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Activity Level and Sport Type in Adolescents Correlate with the Development of Cam Morphology

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Background: The purpose of this study was to evaluate the influence of the volume and type of sport on the development of cam-type femoroacetabular impingement and acetabular dysplasia.

Methods: The Physical Activity Questionnaire for Adolescents (PAQ-A) was administered to Iowa Bone Development Study participants at the age of 17 years to identify those who had participated in at least 2 seasons of high school interscholastic sports. Based on relative peak strain and ground reaction forces, subjects were grouped as power sport athletes (basketball, cheerleading, football, gymnastics, soccer, and volleyball), non-power sport athletes (wrestling, baseball, cross-country or track and field, softball, or tennis), or non-athletes. Using anteroposterior views of the left hip formatted from dual x-ray absorptiometry (DXA) scans, the alpha angle, head-neck offset ratio (HNOR), and lateral center-edge angle (LCEA) were evaluated longitudinally at the ages of 17, 19, and 23 years. Logistic regression was used to evaluate the odds of hip cam morphology (alpha angle >55° and/or HNOR <0.17) or acetabular dysplasia (LCEA <24°) at the age of 23 years in all athlete groups. The relationships between physical activity level and hip measures (alpha angle, HNOR, and LCEA) from the ages of 17 to 23 years were examined using linear mixed models adjusted for sex.

Results: Compared with non-athletes at the age of 23 years, power sport athletes had significantly greater odds of cam morphology according to the alpha angle (odds ratio [OR], 2.93 [95% confidence interval (CI), 1.02 to 8.41]; p = 0.046) and HNOR (OR, 1.91 [95% CI, 1.01 to 3.60]; p = 0.047), but not greater odds of acetabular dysplasia (p > 0.05). There were no significant differences in the odds of cam morphology or acetabular dysplasia in non-power sport athletes compared with non-athletes (all p > 0.05). Higher physical activity levels were significantly associated with an increase in the alpha angle (beta and standard error, 0.77° ± 0.30°; p = 0.011) and a decrease in the HNOR (−0.003 ± 0.001; p = 0.003), but not the LCEA (−0.05 ± 0.15; p = 0.744).

Conclusions: A higher volume of physical activity and participation in sports with higher peak strain and ground reaction forces during the process of skeletal maturation may increase the risk of developing cam morphology during late adolescence.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Femoroacetabular impingement syndrome is a common hip disorder characterized by decreased femoral head-neck offset (cam), acetabular overcoverage (pincer), or both combined, which can result in early-onset hip osteoarthritis[1,2]. In the general population, the prevalence of cam morphology is approximately 15% to 25% in men and 5% to 15% in women[3-6]. High physical activity throughout skeletal maturation is a commonly accepted etiology of cam morphology development[7]. In particular, aggressive sport participation throughout skeletal maturation has been associated with the development of cam-type femoroacetabular impingement[8-12]. Prospective and retrospective longitudinal studies have associated participation in elite-level soccer, basketball, and ice hockey with the development of cam morphology[13-17]. The proposed mechanism involves repetitive hip flexion and external rotation forces that stimulate osseous overgrowth at the growth plate, particularly in the anterolateral aspect of the proximal femoral physis[18].

In contrast, there is a paucity of data with regard to the association between intense adolescent physical activity and acetabular version or femoral head coverage. During normal skeletal maturation, the triradiate physis ossifies and the

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A344).

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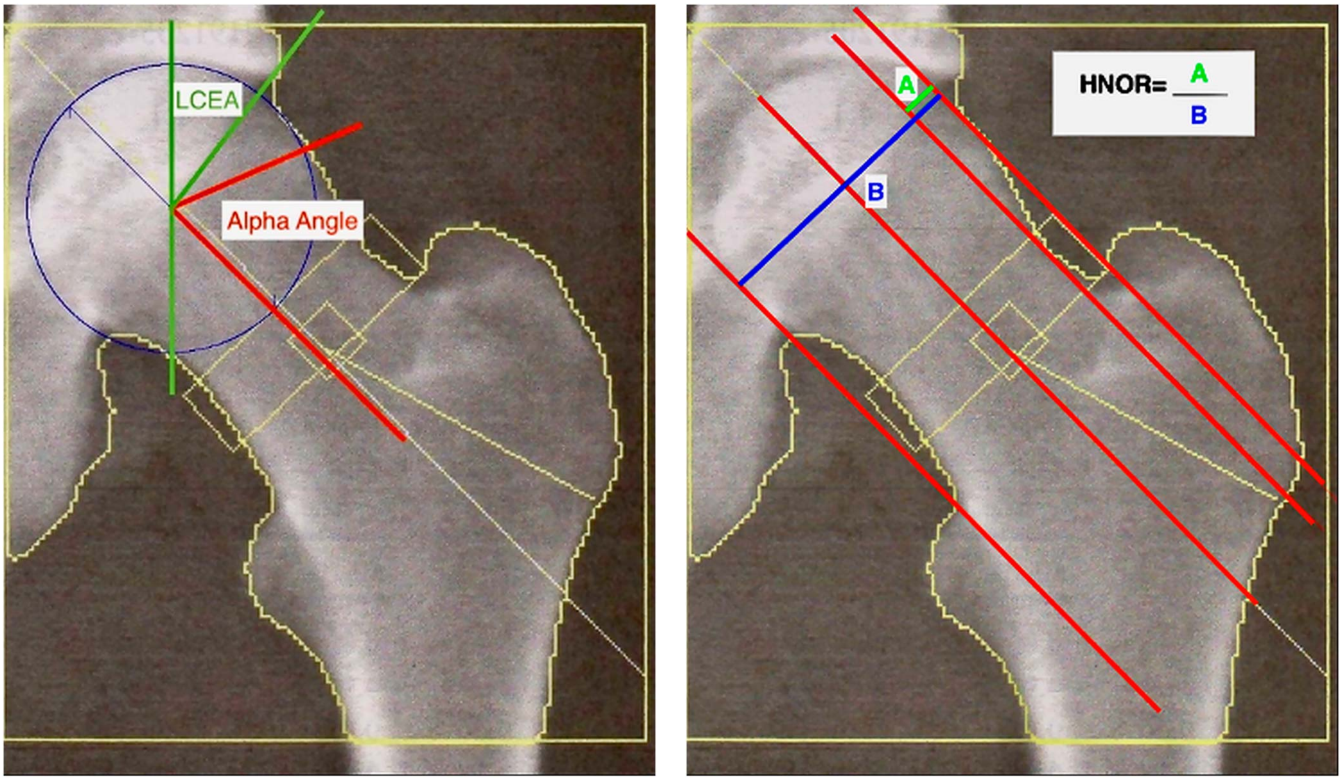

Fig. 1-A Fig. 1-B

Figs. 1-A and 1-B Examples of DXA scans showing the left hip with the alpha angle and LCEA (**Fig. 1-A**) and HNOR (HNOR = A [neck offset distance]/B [width of femoral head]) measurements overlaid (**Fig. 1-B**). Yellow lines were automatically placed during DXA scan routine analysis and outline the bone density area of interest. In scans with very low bone mass, the yellow lines may not perfectly outline the bone. The true borders of the bone were used to measure the alpha angle, HNOR, and LCEA.

posterior wall of the acetabulum grows, resulting in a change in osseous acetabular version[12,19]. It is currently unknown whether adolescent sport participation can alter the development of acetabular dysplasia or certain sports simply self-select for athletes with a particular osseous morphology of the hip[20]. In a group of 63 female collegiate track and field, soccer, and volleyball players, Kapron et al.[21] found a higher prevalence of acetabular dysplasia, defined as a lateral center-edge angle (LCEA) of <20°, compared with previously reported rates for the general population (21% compared with 3.5% to 4%). Similarly, Hamilton et al.[22] observed relative femoral retroversion in adolescent female dancers involved in intensive ballet training.

Because femoroacetabular impingement and acetabular dysplasia are both risk factors for the development of hip osteoarthritis[23-28], identifying certain populations at risk for developing cam morphology or worsening acetabular overcoverage or undercoverage could help to improve treatment and prevent future hip osteoarthritis. Therefore, the purpose of this study was to compare the development of cam morphology and acetabular overcoverage or undercoverage among groups of adolescents participating in sports with elevated peak strain

TABLE I Total Participants Included per Visit*

Visit	No. of Patients	Age† *(yr)*	Included Patients	Excluded Patients‡
1	379	17.5 ± 0.4 (16.8 to 18.5)	317	62
2	329	19.8 ± 0.7 (18.6 to 22.1)	263	66
3	322	23.4 ± 0.8 (22.8 to 25.2)	260	62

*Total included in data analysis. †The values are given as the mean and the standard deviation, with the 95% CI in parentheses. ‡Visit 1: 62 participants were excluded because of poor-quality DXA scans or inadequate physical activity data. Visit 2: 66 participants either missed visit 2, had poor-quality scans, or had inadequate data. Visit 3: 62 participants either missed visit 3, had poor-quality scans, or had inadequate data.

TABLE II Baseline Characteristics by Activity Group

Variable	Non-Athlete (N = 92)	Non-Power Sports (N = 50)	Power Sports (N = 118)
Age* *(yr)*	17.5 ± 0.4	17.6 ± 0.4	17.5 ± 0.4
Body mass index* *(kg/m²)*	25.1 ± 6.5	23.4 ± 4.9	24.3 ± 4.3
Female sex†	52 (56.5%)	33 (66.0%)	63 (53.4%)
Race†			
White	89 (96.7%)	49 (98.0%)	114 (96.6%)
Black	0 (0%)	0 (0%)	2 (1.7%)
Asian	1 (1.1%)	1 (2.0%)	0 (0%)
Hispanic	2 (2.2%)	0 (0%)	2 (1.7%)
LCEA* *(deg)*	29.3 ± 6.5	28.9 ± 4.6	29.2 ± 5.2
<24°†	23 (25.3%)	8 (16.0%)	21 (17.8%)
>40°†	5 (5.4%)	2 (4%)	5 (4.2%)
Alpha angle* *(deg)*	41.5 ± 7.1	42.1 ± 6.5	43.6 ± 9.5
>55° at age 17 yr†	5 (4.6%)	1 (1.6%)	8 (5.6%)
HNOR*	0.2 ± 0	0.2 ± 0	0.2 ± 0
<0.17 at age 17 yr†	57 (51.8%)	34 (54.0%)	83 (57.7%)
PAQ-A* (1 to 5)	2.1 ± 0.8‡§	2.6 ± 0.8	2.5 ± 0.8
Caloric intake* *(kcal/day)*	1,534.0 ± 691.5	1,541.9 ± 516.8	1,709.2 ± 951.4
Height* *(cm)*	170.0 ± 9.8#	169.8 ± 9.6	173.4 ± 9.4

*The values are given as the mean and the standard deviation. †The values are given as the number of patients, with the percentage in parentheses. ‡P < 0.01 compared with the non-power sport athlete group. §P < 0.001 compared with the power sport athlete group. #P < 0.05 compared with the power sport athlete group.

and ground reaction forces (which we will call power sports) compared with both those with less peak strain and ground reaction forces (non-power sports) and non-athletes. We hypothesized that participation in power sports would be associated with greater odds of cam-type femoroacetabular impingement (alpha angle of >55° and/or head-neck offset ratio [HNOR] of <0.17)[29,30] and acetabular dysplasia (LCEA of <24°) compared with non-power sport athletes or non-athletes at skeletal maturity; we also hypothesized that higher scores on the Physical Activity Questionnaire for Adolescents (PAQ-A) during adolescence, regardless of sport participation, would be associated with cam-type femoroacetabular impingement (alpha angle of >55° and/or HNOR of <0.17) and acetabular dysplasia (LCEA of <24°).

TABLE III The Incidence of Newly Developed Cam Morphology at the Age of 23 Years

	Incident Cam Morphology*		
Sport Group	Absent	Present	Total
Non-athlete	85 (96.59%)	3 (3.41%)	88
Non-power sports athlete	45 (91.84%)	4 (8.16%)	49
Power sports athlete	99 (89.19%)	12 (10.81%)	111
Total	229	19	248

*The values are given as the number of patients, with or without the row percentage in parentheses.

Materials and Methods

This study was approved by the institutional review board at the University of Iowa.

Iowa Bone Development Study

This study utilized existing data from the Iowa Bone Development Study[31], which is a prospective cohort study of the effects of fluoride and other factors on bone development. Between 1998 and 2001, participants from the Iowa Fluoride Study birth cohort were enrolled at approximately 5 years of age. Follow-up visits occurred about every 2 to 3 years, when dietary intake and physical activity questionnaires were administered, heights and weights were measured, and dual x-ray absorptiometry (DXA) scans were performed. The current analyses were restricted to data collected at follow-up visits at the ages of 17, 19, and 23 years.

Sport Participation and Physical Activity

At the age of 17 years, subjects were asked via a mailed survey to report the amount and type of high school interscholastic sport participation. They also completed the PAQ-A[32], a 7-day-recall questionnaire that assesses self-reported moderate to vigorous

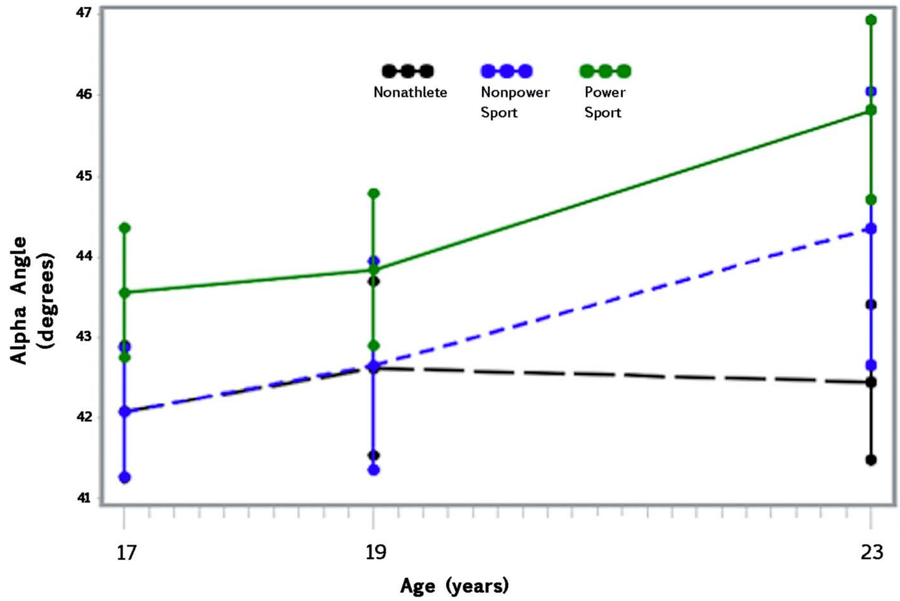

Fig. 2
The mean alpha angle by high school sport group from ages 17 to 23 years. The error bars indicate the standard error.

physical activity during the school year. Items are scored on a scale of 1 to 5 and were averaged, with a higher activity level indicated by a higher mean score. Participants were grouped into sport categories based on their responses to participation in athletics using a previous classification by Ward et al.[33]. Athletes were defined as those who participated in at least 2 seasons of high school interscholastic sports[33]. Two seasons were chosen because bone intervention studies have suggested that a minimum of 7 months is needed for bone adaptation[34]. Those who participated for ≤1 season were considered non-athletes. We further subdivided athletes based on a previously used power sports classification system based on relative peak strain and ground reaction forces experienced in various sports[35]. Power sport athletes were defined as those participating in basketball, cheerleading, football, gymnastics, soccer, and volleyball, and non-power sport athletes were defined as those participating in wrestling, baseball, cross-country or track and field, softball, or tennis, or power sport athletes participating in only 1 season[33].

Imaging the Hip

Using DXA scans at the mean ages of 17, 19, and 23 years, subjects were evaluated for cam-type femoroacetabular impingement and acetabular dysplasia. Scans were acquired using the Hologic 4500A densitometer; a single, supine,

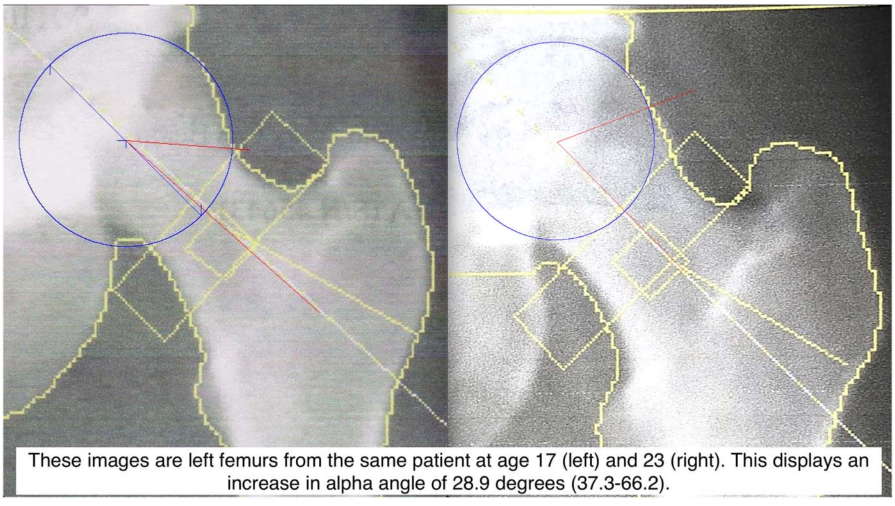

Fig. 3
A patient who developed cam morphology between the ages of 17 years (left) and 23 years (right), with an associated increase in alpha angle from the ages of 17 to 23 years.

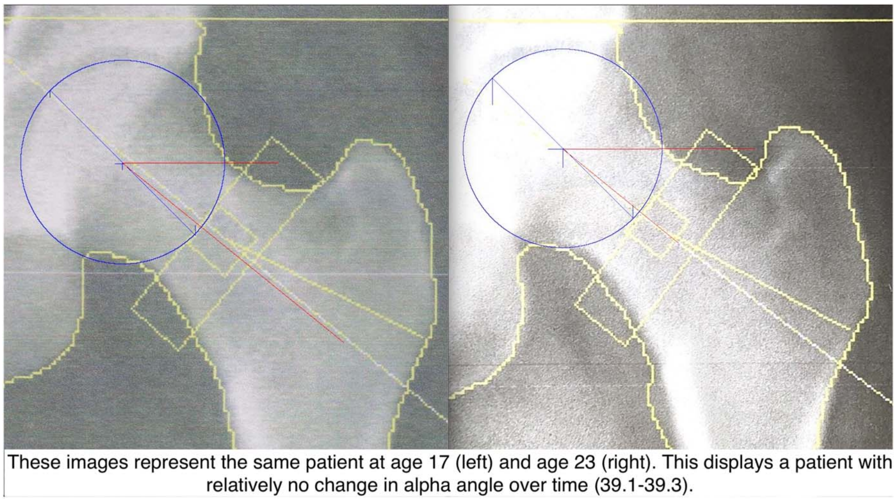

Fig. 4

A patient with essentially no change in alpha angle from the ages of 17 years (left) to 23 years (right).

anteroposterior view of the left femoral neck was isolated from a digital copy of the scan. During the scan, the lower extremity was internally rotated (resembling an anteroposterior radiographic view) and was supported at the knee and foot to limit movement. The alpha angle, HNOR, and LCEA were measured using the left proximal femoral view with ImageJ (National Institutes of Health [NIH]). The alpha angle was measured and the presence of cam morphology was defined as an alpha angle of >55° (Fig. 1-A)[8,29]. Femoral head-neck offset was measured by drawing parallel lines through the most anterior aspect of the femoral head and the most anterior aspect of the femoral neck and then measuring the distance between them (Fig. 1-B)[36]. The HNOR was found by dividing the offset measurement by the femoral head diameter; a value of <0.17 was used to define cam morphology[37,38]. For LCEA, as the hemipelvis and contralateral hip were not visible, a vertical line through the center of the femoral head was used as the reference point, with the LCEA measured to the lateral edge of the sclerotic acetabular sourcil. We defined acetabular dysplasia as an LCEA of <24° and pincer morphology as >40°, thus including most hips with borderline dysplasia (LCEA, 20° to 25°) as well as those with more severe dysplasia (LCEA, <20°) (Fig. 1-A). Measurements were taken twice by a medical student (A.S.) at 2 separate time points at least 2 weeks apart to determine intrarater reliability. In addition, measurements of a random sample of 10 subjects were made by a board-certified orthopaedic surgeon (R.W.W.) and were used to determine interrater reliability.

Statistical Analysis

Descriptive statistics were calculated, and the distributions of continuous variables were evaluated using the Shapiro-Wilk test and through evaluation of histograms. Logistic regression was used to model the relationship between odds of hip morphology (cam morphology: alpha angle of >55° or HNOR of <0.17; hip dysplasia: LCEA of <24° or >40°) and sporting group (power sport athlete, non-power sport athlete, and non-athlete) at the age of 23 years, with and without adjustment for sex. Linear mixed models were used to evaluate the relationships between physical activity score and alpha angle, HNOR, and LCEA from the age of 17 to 23 years. This included a random intercept and physical activity score, alpha angle,

TABLE IV Relationships Among High School Sports Groups and Odds of Cam Morphology According to Alpha Angle at the Age of 23 Years

	Alpha Angle*					
Activity Group	Normal (≤55°)	CAM Morphology (>55°)	OR†	P Value	OR Adjusted for Sex†	P Value
Non-athlete	87 (94.6%)	5 (5.4%)	Reference		Reference	
Non-power sports	45 (90.0%)	5 (10.0%)	1.93 (0.53 to 7.03)	0.3168	2.29 (0.61 to 8.60)	0.2177
Power sports	101 (85.6%)	17 (14.4%)	2.93 (1.04 to 8.27)	0.0424	2.93 (1.02 to 8.41)	0.0461
Athletes (all sports)	146 (86.9%)	22 (13.1%)	2.22 (0.98 to 5.06)	0.0573	2.10 (0.91 to 4.86)	0.0841

*The values are given as the number of patients, with the row percentage in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

TABLE V Relationships Among High School Activity Groups and Odds of Cam Morphology According to HNOR at the Age of 23 Years

	HNOR*					
Activity Group	Normal (≥0.17)	CAM Morphology (<0.17)	OR†	P Value	OR Adjusted for Sex†	P Value
Non-athlete	57 (62.0%)	35 (38.0%)	Reference		Reference	
Non-power sports	29 (58.0%)	21 (42.0%)	1.18 (0.58 to 2.38)	0.6451	1.52 (0.71 to 3.53)	0.2637
Power sports	57 (48.3%)	61 (51.7%)	1.74 (1.00 to 3.03)	0.0496	1.91 (1.01 to 3.60)	0.0469
Athletes compared with non-athletes	86 (51.2%)	82 (48.8%)	1.64 (1.00 to 2.69)	0.0485	1.62 (0.92 to 2.83)	0.0934

*The values are given as the number of patients, with the row percentage in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

HNOR, LCEA, and sex as fixed effects in models. Intraclass correlation coefficients (ICCs) were used to describe interrater reliability. Analyses were completed using SAS statistical software version 9.4 (SAS Institute).

Source of Funding

The Iowa Bone Development Study was supported in part by NIH grants R01-DE09551, R01-DE12101, UL1-RR024979, UL1-TR002537, and R56-DE012101; the Roy J. Carver Charitable Trust; and the Delta Dental of Iowa Foundation. One author (A.S.) received an individual stipend of support through a medical student summer research fellowship. The present secondary analysis study did not receive additional external funding.

Results

After excluding participants with missing physical activity data or low-quality DXA scans (n = 62), a total of 317 participants were included for analysis. Of these 317 participants, 207 completed all 3 sequential scans at means of 17.5, 19.8, and 23.4 years. The remaining participants had a DXA scan at the age of 17 years and 1 subsequent scan (at the age of either 19 or 23 years) (Table I). Among the 317 participants, there were no significant differences in age, body mass index, sex, race, daily caloric intake, LCEA, alpha angle, or HNOR at baseline (age of 17 years) among the sporting groups (power sport athlete, non-power sport athlete, and non-athlete) (all $p > 0.05$) (Table II). As expected, physical activity levels were significantly lower on the PAQ-A in the non-athletes (mean and standard deviation, 2.1 ± 0.8) compared with both power sport athletes (2.5 ± 0.8; $p < 0.001$) and non-power sport athletes (2.6 ± 0.8; $p = 0.003$). In addition, power sport athletes were significantly taller ($p = 0.030$) at 173.4 ± 9.4 cm compared with non-athletes at 170.0 ± 9.8 cm.

Alpha Angle

We found excellent interrater reliability for measurement of the alpha angle (ICC, 0.91 [95% confidence interval (CI), 0.82 to 0.96]; $p < 0.001$). The incidence of cam morphology at the age of 17 years was low and did not differ between groups (Table II). Some patients developed cam morphology between the ages of 17 and 23 years, and others did not (Tables I and III, Figs. 2, 3, and 4). Compared with non-athletes, power sport athletes had significantly greater odds of cam morphology at the age of 23 years (odds ratio [OR], 2.93 [95% CI, 1.04 to 8.27]; $p = 0.0424$); however, there was no significant difference between non-power sport athletes and non-athletes (OR, 1.93 [95% CI, 0.53 to 7.03]; $p = 0.3168$) (Table IV). When both types of athletes were combined into a single group, there were greater odds of cam morphology in athletes compared with non-athletes at the age of 23 years, but this did not reach significance (OR, 2.22 [95% CI, 0.98 to 5.06]; $p = 0.057$). Findings were similar following adjustment for sex (Table IV). Linear mixed models also revealed that higher levels of physical activity (higher PAQ-A scores) were

TABLE VI Relationships Among High School Sporting Activity Groups and Odds of Acetabular Dysplasia at the Age of 23 Years

Activity Group	Normal LCEA* (≥24°)	Dysplastic LCEA* (<24°)	OR†	P Value	OR Adjusted for Sex†	P Value
Non-athlete	72 (78.3%)	20 (21.7%)	Reference		Reference	
Non-power sports	41 (82.0%)	9 (18.0%)	0.78 (0.33 to 1.90)	0.5981	0.76 (0.31 to 1.82)	0.5338
Power sports	85 (72.0%)	33 (28.0%)	1.40 (0.74 to 2.65)	0.3037	1.42 (0.75 to 2.70)	0.2818
Athletes compared with non-athletes	126 (75.0%)	42 (25.0%)	1.51 (0.85 to 2.68)	0.1566	1.56 (0.88 to 2.78)	0.1297

*The values are given as the number of patients, with the row percentage in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

TABLE VII Relationships Among High School Sporting Activity Groups and Odds of Pincer Morphology at the Age of 23 Years

Activity Group	No Pincer Morphology (LCEA, ≤40°)*	Pincer Morphology (LCEA, >40°)*	OR†	P Value	OR Adjusted for Sex†	P Value
Non-athlete	88 (95.7%)	4 (4.3%)	Reference		Reference	
Non-power sports	49 (98.0%)	1 (2.0%)	0.45 (0.05 to 4.13)	0.4794	0.53 (0.06 to 5.07)	0.5854
Power sports	115 (97.5%)	3 (2.5%)	0.57 (0.13 to 2.63)	0.4747	0.53 (0.11 to 2.50)	0.4247
Athletes compared with non-athletes	164 (97.6%)	4 (2.4%)	0.71 (0.17 to 3.06)	0.6505	0.63 (0.14 to 2.73)	0.5325

*The values are given as the number of patients, with the row percentage in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

significantly associated with an increase in the alpha angle (beta and standard error, 0.77° ± 0.30°; p = 0.011) from the ages of 17 to 23 years.

HNOR

The interrater reliability for the measurement of HNOR was high (ICC, 0.92 [95% CI, 0.45 to 0.99]; p = 0.004). Similarly, participants who had been power sport athletes in adolescence had significantly greater odds of cam morphology by the HNOR definition (<0.17) compared with non-athletes (OR, 1.74 [95% CI, 1.00 to 3.03]; p = 0.0496) at the age of 23 years (Table V). The results were sustained when adjusted for sex (OR, 1.91 [95% CI, 1.01 to 3.60]; p = 0.0469). Linear mixed models adjusted for sex also revealed that higher levels of physical activity (higher PAQ-A score) were associated with a lower HNOR (beta and standard error, −0.003 ± 0.001; p = 0.003) at the age of 23 years.

Acetabular Morphology

The interrater reliability for the LCEA was also excellent (ICC, 0.99 [95% CI, 0.97 to 0.99]; p < 0.001). Neither acetabular dysplasia (LCEA of <24°) nor pincer morphology (LCEA of >40°) was associated with participation in sports during adolescence in our analyses (all p > 0.05) (Tables VI, VII, and VIII). Additionally, there was no significant longitudinal relationship found between physical activity level (PAQ-A score) and LCEA (beta and standard error, −0.05° ± 0.15°; p = 0.7437) in linear mixed models adjusted for sex.

Discussion

The present study found that participation in power sports (basketball, cheerleading, football, gymnastics, soccer, or volleyball) during adolescence before skeletal maturity was associated with a greater likelihood of the development of femoral cam morphology (alpha angle of >55° and HNOR of <0.17) by the age of 23 years. A high physical activity level (PAQ-A) score, regardless of sport participation, was also associated with the development of cam morphology. We did not observe this relationship with non-power sports (wrestling, baseball, cross-country or track and field, softball, and tennis). These results affirm some of our hypotheses, although sport choice and activity level were not associated with acetabular dysplasia (LCEA of <20°) or pincer morphology (LCEA of >40°). These findings suggest that a higher volume of physical activity and participation in sports with higher peak strain and ground reaction forces during the process of skeletal maturation increase the risk of developing cam morphology during late adolescence or early adulthood.

Bone growth is complete near the end of adolescence or the beginning of early adulthood, but bone tissue continues to reshape and remodel during and after this time period, particularly in those who participate in a higher volume and intensity of physical activity during earlier adolescence[33,35,39-41]. Our findings support a link between sport participation during the final stages of skeletal development and presence of cam morphology at skeletal maturity[10,13-16,21]. The proposed mechanism is that increased stress on an

TABLE VIII Relationships Among High School Sporting Activity Groups and Odds of Both Dysplasia and Pincer Morphology at the Age of 23 Years

Activity Group	Normal LCEA*	LCEA <24° or >40°*	OR†	P Value	OR Adjusted for Sex†	P Value
Non-athlete	68 (73.9%)	24 (26.1%)	Reference		Reference	
Non-power sports	40 (80%)	10 (20%)	0.71 (0.31 to 1.63)	0.4181	0.70 (0.30 to 1.62)	0.4025
Power sports	82 (69.5%)	36 (30.5%)	1.24 (0.68 to 2.29)	0.4820	1.25 (0.68 to 2.30)	0.4738
Athletes compared with non-athletes	122 (72.6%)	46 (27.4%)	1.39 (0.80 to 2.42)	0.2357	1.41 (0.81 to 2.44)	0.2263

*The values are given as the number of patients, with the row percentage in parentheses. †The values are given as the OR, with the 95% CI in parentheses.

open capital femoral physis leads to pathologic bone overgrowth at the anterolateral head-neck junction[18]. This is measured by either the alpha angle or HNOR, and both of these measures of head-neck offset morphology were associated with the volume and type (power or non-power sports) of athletic participation. Therefore, the present study corroborates previous literature that linked increased stress across the femoral physis with structural cam-type femoroacetabular impingement morphology on radiographs[10,13-16,21].

Although the odds were higher in those who participated in power sports, the prevalence of cam morphology defined by an increased alpha angle in our study was lower than those described in reports of elite soccer players (60% to 68%)[13,42], basketball players (89%)[16], football players (72%)[43], and ice hockey players (69%, up to 90% in goalies)[14]. In our cohort, the prevalence of cam morphology defined by an alpha angle of >55° at the age of 23 years was 14.4% for power sport athletes and 13.1% for all athletes (power and non-power sport athletes), compared with 5.4% in non-athletes. Our sample of young adults represents the local population in a single region of the United States and includes both single-sport and multisport athletes with a range of abilities and commitment levels, which may not be comparable with previous studies evaluating elite athletes in a single sport[13,14,43]. The overall volume of peak strain and ground reaction forces experienced in our cohort was likely lower than that typically seen in elite athletes. Furthermore, our study used an anteroposterior hip image taken from DXA scans rather than a Dunn or frog-leg lateral view, which are often more sensitive in identifying smaller cam lesions. We found that the incidence of cam morphology defined by the alpha angle varied substantially from the incidence defined by the HNOR (5.6% by alpha angle and 57.7% by HNOR in power sport athletes). Cam morphology most commonly develops at the 1 to 2 o'clock position of the femoral neck and can be missed on an anteroposterior view, which primarily images the 12 o'clock aspect, and that may explain the difference between these 2 measurements[44]. To detect cam morphology, a 3-view radiographic series (anteroposterior, 45° Dunn lateral, frog-leg lateral) was shown to be best when a computed tomographic (CT) scan was used as the gold standard[45].

In contrast, our study did not support the hypothesis that changes in the acetabulum occur from adolescent athletic participation. The literature supports a lower LCEA in some elite athletic populations; however, it has been debated whether this represents a structural adaption from use or a selection bias favoring athletes with specific hip biomechanics. Ross et al.[46] observed a significantly lower mean LCEA in elite ice hockey goalies (27.3° compared with 29.6°; $p = 0.03$), a position that requires constant deep hip flexion, and Mayes et al.[47] observed a lower LCEA in professional ballet dancers, with 18% having an LCEA of <25° compared with 0% to 3% in other types of professional athletes. To understand the etiology of these observations, longitudinal studies tracking high-level skeletally immature athletes in these specific activities into adulthood are needed.

This study had several limitations. First, this study involved secondary data analyses of Iowa Bone Development Study data not collected for this purpose. We looked only at radiographic evidence of impingement and dysplasia, and we could not query participants with regard to symptoms or obtain additional studies to fully evaluate the presence of open or closed physes, femoroacetabular impingement syndrome, and/or hip dysplasia. Thus, only an association between participation in power sports and greater likelihood of developing cam morphology could be discussed. The images used for this study were obtained from non-weight-bearing DXA scans providing an anteroposterior view of a single hip from the ages of 17 to 23 years of age. Although we found a significant difference between alpha angles in power sport athletes compared with non-athletes, the difference between 42° (non-athlete) and 44° (power sport athlete) is minor and may fall within the error of measurement[48]. The prevalence of cam morphology can also be underestimated by using only the anteroposterior view[49,50]. However, in a systematic review, van Klij et al.[51] found that most studies utilize only the anteroposterior view when reporting the presence of cam morphology, typically with a threshold value of >60°. In addition, hip dysplasia encompasses a wide variety of acetabular shapes and orientations that were not assessed in the present study[52]. The method of LCEA measurement in the current study had limitations due to the inability to define the horizontal axis of the pelvis. The classification of sport groups used in our study precludes analysis on a single sport level, and the cohort size limited further subanalysis by individual sport. Also, the absence of data from younger ages and the inability to report cumulative hours of physical activity throughout the process of skeletal maturation were other limitations.

In conclusion, a higher volume of physical activity and participation in sports with higher peak strain and ground reaction forces during the process of skeletal maturation may increase the risk of developing cam morphology during late adolescence. ■

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References

1. Kowalczuk M, Yeung M, Simunovic N, Ayeni OR. Does femoroacetabular impingement contribute to the development of hip osteoarthritis? A systematic review. Sports Med Arthrosc Rev. 2015;23(4):174-9.

2. Griffin DR, Dickenson EJ, O'Donnell J, Agricola R, Awan T, Beck M, Clohisy JC, Dijkstra HP, Falvey E, Gimpel M, Hinman RS, Hölmich P, Kassarjian A, Martin HD, Martin R, Mather RC, Philippon MJ, Reiman MP, Takla A, Thorborg K, Walker S, Weir A, Bennell KL. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. Br J Sports Med. 2016 Oct; 50(19):1169-76.

3. Reichenbach S, Jüni P, Werlen S, Nüesch E, Pfirrmann CW, Trelle S, Odermatt A, Hofstetter W, Ganz R, Leunig M. Prevalence of cam-type deformity on hip magnetic resonance imaging in young males: a cross-sectional study. Arthritis Care Res (Hoboken). 2010 Sep;62(9):1319-27.

4. Frank JM, Harris JD, Erickson BJ, Slikker W 3rd, Bush-Joseph CA, Salata MJ, Nho SJ. Prevalence of femoroacetabular impingement imaging findings in asymptomatic volunteers: a systematic review. Arthroscopy. 2015 Jun;31(6):1199-204.

5. Hack K, Di Primio G, Rakhra K, Beaulé PE. Prevalence of cam-type femoroacetabular impingement morphology in asymptomatic volunteers. J Bone Joint Surg Am. 2010 Oct 20;92(14):2436-44.

6. Gosvig KK, Jacobsen S, Sonne-Holm S, Palm H, Troelsen A. Prevalence of malformations of the hip joint and their relationship to sex, groin pain, and risk of osteoarthritis: a population-based survey. J Bone Joint Surg Am. 2010 May;92(5): 1162-9.

7. Grantham WJ, Philippon MJ. Etiology and pathomechanics of femoroacetabular impingement. Curr Rev Musculoskelet Med. 2019 Jul 5;12(3): 253-9.

8. Siebenrock KA, Ferner F, Noble PC, Santore RF, Werlen S, Mamisch TC. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. Clin Orthop Relat Res. 2011; 469(11):3229-40.

9. Siebenrock KA, Schwab JM. The cam-type deformity—what is it: SCFE, osteophyte, or a new disease? J Pediatr Orthop. 2013 Jul-Aug;33(Suppl 1):S121-5.

10. Nepple JJ, Vigdorchik JM, Clohisy JC. What is the association between sports participation and the development of proximal femoral cam deformity? A systematic review and meta-analysis. Am J Sports Med. 2015 Nov;43(11):2833-40.

11. van Klij P, Heijboer MP, Ginai AZ, Verhaar JAN, Waarsing JH, Agricola R. Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-year follow-up. Br J Sports Med. 2019 May;53(9):532-8.

12. Hingsammer AM, Bixby S, Zurakowski D, Yen YM, Kim YJ. How do acetabular version and femoral head coverage change with skeletal maturity? Clin Orthop Relat Res. 2015 Apr;473(4):1224-33.

13. Agricola R, Heijboer MP, Ginai AZ, Roels P, Zadpoor AA, Verhaar JA, Weinans H, Waarsing JH. A cam deformity is gradually acquired during skeletal maturation in adolescent and young male soccer players: a prospective study with minimum 2-year follow-up. Am J Sports Med. 2014 Apr;42(4):798-806.

14. Lerebours F, Robertson W, Neri B, Schulz B, Youm T, Limpisvasti O. Prevalence of cam-type morphology in elite ice hockey players. Am J Sports Med. 2016 Apr; 44(4):1024-30.

15. Siebenrock KA, Kaschka I, Frauchiger L, Werlen S, Schwab JM. Prevalence of cam-type deformity and hip pain in elite ice hockey players before and after the end of growth. Am J Sports Med. 2013 Oct;41(10):2308-13.

16. Siebenrock KA, Ferner F, Noble PC, Santore RF, Werlen S, Mamisch TC. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. Clin Orthop Relat Res. 2011 Nov;469(11):3229-40.

17. Knapik DM, Gaudiani MA, Camilleri BE, Nho SJ, Voos JE, Salata MJ. Reported prevalence of radiographic cam deformity based on sport: a systematic review of the current literature. Orthop J Sports Med. 2019 Mar;7(3): 2325967119830873.

18. Roels P, Agricola R, Oei EH, Weinans H, Campoli G, Zadpoor AA. Mechanical factors explain development of cam-type deformity. Osteoarthritis Cartilage. 2014 Dec;22(12):2074-82.

19. Grammatopoulos G, Jamieson P, Dobransky J, Rakhra K, Carsen S, Beaulé PE. Acetabular version increases during adolescence secondary to reduced anterior femoral head coverage. Clin Orthop Relat Res. 2019 Nov;477(11): 2470-8.

20. Fraser JL, Sugimoto D, Yeng YM, d'Hemecourt PA, Stracciolini A. Bony morphology of femoroacetabular impingement in young female dancers and single-sport athletes. Orthop J Sports Med. 2017;5(8):2325967117723108.

21. Kapron AL, Peters CL, Aoki SK, Beckmann JT, Erickson JA, Anderson MB, Pelt CE. The prevalence of radiographic findings of structural hip deformities in female collegiate athletes. Am J Sports Med. 2015 Jun;43(6):1324-30.

22. Hamilton D, Aronsen P, Løken JH, Berg IM, Skotheim R, Hopper D, Clarke A, Briffa NK. Dance training intensity at 11-14 years is associated with femoral torsion in classical ballet dancers. Br J Sports Med. 2006;40(4):299-303.

23. Agricola R, Heijboer MP, Bierma-Zeinstra SMA, Verhaar JAN, Weinans H, Waarsing JH. Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). Ann Rheum Dis. 2013;72(6):918-23.

24. Clohisy JC, Dobson MA, Robison JF, Warth LC, Zheng J, Liu SS, Yehyawi TM, Callaghan JJ. Radiographic structural abnormalities associated with premature, natural hip-joint failure. J Bone Joint Surg Am. 2011;93(Suppl 2):3-9.

25. Ganz R, Leunig M, Leunig-Ganz K, Harris WH. The etiology of osteoarthritis of the hip: an integrated mechanical concept. Clin Orthop Relat Res. 2008 Feb;466(2): 264-72.

26. Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res. 2003; (417):112-20.

27. Sankar WN, Nevitt M, Parvizi J, Felson DT, Agricola R, Leunig M. Femoroacetabular impingement: defining the condition and its role in the pathophysiology of osteoarthritis. J Am Acad Orthop Surg. 2013;21(Suppl 1):S7-15.

28. Harris WH. Etiology of osteoarthritis of the hip. Clin Orthop Relat Res. 1986 Dec; (213):20-33.

29. Notzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg Br. 2002 May;84(4):556-60.

30. Peelle MW, Della Rocca GJ, Maloney WJ, Curry MC, Clohisy JC. Acetabular and femoral radiographic abnormalities associated with labral tears. Clin Orthop Relat Res. 2005 Dec;(441):327-33.

31. Eichenberger Gilmore JM, Pauley CA, Burns TL, Torner JC, Letuchy EM, Janz KF, Willing MC, Levy SM. A hip analysis protocol for pediatric bone densitometry: the Iowa Bone Development Study. J Clin Densitom. 2010 Oct-Dec;13(4):361-9.

32. Kowalski KC, Crocker PRE, Faulkner RA. Validation of the Physical Activity Questionnaire for Older Children. Pediatric Exercise Science. 1997;9(2):174-86.

33. Ward RC, Janz KF, Letuchy EM, Peterson C, Levy SM. Contribution of high school sport participation to young adult bone strength. Med Sci Sports Exerc. 2019 May; 51(5):1064-72.

34. Weaver CM, Gordon CM, Janz KF, Kalkwarf HJ, Lappe JM, Lewis R, O'Karma M, Wallace TC, Zemel BS. The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations. Osteoporos Int. 2016 Apr;27(4): 1281-386.

35. Groothausen J, Siemer H, Kemper HCG, Twisk J, Welten DC. Influence of peak strain on lumbar bone mineral density: an analysis of 15-year physical activity in young males and females. Pediatr Exerc Sci. 1997;9(2):159.

36. Clohisy JC, Carlisle JC, Beaule PE, Kim YJ, Trousdale RT, Sierra RJ, Leunig M, Schoenecker PL, Millis MB. A systematic approach to the plain radiographic evaluation of the young adult hip. J Bone Joint Surg Am. 2008 Nov;90(Suppl 4): 47-66.

37. Peelle MW, Della Rocca GJ, Maloney WJ, Curry MC, Clohisy JC. Acetabular and femoral radiographic abnormalities associated with labral tears. Clin Orthop Relat Res. 2005;(441):327-33.

38. Eijer H, Leunig M, Mahomed MN, Ganz R. Cross-table lateral radiographs for screening of anterior femoral head-neck offset in patients with femoro-acetabular impingement. Hip Int. 2001;11(1):37-41.

39. Janz KF, Letuchy EM, Burns TL, Eichenberger Gilmore JM, Torner JC, Levy SM. Objectively measured physical activity trajectories predict adolescent bone strength: Iowa Bone Development Study. Br J Sports Med. 2014 Jul;48(13): 1032-6.

40. Duckham RL, Baxter-Jones AD, Johnston JD, Vatanparast H, Cooper D, Kontulainen S. Does physical activity in adolescence have site-specific and sex-specific benefits on young adult bone size, content, and estimated strength? J Bone Miner Res. 2014 Feb;29(2):479-86.

41. Gunter KB, Almstedt HC, Janz KF. Physical activity in childhood may be the key to optimizing lifespan skeletal health. Exerc Sport Sci Rev. 2012 Jan;40(1):13-21.

42. Gerhardt MB, Romero AA, Silvers HJ, Harris DJ, Watanabe D, Mandelbaum BR. The prevalence of radiographic hip abnormalities in elite soccer players. Am J Sports Med. 2012 Mar;40(3):584-8.

43. Kapron AL, Anderson AE, Aoki SK, Phillips LG, Petron DJ, Toth R, Peters CL. Radiographic prevalence of femoroacetabular impingement in collegiate football players: AAOS Exhibit Selection. J Bone Joint Surg Am. 2011 Oct 5;93(19):e111(1-10).

44. Clohisy JC, Carlisle JC, Trousdale R, Kim YJ, Beaule PE, Morgan P, Steger-May K, Schoenecker PL, Millis M. Radiographic evaluation of the hip has limited reliability. Clin Orthop Relat Res. 2009 Mar;467(3):666-75.

45. Nepple JJ, Martel JM, Kim YJ, Zaltz I, Clohisy JC. Do plain radiographs correlate with CT for imaging of cam-type femoroacetabular impingement? Clin Orthop Relat Res. 2012 Dec;470(12):3313-20.

46. Ross JR, Bedi A, Stone RM, Sibilsky Enselman E, Kelly BT, Larson CM. Characterization of symptomatic hip impingement in butterfly ice hockey goalies. Arthroscopy. 2015;31(4):635-42.

47. Mayes S, Ferris A-R, Smith P, Garnham A, Cook J. Bony morphology of the hip in professional ballet dancers compared to athletes. Eur Radiol. 2017; 27(7):3042-9.
48. Carreira DS, Emmons BR. The reliability of commonly used radiographic parameters in the evaluation of the pre-arthritic hip: a systematic review. JBJS Rev. 2019 Feb;7(2):e3.
49. Gosvig KK, Jacobsen S, Palm H, Sonne-Holm S, Magnusson E. A new radiological index for assessing asphericity of the femoral head in cam impingement. J Bone Joint Surg Br. 2007 Oct;89(10):1309-16.
50. Barton C, Salineros MJ, Rakhra KS, Beaulé PE. Validity of the alpha angle measurement on plain radiographs in the evaluation of cam-type femoroacetabular impingement. Clin Orthop Relat Res. 2011 Feb;469(2):464-9.
51. van Klij P, Reiman MP, Waarsing JH, Reijman M, Bramer WM, Verhaar JAN, Agricola R. Classifying cam morphology by the alpha angle: a systematic review on threshold values. Orthop J Sports Med. 2020 Aug;8(8):2325967120938312.
52. Nepple JJ, Wells J, Ross JR, Bedi A, Schoenecker PL, Clohisy JC. Three patterns of acetabular deficiency are common in young adult patients with acetabular dysplasia. Clin Orthop Relat Res. 2017 Apr;475(4):1037-44.