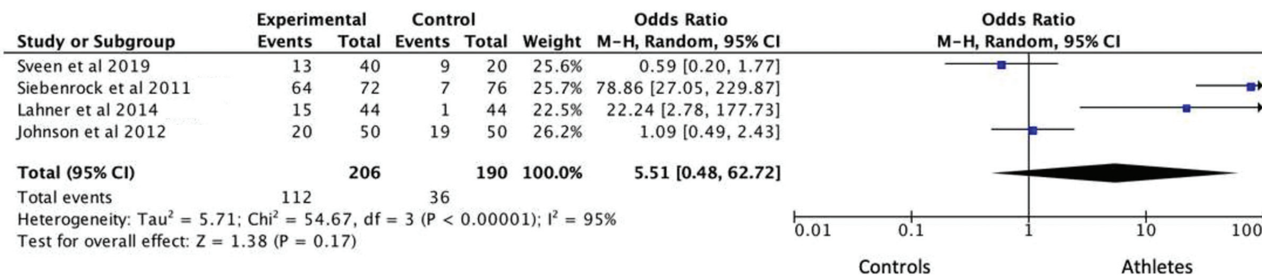

Figure 3. Prevalence of cam-type FAI per hip in athletes vs controls. The term *events* here refers to the occurrence of cam morphology per hip in athletes and controls. For example, in the 2019 study by Sveen et al,[56] 13 experimental events implies that 13 hips had cam morphology out of the 40 hips assessed. Of the 20 assessed control hips, 9 had cam-type FAI. FAI, femoroacetabular impingement; M-H, Mantel-Haenszel.

assessed by 3 authors (C.D., M.P., Y.S.). Included articles underwent validity assessment by 3 authors (C.D., M.P., Y.S.) using the appropriate Joanna Briggs Institute critical appraisal checklist.[13] Articles scoring <50% were excluded. Disagreements were settled by majority opinion, and the senior author (V.K.) was involved if a majority opinion could not be reached.

Data Analysis

Meta-analyses were performed to compare alpha angle measurements between athletes and controls. In addition, the difference in prevalence of FAI across various sports, training durations, and frequencies was analyzed.

All meta-analyses were conducted using Review Manager 5.3 (Nordic Cochrane Centre; Cochrane Collaboration). Heterogeneity was assessed using the I^2 statistic, and random-effects modeling was used for pooling of heterogeneous data. When random effects modeling was employed, weights were assigned using the Mantel-Haenszel method for pooling of prevalence odds ratios and the inverse variance method for standardized mean difference calculations. If studies did not report standard deviation, this was estimated using the formula provided by Higgins et al.[14] Statistical significance was defined by $P \leq .05$.

For data extraction and quantitative synthesis, (1) if mean alpha angle was not reported, alpha angles in the anterosuperior region or at the 1-o'clock position were used; (2) if open and closed physis groups existed, alpha angles from closed physis groups were used; (3) if standard deviations for right and left hip alpha angles were listed, only right hip values for alpha angle and standard deviation were used to create the forest plots; and (4) lateral view alpha angles were preferable, although anterior-posterior values were used if lateral angles were not listed. The values for epiphyseal extension listed in Table 2 were extracted from the 1-o'clock position since they correlated with alpha angle ($P < .001$ in the anterosuperior quadrant for all angles and $P < .006$ for alpha angles $>55°$).[52]

RESULTS

The initial literature search identified 1453 studies and 7 through other sources. In total, 58 studies were finally included in the qualitative and quantitative analyses, with 5683 participants (Figure 1).

Prevalence of Cam-Type FAI

A total of 49 texts described a higher prevalence of cam-type FAI in athletes than in an asymptomatic general

TABLE 2
Comparison of Hip Morphologies Reported in Athletes vs Controls[a]

Author: Sport	No.	Sex, %	Definition of Cam Deformity	Prevalence of Cam Morphology, %		Mean AA, deg	% of Total Hips		Statistically Significant ($P < .05$)
				Hips	Patients		Labral Tear	Herniation Pits	
Agricola (2012)[1]: soccer			AA >60°			Not calculated			
Athletes	89	100M			26				No (P = .31)
Nonathletes	92	100M			17				
Aminoff (2020)[3]: skiing			AA ≥55°			Not calculated			
Athletes	61	52M, 48F			49				Yes (P = .009)
Nonathletes	26	35M, 65F			19				
Ayeni (2014)[4]: ice hockey			AA >50°						
Athletes	20	55M, 45F			55	54.2			Yes for AA (P = .003), no for prevalence of cam (P = .105)
Nonathletes	20	55M, 45F			25	43.2			
Duthon (2013)[18]: dance			AA >55°						
Athletes	20	100F				47.4	85	60	Yes but only for herniation pits (P = .038), not for AA (P = .550) or labral tears (P > .99).
Nondancers	14	100F				46	85	21	
Falotico (2019)[19]: soccer			AA >82°						
Athletes	60	100M				83[b]			Yes (P < .001 for AA and morphology)
Nonathletes	32	100M				67[c]			
Johnson (2012)[26]: soccer			AA ≥55°						
Athletes	50	50M, 50F		40	48	R: 53.8; L: 52.1			No (P = .688 for cam, P = .126 for AA in R hip, and P = .717 for AA in L hip)
Nonathletes	50	50M, 50F		38	44	R: 52.0; L:51.7			
Jónasson (2016)[27]: soccer and ice hockey			Undefined						
Athletes	32[d]	100M				R: 57.7; L:56.1			No
Nonathletes	30	100M				R: 54.4; L: 52.1			
Kolo (2013)[32]: dance			AA >55°						
Athletes	30	100F				46.7[e]	47.5	52.5	Yes for acetabular cartilage lesion (P = .026) and herniation pits (P = .002), no for AA (P = .863) and labral tears (P = .095)
Nonathletes	14	100F				46[f]	28.6	17.9	
Lahner (2014)[34]: soccer			AA >55°						
Semiprofessional	22	100M		47.7	62.5	57.3			Yes (P = .008)
Amateur	22	100M		29.5	27.3	51.7			
Lahner (2014)[33]: track and field			AA >55°						
Athletes	22	50M, 50F		34		52.2			Yes (P = .004)
Nonathletes	22	50M, 50F		2.7		48.1			
Siebenrock (2011)[53]: basketball			AA >55°						
Athletes	37	100M		89		60.5			Yes (P = .001 for cam and P < .001 for AA)
Nonathletes	38	100M		9		47.4			
Siebenrock (2013)[52]: basketball			AA >55°						
Athletes	37	100M				60.8[g]			Yes (P < .001 for AA and epiphyseal extension)
Nonathletes	38	100M				49.2[h]			
Siebenrock (2013)[54]: ice hockey			AA >55°						
Symptomatic athletes	15	100M				62			Yes (P < .001)
Asymptomatic athletes	62	100M				52.2			
Sveen (2019)[56]: skiing			AA >55°[i]						
Athletes	20	100M		32.5	50	52.35			No (P > .99 for cam and P = .938 for AA)
Nonathletes	10	100M		45	50	52.45			

(continued)

TABLE 2
(continued)

Author: Sport	No.	Sex, %	Definition of Cam Deformity	Prevalence of Cam Morphology, %: Hips	Prevalence of Cam Morphology, %: Patients	Mean AA, deg	% of Total Hips: Labral Tear	% of Total Hips: Herniation Pits	Statistically Significant ($P < .05$)
Wyles (2017)[59]: LROM			AA > 55°[a,j]						
Athletes with LROM	13	88M, 12F		91		58			Yes (P = .0165 for cam and P < .0001 for AA)
Athletes with IR >10°	13	88M, 12F		46		44			

[a]AA, alpha angle; F, female; IR, internal rotation; L, left; LROM, limited hip range of motion; M, male; R, right.
[b]Cam and/or pincer morphology: 92.5%.
[c]Cam and/or pincer morphology: 28.1%.
[d]Football, n = 17; ice hockey, n = 15.
[e]Acetabular cartilage lesions >5 mm: 28.8%.
[f]Acetabular cartilage lesions >5 mm: 7.1%.
[g]Epiphyseal extension: open, 0.78; closed, 0.80.
[h]Epiphyseal extension: open, 0.64; closed, 0.75.
[i]On at least 2 magnetic resonance images per hip.
[j]On lateral radiographs.

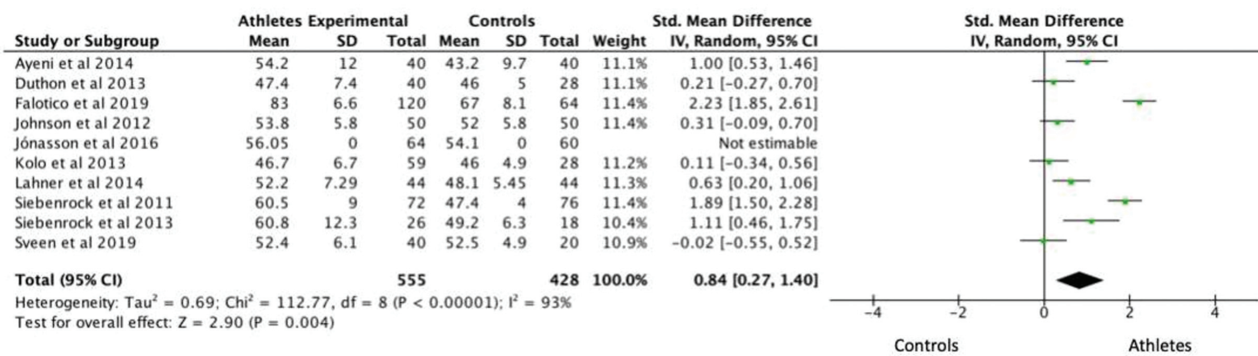

Figure 4. Standardized mean difference in alpha angle of athletes vs controls. IV, inverse variance.

population.[49] Twelve studies included nonathletic controls and compared the prevalence of FAI morphology between athletes and controls, of which 8 demonstrated statistical significance (Table 2).

Pooled analysis of the results revealed a higher prevalence of FAI per individual in athletes as compared with nonathletes, who are 1.83 times more likely to be diagnosed (95% CI, 1.12-3.01; P = .02) (Figure 2), and a similar trend in prevalence per hip, which did not reach significance (odds ratio, 5.51; 95% CI, 0.48-62.72; P = .17) (Figure 3).

When athletes of various sports were compared, impingement sports tended to show the highest prevalence of cam FAI, with cutting and contact sports also frequently reporting high prevalence. Ice hockey players had the highest prevalence of cam-type FAI[46] (Table 3).

Of 10 studies, 9 reported a higher alpha angle in athletes versus nonathletes (Table 2, Figure 4), with 5 citing statistical significance. Pooled analysis showed that athletes had a significantly higher mean alpha angle than controls (95% CI, 0.27-1.40; P = .004). We were unable to calculate standardized mean difference values from Jónasson et al,[27] so their values are not included in this synthesis.

Specifically, ice hockey, an impingement sport, is one of the most reported sports in the literature (see Table 1). Elite ice hockey players are >3 times more likely to develop cam morphology than the general population.[38] Moreover, significantly greater alpha angles are recorded in ice hockey players.[4] Ice hockey players are also >4 times more likely than skiers to have an alpha angle >55° (Table 4), and 79% of ice hockey players showed cam impingement as opposed to 40% of skiers.[46]

Cam Morphology and Hip Kinematics

The position of a cam deformity is described across a radial clock face at the femoral head-neck junction on magnetic resonance images, where superior is 12 o'clock and anterior 3 o'clock. Nine studies reported a maximum alpha angle in athletes in the anterosuperior quadrant, with 6 studies specifically mentioning the 1-o'clock position (Table 5).

In studies that compared hips subjected to different kinematic conditions, certain "at risk" movements conferred a risk for a higher prevalence of a cam deformity and affected the 3-dimensional morphology of the cam

TABLE 3
Radiographic Measurements and the Prevalence of FAI Reported in Athletes of Various Sports[a]

Author: Sport	No.	Sex, %	Definition of Cam Deformity	Alpha Angle, deg	Statistically Significant ($P < .05$)	LCEA and ACEA, deg	Statistically Significant ($P < .05$)	Cam Prevalence by AA	Statistically Significant ($P < .05$)
Fraser (2017)[20]			AA >55°						
Dancers	30	100F		49.5	Yes: lower in dancers vs nondancers, $P = .001$	33.8 and 36	Yes, higher in dancers, $P = .016$, vs nondancers, $P = .035$	18.3	
Nondancers	26	100F		53.9		30.9 and 32.3		42.3	
Kapron (2015)[30]			AA >50°						
Track and field	28	100F		48.2				27	
Soccer	22	100F		40				5	
Volleyball	13	100F		39.1				4	
Lee (2016)[37]			AA >50°	Not reported					
Soccer	44	78M, 22F						28.2	
Baseball	36	78M, 22F						23.1	
Taekwondo	35	78M, 22F						22.4	
Weightlifting	15	78M, 22F						9.6	
Philippon (2013)[46]			AA ≥55°						
Ice hockey	61	100M		60.1	Yes: higher in ice hockey vs skiing, $P < .005$			75	Yes: higher in ice hockey vs skiing, $P < .006$
Skiing	27	100M		55.2				42	

[a]AA, alpha angle; ACEA, anterior center-edge angle; F, female; FAI, femoroacetabular impingement; LCEA, lateral center-edge angle; M, male.

TABLE 4
Likelihood of FAI in Athletes vs Controls[a]

Author: Sport	No.	Sex, %	Cam Deformity Definition	Controls	Odds Ratio	95% CI
Ayeni (2014)[4]: ice hockey	20 athletes, 20 nonathletes	45M, 55F	AA >50°	Nonathletes	3.35	0.31-35.36
Philippon (2013)[46]: ice hockey						
10-19 y	61 ice hockey players, 27 skiers	100M	AA ≥55°	Skiers (10-19 y)	4.46	1.5-13.2
16-19 y	26 ice hockey players, 12 skiers	100M	AA ≥55°	Skiers (16-19 y)	36	4.0-462.8

[a]AA, alpha angle; F, female; FAI, femoroacetabular impingement; M, male.

deformity. The location of the maximum alpha angle is different in positional players versus goalkeepers in ice hockey, 1:45 versus 1 o'clock, respectively[51] (Table 5). This same study also found a significantly higher alpha angle on the anterior-posterior view in goaltenders versus positional players (Table 6). Two studies identified asymmetry in morphology among hips exposed to different kinematic parameters in sporting activity, with a lower alpha angle ($P < .01$), lower prevalence of cam ($P = .026$), but greater pain in golfers' lead versus trail hips.[16,17]

Other Factors Influencing Cam Morphology

Five studies reported significant associations between the prevalence of cam morphology and (1) the level at which athletes were competing and (2) the frequency and/or duration of training (Table 7).[19,34,43,48,57]

Athletes who trained at a higher frequency were 2.59 times more likely to develop FAI (95% CI, 1.49-4.51; $P < .001$) (Figure 5).

Increased age was associated with increased prevalence of cam (n = 2/3; $P < .05$) and increased alpha angle (n = 4/5; $P < .05$). Few studies reported the association between the age at which athletes started training and their alpha angle (n = 1/2; $P < .05$) (Table 8).

Ethnicity was assessed in 2 studies.[21,42] No significant differences were found between the hips of Asian and non-Asian players in the Japanese baseball league.[21] In soccer, however, East Asian athletes had the lowest prevalence of cam (19%; $P < .032$) when compared with their White, Black, and Arabic counterparts, who displayed a similar prevalence of 60% to 72%.[42] Similarly, large pathological cam lesions (>78°) were absent in East Asian players and most commonly seen in White players ($P = .041$).

Pincer and Its Relation to Cam-Type FAI

Pincer morphology is less frequently discussed in relation to sporting activity than cam morphology in the literature; however, it has been noted to be relatively more prevalent in athletes participating in Gaelic football and hurling, baseball, ballet and American football (Table 9).

DISCUSSION

The purpose of this review was to determine the effect of sport on hip morphology and whether the kinematic

TABLE 5
How the Location of Maximum AA Compares Among Sports[a]

Author	Sport	No.	Sex, %	Definition of Cam Deformity	Location of Maximum AA	Greatest Mean AA, deg	Maximum AA, deg	Imaging modality used
Aminoff (2020)[3]	Skiing (Alpine and mogul)	61 young elite skiers, 26 nonathletes	Skiers: 52M, 48F; nonathletes: 35M, 65F	AA ≥55°	1 o'clock			MRI of bilateral hips without contrast
Carsen (2014)[9]	NA but daily activity level was higher in patients with cam morphology, P = .02	44	61M, 39F	AA ≥50.5° at the 3-o'clock position	Anterosuperior (1:30 o'clock)	50.05	64.6	MRI of bilateral hips without contrast
Degen (2016)[15]	Baseball	70	100M	AA >50°[b]				Radiographs (supine AP and 90° Dunn lateral) and CT scans
Duthon (2013)[18]	Ballet	20 professional ballet dancers, 14 active controls	100F	AA >55°	Anterosuperior	47.4	76	Pelvic 1.5-T MRI in the back-lying position. Additional MRI taken in the split position for the dancers
Kolo (2013)[32]	Dance	30 professional dancers, 14 nondancers	100F	AA >55°	Anterosuperior	46.7		Pelvic 1.5-T MRI in the supine position. For the dancers, additional MRI taken in the splits position
Palmer (2018)[45]	Soccer, basketball, ice hockey	210	74M, 26F	AA >60°	1 o'clock	65.2	70.8	MRI of bilateral hips. Two morphological sequences were obtained: 3-dimensional water selective fluid and 3-dimensional proton density fat saturation
Ross (2015)[51]	Ice hockey	44 butterfly goalies vs 26 positional players	100M	Undefined	1 vs 1:45 o'clock on CT, $P < .0001$	80.9 vs 68.6 on CT, $P < .0001$	103 vs 94	Preoperative AP and modified Dunn lateral radiographs and CT of the affected hips
Siebenrock (2013) (1)[52]	Basketball	37 athletes, 38 controls	100M	AA >55°	1 o'clock in closed physes	60.8		MRI of bilateral hips
Siebenrock (2013) (2)[54]	Ice hockey	77	100M	AA >55°	1 o'clock	54.1: open (49.1) vs closed physis (58.2)	87	3.0-T MRI of bilateral hips without contrast
Siebenrock (2011)[53]	Basketball	37 athletes, 38 controls	100M	AA >55°	1 o'clock	64.3		MRI of bilateral hips without contrast
Sveen (2019)[56]	Skiing (cross-country)	20 elite skiers, 10 controls	100M	AA >55°	Anterosuperior	58.7		Pelvic 1.5-T MRI of bilateral hips without contrast

[a]AA, alpha angle; AP, anterior-posterior; CT, computed tomography; F, female; M, male; MRI, magnetic resonance imaging; NA, not applicable.
[b]Location of majority of cam lesions: anterosuperolateral, 98%.

conditions to which the hip is exposed influences the development of the cam deformity. In addition, we sought to identify factors that may influence cam development. Increased athletic activity is associated with a higher prevalence of cam and a greater alpha angle. The greatest alpha angles are in the anterosuperior quadrant, specifically at the 1-o'clock position. Sports can be categorized according to biomechanical similarities, which show differences in FAI prevalence and/or alpha angles, and these categories reflect differing risks for cam development, with impingement, cutting, and contact sports most likely predisposing an athlete to cam morphology (see Table 1). Similarly, there are positional differences in the cam morphology in ice hockey players. This suggests that different kinematic conditions may result in different femoral head-neck morphological abnormalities. However, there is a paucity of data for the female athletes, with only 15 of the 34 studies listed in Tables 2 to 8 including female data. Much of the current literature also focuses on a small variety of sports, such as ice hockey or soccer.

Hip Morphology Across Sporting Populations

Our results depict that contact sports and sports that involve deep flexion and rotation (impingement) have a higher prevalence of cam morphology in comparison with endurance, flexibility, and cutting sports.[43] Therefore, as expected, the alpha angles in athletes engaged in sports involving impingement are higher than in the athletes engaged in cutting sports. This provides strong support in favor of different sporting loads leading to a variation in the pathology of the hip.

The high frequency of FAI among ice hockey players may be due to the repetitive stress placed on the hip as

TABLE 6
How Morphology and Radiographic Angles Vary Among Positions Within Sports[a]

Author: Sport	No.	Sex, %	Definition: Cam Deformity	Definition: Pincer Morphology	Imaging Modality Used	Prevalence of Cam, %	Mean, deg: AA	Mean, deg: LCEA	Statistically Significant ($P < .05$)
Degen (2016)[15]: baseball	70	100M	AA >50°	LCEA >40°	Postop radiographs		68.9 (preop), 38.7 (postop)	29.3 (preop), 28.4 (postop)	No: playing position (infield, outfield, infield/outfield, pitcher, catcher) vs impingement pattern (cam, pincer, or subspine), $P \geq .459$; side of affected hip vs position, $P = .516$
Larson (2017)[35]: ice hockey (positional and goalkeepers)	59	Assumed 100M	AA >50° (Dunn lateral)	Undefined	AP pelvis and bilateral Dunn lateral radiographs		52.2 (AP); 61.0 (Dunn lateral)	28.3: higher in positional players, lower in goalies	Mean LCEA lower in goalies than positional players, but the data set was underpowered and results not statistically significant
Larson (2013)[36]: American football	125	100M	AA >55°	LCEA >39° or positive crossover sign with the posterior acetabular wall lateral or medial to the center of the femoral head	AP bilateral pelvic and frog-lateral plain radiographs	75, players (65, hips). FAI: quarterback (100), running back (100), wide receiver (100), lineman (83.3), safety/cornerback (84), linebacker (93.3), backfield (87.5), kicker (100), tight end (100)	62 (AP); 62 (lateral)		No: radiographic FAI vs player position, $P = .166$
Lerebours (2016)[38]: ice hockey	130	Assumed 100M	AA ≥55° on a frog-leg lateral view	Crossover sign	Bilateral AP pelvis and frog-leg lateral radiographs				No, $P = .076$
Positional						54.6 (centers)	R: 58.9; L:60.1 (centers)	Higher	
Goalkeepers						93.8	R: 66.4; L: 65.8	Lowest (R: 27.6; L: 26.4)	
Menge (2017)[40]: soccer	51	Assumed 100M	Undefined	Undefined	AP pelvis, false profile, and Dunn view at 45° of the affected hip; MRI without contrast				Yes[b]
Nepple (2012)[44]: American football (linemen, tight ends, and linebackers vs other positions)	107	Assumed 100M	Abnormal AA	Acetabular retroversion	AP and frog-leg lateral radiographs	76,[c] 56[d]			No: $P = .086$ for cam; $P = .08$ for global overcoverage
Polat (2019)[48]: soccer	214	100M	AA >55°, decreased anterior femoral offset (<10 mm) and pistol grip deformity	Center-edge angle >39°, decreased Tönnis angle <0° on AP views and crossover signs	AP and frog-leg lateral radiographs	26.2	50.7 (right hips), 50.3 (left hips)	28.6 (right hips), 29.5 (left hips)	No for prevalence of cam among 28 goalkeepers, 30 defenders, 21 strikers, 49 midfielders, 56 right wingers, and 30 left wingers
Ross (2015)[51]: ice hockey		Assumed 100M	Increased AA	Crossover sign or LCEA >40°	AP and modified Dunn lateral radiographs and CT of the affected hips				
Goalkeepers	44					91	54 (AP); 60.4 (lateral)	27.3	Yes for LCEA ($P = .03$), AP AA ($P = .02$) but no for lateral AA ($P = .2$)[e]
Positional (controls)	26						61.3 (AP); 63.4 (lateral)	29.6	

[a]AA, alpha angle; AP, anterior-posterior; CT, computed tomography; FAI, femoroacetabular impingement; L, left; LCEA, lateral center-edge angle; M, male; MRI, magnetic resonance imaging; postop, postoperative; preop, preoperative; R, right.
[b]Linemen were less likely to return after hip arthroscopy vs other players (odds ratio, 5.6; 95% CI, 1.1-35; $P = .04$).
[c]Global overcoverage (linemen, tight ends, linebackers): 30.2%.
[d]Global overcoverage (other positions): 16.2%.
[e]No significant difference between goalies and positional players for mean femoral version and femoral neck-shaft angle ($P = .43$ and $P = .66$, respectively).

TABLE 7
Relationship Between the Level, Frequency, and/or Duration of Training and Prevalence of Cam Morphology[a]

Author: Sport	No.	Sex, %	Definition of Cam Deformity	FAI, %	Statistically Significant ($P < .05$)
Carsen (2014)[9]: nonathletes[b]	44	61M, 39F	AA ≥50.5°		Yes, P = .02
Falotico (2019)[19]: soccer			AA >82°		
Asymptomatic who had been playing professional soccer for at least 5 y	60	100M			Yes, P = .033 for training duration and AA
Volunteers evaluated at the orthopaedics emergency room of Sao Paulo Hospital, had no hip symptoms, and had never been athletes	32	100M			
Lahner (2014)[34]: soccer[c]			AA >55°		
Semiprofessional	22	100M		62.5	Yes, P = .007 for training level and prevalence of FAI, P = .008 for training level and AA
Amateur	22	100M		27.3	
Larson (2013)[36]: American football[d]	125	Assumed 100M	AA >55°		
NFL drafted				88.1	No, P = .430
NFL undrafted				92.7	
Nawabi (2014)[43]: variety, most commonly soccer, ice hockey, and American football[e]			Undefined		
High-level athletes	288	61.5M, 38.5F			Yes, P < .001
Recreational athletes	334	53.6M, 46.4F			
Polat (2019)[48]: soccer					
Training >12.5 h/wk	214	100M	AA >55°	41.7	Yes, P = .03
Training <12.5 h/wk				22.9	
Playing soccer for ≥3 y	214	100M	AA >55°	39.5	Yes, P = .01
Playing soccer for <3 y				13.7	
Tak (2015)[57]: soccer	63	Assumed 100M	AA >60°		
Started playing at a professional club at age <12 y				63.6	Yes, P = .042 for training level and frequency and prevalence of FAI
Started playing at an amateur club (≤3/wk) at age ≥12 y				40.2	

[a]AA, alpha angle; F, female; FAI, femoroacetabular impingement; M, male; NFL, National Football League.
[b]Daily activity: with cam morphology, 7.1 hours; without cam morphology, 2.9 hours.
[c]Mean AA, semiprofessional, 57°; amateur, 51.8°.
[d]Mixed FAI: NFL drafted, 61.9%; NFL undrafted, 65.9%.
[e]Age at surgery: high-level athletes, 20.2 years; recreational, 33 years.

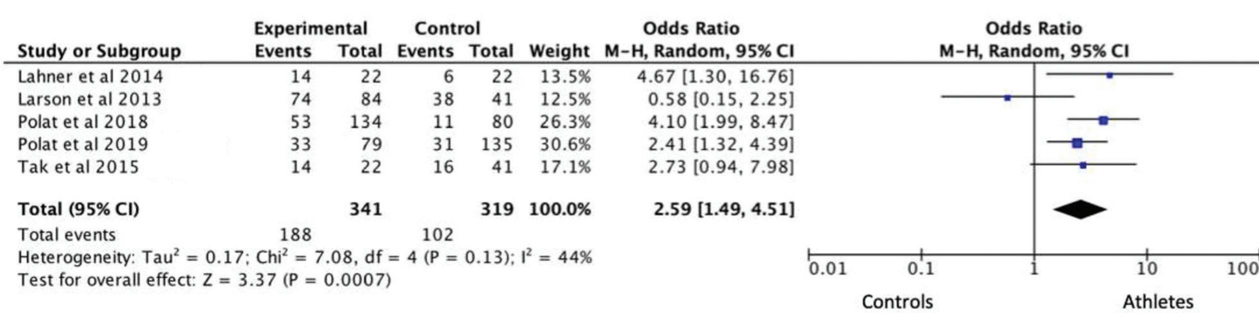

Figure 5. Effect of increased frequency and/or duration of training on cam morphology. M-H, Mantel-Haenszel.

a result of the unique impinging skating motion and position employed, suggesting that the type of sport influences morphology.[55] This is in comparison with skiers, for example (Table 4), for which the snow could attenuate the impact on landing and the forces transmitted across the hip. This would reduce the cumulative stress placed on the physis of skiers. This implies a model wherein reduced impact stresses lead to the development of less severe cam morphology. In accordance with this, no significant difference in the prevalence of cam was found between cross-country skiers and nonathletes.[56] In contrast, mogul and Alpine skiers reported a significantly higher prevalence of cam versus controls.[3] Alpine and mogul skiing involves high ground-reaction forces, and in the mogul discipline, 2 acrobatic jumps will result in high-impact landings. Competitions are additionally often held on hard and uneven snow, meaning that the snow will offer less impact protection to these skiers than to cross-country skiers.

TABLE 8
Relationship Between the Age of Athletes and Prevalence of FAI/AA[a]

Author: Sport	No.	Sex, %	Definition of Cam Deformity	Prevalence of FAI, %	Statistically Significant ($P < .05$)
Agricola (2014)[2]: soccer[b]	63	100M	AA >60°		Yes for AA (P = .018), no for prevalence of FAI (P = .51).
12-13 y				36.5	
14-15 y at follow-up				38.9	
Carton (2019)[10]: Gaelic football and hurling[c]	700	93.9M, 6.1F	AA >55° (Dunn view) or AA >65° (AP view)		Yes, except in post hoc analysis in the older 2 groups. P = .002 (at the $P < .01$ level for all 3 age groups). Post hoc analysis: mean AA for <25 y was significantly different vs 25-34 y and ≥35 y. No difference: 25-34 y vs ≥35 y.
Falotico (2019)[19]: soccer			AA >82°		
Started playing competitive soccer (≥4/wk) at age <12 y	37	100M			Yes, $P < .001$, age when athlete started playing competitive soccer is inversely correlated with AA
Started playing competitive soccer (≥4/wk) at age >12 y	23	100M			
Harris (2016)[25]: ballet[d]	47	45M, 55F	Undefined		Yes, P = .030 for increasing age and AA, r = 0.311
Lee (2016)[37]: variety[e]	338	68M, 32F	AA >50°	54.5 (teenagers), 61.8 (20s)	NA
Lerebours (2016)[38]: ice hockey	130	Assumed 100M	AA ≥55°		No for age and prevalence of an elevated AA
Philippon (2013)[46]: ice hockey[f]	61	100M	AA ≥55°		Yes, $P < .001$ for age and AA
Philippon (2013)[46]: skiing[g]	27	100M	AA ≥55°		No, P = .254 for age and AA
Polat (2019)[48]: soccer	214	100M	AA >55°	0 (10-12 y), 19.1 (13-15 y), 60 (16-17 y)	Yes, $P < .05$ for age and prevalence of FAI
Tak (2015)[57]: soccer	63	Assumed 100M	AA >60°		No, P = .1 for start age and AA
Started playing high-frequency soccer at age <12 y				51	
Started playing high-frequency soccer at age ≥12 y				17	

[a]Percentage of FAI on frog-leg lateral was used. AA, alpha angle; AP, anterior-posterior; F, female; FAI, femoroacetabular impingement; M, male; NA, no statistical analysis.
[b]Mean AA: 12-13 years old, 59.4°; 14-15 years old, 61.3°.
[c]Age groups: <25, 25-34, and ≥35 years.
[d]Younger and older dancers (18-39 years; mean ± SD, 23.4 ± 5.4 years). No specific age range per group was given; however, correlation (r = 0.311) was found between increasing age and AA.
[e]Soccer, baseball, and mixed martial arts (eg, taekwondo and judo).
[f]Age groups: 10-12 years (peewee), 13-15 years (bantam), and 16-19 years (midget).
[g]Age groups: 10-12, 15, and 16-18 years.

A higher incidence of cam deformity was found in patients participating in martial arts—for example, taekwondo or hapkido—as compared with those whose primary sport was not a martial art.[28] As with Alpine and mogul skiing, martial arts involve sudden shocks applied to the acetabular rim. It is not unfeasible that sports that involve high ground-reaction forces, in addition to those involving the "at risk" impinging movements, confer a risk for the development of cam morphology.

Dancers more commonly have pincer morphology than cam morphology, with the alpha angle being significantly lower in dancers than nondancers[20] (see Table 3). Kolo et al[32] discovered the presence of cam morphology in only 1 of 30 dancers. No significant difference was found in alpha angle or labral tears between dancers and nonathletes, although statistically significant differences were recorded for acetabular cartilage lesions and herniation pits between the groups (see Table 2). Pincer impingement with subluxation-associated acetabular labral and cartilage lesions and herniation pits is therefore far more prevalent in dancers than cam-type FAI. Additionally, the lateral and anterior center-edge angles of dancers are significantly higher than those of nondancers. This supports the premise of dancers' having a higher prevalence of pincer morphology and elevated lateral center-edge angles and lower alpha angles than single-sport athletes who are nondancers,[20] and it suggests a difference in radiological presentation and FAI types among sports.

Overall, cam morphology tends to be more frequent in other sports—for example, ice hockey, soccer, basketball, golf, track and field, and rowing. A high prevalence of mixed morphology was also noted in soccer, baseball, and American football players (Table 9), implying that the kinetics and kinematics involved in many sports predispose to cam and pincer and not necessarily isolated morphology.

Positional Differences

Ice hockey butterfly goalkeepers are suggested to be most at risk of cam-type FAI owing to the biomechanical demands of flexion and internal rotation, similar to the

TABLE 9
Comparing Pincer, Mixed, and Cam Morphology in a Variety of Sports[a]

		Definition of Deformity		Prevalence of Morphology, %		
Author	Sport	Pincer	Cam	Pincer	Mixed	Cam
Boykin (2013)[5]	Rowing	LCEA >40°, a crossover sign, or coxa profunda / protrusio	AA >50°	0	24	48
Brunner (2016)[6]	Ice hockey	Acetabular depth ≤3 mm (coxa profunda) and/or a negative angle of the cranial portion of the acetabulum (acetabular retroversion)	Large decrease of the anterior head-neck offset	23	18	27
Carton (2019)[10]	Gaelic football and hurling	Crossover sign on AP pelvis, a clear bony prominence, or rim fracture on the acetabular rim on the false profile view	AA >55° (Dunn view) or AA >65° (AP view)	100		72
Casartelli (2018)[11]	Ice hockey	Acetabular retroversion and/or depth ≤3 mm	AA >60°	1	1	7
Degen (2016)[15]	Baseball	LCEA >40°	AA >50°	58		98
Dickenson (2016)[17]	Golf	Negative measure of acetabular depth	AA >55°	0		16
Fukushima (2016)[21]	Baseball	LCEA ≥40°, acetabular roof obliquity ≤0°, crossover sign, posterior wall sign, and coxa profunda	Pistol grip deformity	40, Asians; 31, non-Asians	29, Asian; 38, non-Asian	14, Asians; 10, non-Asians
Gerhardt (2012)[23]	Soccer	Coxa profunda, protrusio acetabuli, reduced extrusion index, and an acetabular index <0	AA >55°, excessive bone formation at the femoral head-neck junction, loss of normal femoral head sphericity, or flattening of the femoral head-neck offset on frog-leg lateral hip radiographs	27, male; 10, female		68, male; 50, female
Harris (2016)[25]	Ballet	Crossover sign, posterior wall sign, ischial spine sign, LCEA >40°, coxa profunda, protrusio acetabuli	Undefined	74		32
Kang (2009)[28]	Variety	Undefined	Undefined	12	5	56
Kapron (2012)[29]	Soccer			7, LCEA >40°; 16, acetabular index <0°		55
Kapron (2015)[30]	Soccer, skiing, volleyball, track and field	LCEA >40° with or without acetabular index <0°	AA >50° and/or femoral head-neck offset <8 mm	1		14
Knapik (2018)[31]	American football	Undefined	AA >55°	0		73
Kolo (2013)[32]	Ballet	Undefined	AA >55°	29, acetabular cartilages lesions >5 mm; 53, herniation pits		3
Lahner (2014)[33]	Track and field	LCEA >40°	AA >55°	9, controls	5, controls	50
Larson (2013)[36]	American football	Positive crossover sign with the posterior acetabular wall at or lateral/medial to the center of the femoral head	AA >55°	78	63	75
Lee (2016)[37]	Baseball, soccer, taekwondo, weightlifting	Crossover of the anterior wall of acetabulum over the posterior wall (focal crossover sign, figure-of-8 sign), coxa profunda, or acetabular protrusio	AA >50°	28	17	55
Mariconda (2014)[39]	Capoeira	Crossover sign, acetabular index ≤0°, and/or LCEA ≥39°	AA >50° and/or femoral head-neck offset <8 mm	38	33	92
Menge (2017)[40]	Soccer	Undefined	Undefined		90	
Monckeberg (2017)[41]	Soccer	Crossover sign or LCEA >40°	AA >55° or decreased anterior femoral offset <8 mm	42, asymptomatic skeletally immature; 51, mature		47, asymptomatic skeletally immature athletes; 49, mature
Nepple (2012)[44]	American football	Acetabular retroversion	Abnormal AA	85	62	72
Polat (2019)[48]	Soccer	CEA >39°, decreased Tönnis angles <0° on AP views and crossover signs	AA >55°, decreased anterior femoral offset <10 mm, and pistol grip deformity	2	2	26
Ross (2015)[51]	Ice hockey	Crossover sign or LCEA >40°	Increased AA	6		90
Yépez (2017)[60]	Soccer	CEA ≥35° or acetabular index ≤0°	AA ≥55° or head–neck offset <7 mm	11		78

[a]The highest percentage values were recorded irrespective of the view used. AA, alpha angle; AP, anterior-posterior; CEA, center-edge angle; LCEA, lateral center-edge angle.

flexion, adduction, internal rotation impingement test.[43,47,58] Similar demands of extreme internal rotation are placed on athletes in ballet[12] and golf.[24] Indeed, butterfly goalkeepers have a significantly higher alpha angle in comparison with outfield players, and the maximum alpha angle is located in a more lateral position in goalkeepers (1 vs 1:45 o'clock). Anterosuperior impingement may be related to end-range internal rotation.[58] Siebenrock et al[54] noted higher alpha angles in symptomatic versus asymptomatic ice hockey players at 1-, 2-, and 12-o'clock. At these positions, a negative correlation was reported between alpha angle and internal rotation. This suggests that symptomatic cam is associated with functional deficits relating to the "at risk" positions, including decreased internal rotation. However, it is not known whether the relationship between cam deformity and internal rotation relationship is functional and a result of osseous impingement or a consequence of the symptomatic pain experienced. Kinematic exposure through positional differences may affect not only the development of the deformity itself and the associated symptoms but also the outcomes of treatment. In soccer, linemen were less likely to return to play after hip arthroscopy in comparison with other positions (odds ratio, 5.6; 95% CI, 1.1-35; P = .04) (Table 6). This has been attributed to the additional movement and rapid changes of direction required in this position, which may result in more severe morphology.

Ballet dancers more frequently display pincer morphology rather than cam deformity. These athletes typically perform 6 movements: arabesque, développé devant, développé à la seconde, grand écart facial, grand écart latéral, and grand plié. Such movements result in linear contact between the superior or posterosuperior rim of the acetabulum and the femoral head-neck junction. Furthermore, performing the splits results in direct contact between the acetabulum and the anterosuperior femoral head-neck junction. These movements all involve extremes of abduction, flexion, and rotation, once again suggesting that extreme stresses on the hip joint result in FAI syndrome.[32] It is unknown whether these stresses may contribute to the development of pincer deformity; however, interestingly, just as cam morphology is more commonly present in the anterosuperior aspects of the femoral neck, specifically the 1-o'clock position, pincer morphology targets the superior, posterosuperior, and anterosuperior portions of the femoral head-neck junction. In addition, in ballet, female dancers typically dance more en pointe, while male dancers are expected to perform bigger jumps, thereby placing the hips of each sex under different kinematic conditions. This may partially explain the marked sex differences observed in cam prevalence in ballet dancers, with Harris et al[25] reporting a greater prevalence of cam morphology in male dancers (P = .01).

Other Factors Influencing Cam Development

Intense exercise from a young age places increased stresses on the hip joint, and repetitive microtrauma associated with sport predisposes athletes to hip pathology that would not exist or remain asymptomatic otherwise.[7] Tak et al[57] found a significant dose-response relationship between the frequency of training among adolescent soccer players and the development of cam, supporting the notion that high-impact activity during skeletal immaturity can lead to cam development. The prevalence of cam was significantly lower in soccer players playing for an amateur club from the age of 12 years onward than those who started playing for a professional club before 12 years (P = .042). In the same age groups, a significant difference in the prevalence of a pathological cam deformity was found (alpha angle >78°) (P = .038). However, there was no statistical significance between the age at which athletes started playing soccer and the prevalence of FAI in athletes competing at the same level (P = .1). This suggests that the frequency and intensity of training could have a greater effect on the development of FAI than the age at which training began.

A significant positive correlation between age and alpha angle has, however, been identified in ice hockey players throughout adolescence. Philippon et al[46] found that 37% of peewee players, 63% of bantam players, and 93% of midget players had alpha angles ≥55°. In fact, ice hockey players in the midget group (16-19 years) were 36 times more likely than skiers to have an alpha angle >55° (Table 4). Agricola et al[2] showed that cam develops during skeletal immaturity in soccer players and likely remains stable after. As age increases, so does the cumulative duration of training and skill level, implying that age, frequency, duration, and level of training all correlate with alpha angle and cam morphology.

Finally, it was interesting to observe an ethnic difference in the prevalence of cam deformity across athletes competing in the same sport at the same level.[42] While it is impossible in this observational study to control the activity in adolescence exactly, this points to a role of genetic factors in the development of cam deformity. Indeed, Pollard et al[50] noted an increased prevalence of cam deformity in the siblings of those treated for FAI.

Although the relative contributions of these disease-modifying factors still must be established, early screening in those at risk will allow for preventive strategies to be developed, thereby promoting joint and sporting longevity.

Strengths and Limitations

This systematic review is the first to establish the types of sport that are associated with a higher prevalence of cam deformity, and so are hip heavy, and to examine kinematic demands that are related to morphological characteristics at the femoral head-neck junction. Additionally, the methodology encompasses a broad and comprehensive systematic literature search of multiple databases, which allowed us to capture the majority of the existing literature.

However, there are some limitations to this review. We included reviews published in the English language and may have missed data published in other languages. Data were recorded heterogeneously across studies, and for complete data extraction and estimation of mean population values, we were required to use assumptions and compare heterogeneous data. Further limitations of quantitative synthesis are discussed in the Methods section.

CONCLUSION

Athletic activity affects the hip joint and predisposes to cam-type FAI. Cam deformity is most commonly associated with sports that include repetitive movements demanding levels of internal rotation as well as impact, in particular impingement, followed by cutting and contact sports. Athletes of these sports have higher alpha angles than less athletic controls, with the highest prevalence of cam morphology among ice hockey players. Cam morphology most frequently occurs at the 1-o'clock position of the radial clock face at the femoral head-neck junction on magnetic resonance imaging, with the position potentially being influenced by the kinematic demands of the sport. Dance sport does not fit this trend, however, and is associated with pincer morphology and subluxation. There is a positive correlation seen in some studies between the alpha angle and both age and activity level and between prevalence of FAI and both age and activity level.

With increased awareness of the positive correlation between athletic activity and FAI among clinicians, physiotherapists, athletes, and coaches, as well as greater radiographic and clinical screening, we hope that athletes will be diagnosed, managed better, and be able to return to play far sooner than is currently possible.

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