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RESEARCH

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# Asymmetric bony hip morphology in asymptomatic professional baseball pitchers: a cross-sectional cohort study

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## Abstract

**Background** Cam (femoral head asphericity) and pincer (acetabular overcoverage) morphologies at the hip are risk factors for femoroacetabular impingement syndrome and labral tears. Baseball pitchers repetitively load their hips during throwing which may place them at risk of developing cam or pincer morphology. These morphologies may develop asymmetrically as baseball pitchers load one hip more than the other during throwing.

**Methods** A cross-sectional cohort study compared bilateral bony hip morphology in asymptomatic male professional baseball pitchers ($n = 16$) and cross-country runner controls ($n = 15$). Cam morphology (alpha angle at 12, 1, 2, and 3 o'clock positions), and acetabular lateral center-edge angle and version were assessed from computed tomography images of the hip in the drive leg (i.e., leg on the same side as the pitching or preferred throwing arm) and contralateral stride leg.

**Results** Maximum alpha angle (adjusted for body mass and age) across clock positions in the drive and stride legs of pitchers was 71.7° (95%CI, 57.6° to 85.8°) and 54.3° (95%CI, 39.1° to 69.5°), respectively (adjusted $p$ value = 0.01). There were no differences in alpha angle between legs in runners or between stride legs in pitchers and runners. Pitchers were 8.8 (95%CI, 1.5 to 36.6) times more likely to have a cam morphology (alpha angle ≥ 60°) at one or more clock positions in a hip compared to runners. There was a greater frequency of an alpha angle ≥ 60° at the 3 o'clock position in the drive compared to stride leg of pitchers ($p = 0.03$). The drive leg in pitchers also had a greater frequency of an alpha angle ≥ 60° at one, two, or three clock positions compared to the stride leg (all $p < 0.05$). The drive leg in pitchers had a lower frequency of elevated lateral center-edge angle compared to the stride leg ($p = 0.03$).

**Conclusions** Asymptomatic professional baseball pitchers exhibited a greater prevalence and larger cam morphology in the drive leg on the same side as the throwing arm compared to the contralateral stride leg. Whether the observed morphological variations have long-term consequences in terms of the development of pain and joint damage requires further investigation.

**Keywords** Arthritis, Cam morphology, Femoroacetabular impingement, Hip joint, Pitching, Proximal femur

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## Introduction

Cam (femoral head asphericity) and pincer (acetabular overcoverage) morphologies at the hip are often asymptomatic, [1, 2] but are associated with a heightened risk for joint pain, labral tears, and osteoarthritis [3–8]. Cam morphology is twice as common in athletes than the general population indicating a role for mechanical loading in its formation [9]. Around two-thirds of athletes exhibit cam morphology, particularly players of American and Australian football, soccer and ice hockey [2, 10]. In contrast, cam morphology is present in less than 25% of the general population [2, 9].

Baseball players may be at risk of developing a cam morphology as they repetitively load their hips during throwing [11–15]. Forces initiated in the lower extremities are transferred via the kinetic chain through the hips to the pelvis, trunk, upper extremity, and ultimately the ball. Previous reports have indicated cam-type morphometry prevalence rates in baseball players ranging from 40 to 70%, depending on population studied and the imaging modality and diagnostic criterion used [13, 15].

Baseball players may have asymmetrical development of hip bony morphology as throwing introduces asymmetrical loading. The stride leg (i.e., leg opposite the pitching arm) generates greater vertical ground reaction forces during pitching than the contralateral drive leg [16, 17] and exhibits greater bone density and estimated strength [18, 19]. This suggests the stride leg is exposed to greater loading and may have a higher prevalence of altered hip bony morphology. However, cam morphology was reportedly twice as prevalent in the drive leg compared to stride leg of right-handed pitchers [15]. Similarly, in female softball pitchers, we recently reported a higher prevalence of cam morphology in drive legs across three clock positions compared with stride legs suggesting drive legs had more extensive cam morphology [20].

To further establish the prevalence of altered hip morphology in baseball pitchers and whether they exhibit asymmetry, the aims of the current study were to assess bone morphology in the hips of: (1) asymptomatic male professional baseball pitchers compared to controls (cross-country runners) and (2) stride and drive leg of baseball pitchers. Cross-country athletes were included as the control cohort as they are physically active but load their hips symmetrically and do not appear to have an increased rate of altered hip morphology, labral tears, or osteoarthritis [20–22].

## Materials and methods

### Study design and participants

A cross-sectional cohort study was undertaken to compare bilateral bony hip morphology in male professional baseball pitchers ('Pitch' group) and cross-country runner controls ('Run' group). Participants were part of a prior study exploring asymmetry of proximal femur bone health [19].

Pitchers were included if they were currently playing as a pitcher in professional Minor League Baseball (Triple-A level). They were recruited from three different teams, with 4–7 pitchers recruited from each team. Controls were included if they: (1) had a history of competing in cross-country within the National Collegiate Athletic Association and (2) had not participated more than twice per month for > 6 months in activities potentially involving asymmetrical lower extremity loading (e.g. soccer, fencing, ten-pin bowling, baseball, softball).

Exclusion criteria for both groups were: (1) a history of hip disease, injury, or surgery; (2) hip pain in the past 2 years; (3) known metabolic bone disease; (4) a history of a femoral fracture or stress fracture; (5) implanted metal within the femur, and; (6) exposure to lower extremity immobilization for more than 2 weeks within the past 2 years.

The study was performed in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board and Machine Produced Radiation Safety Committee of Indiana University (study ID#1503934363). All participants provided written informed consent.

A calibrated stadiometer (Seca 264; Seca GmbH & Co., Hamburg, Germany) and scale (MS140-300; Brecknell, Fairmont, MN) was used to measure height and weight, respectively. The leg on the same side as the pitching arm in pitchers and dominant arm in controls was designated the drive leg ('Drive' group). The contralateral leg was designated the stride leg ('Stride' group). Total hip and femoral neck areal bone mineral density (aBMD) in each leg was measured by dual-energy x-ray absorptiometry (Discovery-W; Hologic, Inc., Waltham, MA, USA), with the data previously reported [18].

### Computed tomography

A multislice CT scanner (Biograph128 mCT; Siemens Healthcare, Knoxville, TN) operating at 120 kVp, 320 mAs, 128 × 0.6 collimation, and pitch 0.8 was used to obtain scans. Scans imaged from 1 cm above the acetabulum to 5 cm below the lesser trochanter. A B60s convolution kernel was used to axially reconstruct images at 1.0 mm slice thickness with a 512 × 512 matrix and 50 cm reconstruction diameter (reconstructed voxel size = $0.976 \times 0.976 \times 1.0$ mm$^3$).

Scans were analyzed as we have previously reported [20] using OsiriX Software (V.6.0.2, Pixmeo, Geneva, Switzerland). The software allows for multiplanar 3D reconstructions so that radial images could be sampled around the axis of the femoral neck at 30° intervals. The coronal axis (12 o'clock position) was positioned parallel to the axis of the proximal femur diaphysis. Femoral head asphericity (cam morphology) was assessed by measuring alpha angle on radial slices at the 12, 1, 2, and 3 o'clock positions (Fig. 1A). An alpha angle of ≥ 60° was used as the criterion for the presence of a cam morphology [23]. We have previously reported intra- and inter-observer intra-class correlation coefficients of 0.99 and 0.97 for repeat alpha angle measures, respectively [24]. Presence of a pincer morphology (acetabular overcoverage) and acetabular dysplasia were determined by measuring the lateral center-edge angle (LCEA) (Fig. 1B) and acetabular version (Fig. 1C). A LCEA ≤ 20° and ≥ 40° were used to indicate acetabular dysplasia and pincer morphology, respectively [25]. Acetabular retroversion and anteversion were indicated by version angles of ≤ 10° and ≥ 20°, respectively [26].

#### Statistical analyses

IBM SPSS Statistics (v29.0.1.0; IBM Corporation, Armonk, NY) was used to perform two-tailed analyses with α = 0.05. An a priori sample size calculation was not performed as the study was exploratory and the sample size was governed by the availability of CT scans from participants enrolled in a prior study exploring proximal femur bone health [19].

Unpaired t-tests were used to compare participant characteristics between groups. Linear mixed-effects models with leg (Drive vs. Stride) as a repeated variable were performed for alpha angle at each clock position, acetabular version, and LCEA. Fixed effects for sport (Pitch vs. Run) and leg (Drive vs. Stride) and their interaction were included with a random intercept for subject. Body mass and age were included as covariates and covariate-adjusted results reported. Height and total years playing were not included as covariates as they were collinear with mass and age, respectively (Pearson correlation coefficients > 0.7 and variance inflation factors > 5).

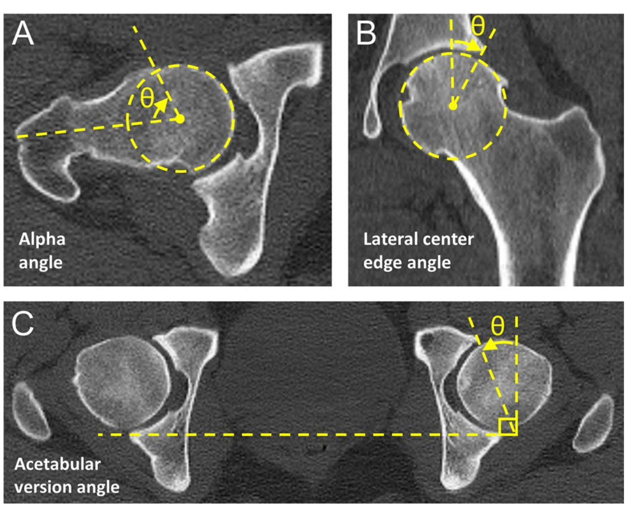


**Fig. 1** Morphometry assessment. **A** Alpha angle was measured between a line connecting the centers of the femoral head and its neck and a line from the center of the femoral head to where the distance from the center of the head exceeded its radius. **B** Lateral center edge angle was measured as the angle between the vertical axis of the pelvis and a line connecting the center of the femoral head and lateral acetabular margin. **C** Acetabular version was measured by a line drawn joining the posterior corners of the bilateral acetabulum and tangential lines drawn from the posterior corner to provide a true sagittal line for each acetabulum. The angle between the sagittal line and a line connecting the anterior and posterior corners of the acetabulum was recorded as acetabular version angle. Image reprinted without modification from: Warden SJ, et al. *Scientific Reports* 2025;15:3262, under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)

Significant interaction terms were explored using one-way models with covariates (body mass and age) to assess differences between: (1) sports (Pitch vs. Run) for each leg and (2) legs (Drive vs. Stride) within each sport group (four post-hoc comparisons per outcome). The false discovery rate approach of Benjamini and Hochberg [27] was used to correct for multiple comparisons and q-values (i.e., adjusted p-values) reported with a significance threshold set at q ≤ 0.05.

Binary logistic regression was used to compare the presence of alpha angle of ≥ 60°, acetabular version ≥ 20° and LCEA ≥ 40° between Pitch and Run adjusting for age and body mass. Unadjusted and adjusted odds ratios with 95% confidence intervals were reported. Generalized estimating equations with a logit link were used to compare the presence of alpha angle of ≥ 60°, acetabular version ≥ 20° and LCEA ≥ 40° between Drive and Stride in Pitch, accounting for within-subject correlation. Models were adjusted for age and body mass. Adjustments for multiple comparisons were not applied to the level of significance as the principal planned comparisons were within one group (i.e., Drive vs. Stride within the Pitch group).

## Results

Pitch ($n = 16$) were older, taller, heavier, and had greater BMI than Run ($n = 15$) (all $p < 0.001$) (Table 1). Both groups started playing their sport prior to the self-reported age of their adolescent growth spurt. Pitch had 5.4% (95% CI, 3.1 to 7.7%) and 3.2% (95% CI, 1.3 to 5.2%) stride-to-drive leg differences in total hip and femoral neck aBMD, respectively (all $p < 0.01$). There were no side-to-side differences in total hip or femoral neck aBMD in Run (all $p = 0.22$ to 0.53).

Example three-dimensionally reconstructed CT scans of the bilateral hips in a runner and baseball pitcher are shown in Fig. 2. There was a significant interaction between sport (Pitch vs. Run) and leg (Drive vs. Stride) for maximum alpha angle across clock positions ($p = 0.001$). The interaction resulted from the maximum alpha angle (adjusted for body mass and age) in the Drive leg of Pitch (71.7°; 95%CI, 57.6° to 85.8°) being greater than in their Stride leg (54.3°; 95%CI, 39.1° to 69.5°) ($q = 0.03$). Maximum alpha angle (adjusted for body mass

**Table 1** Participant characteristics[a]

| Characteristic | Run | Pitch |
|---|---|---|
| **n** | **15** | **16** |
| Age (yr) | 22.1 ± 2.7 | 26.8 ± 2.1* |
| Height (m) | 1.79 ± 0.07 | 1.92 ± 0.05* |
| Mass (kg) | 67.7 ± 7.4 | 94.4 ± 8.5* |
| Body mass index (kg/m$^2$) | 21.1 ± 1.7 | 25.5 ± 2.0* |
| Drive leg (R/L)[b] | 15/0 | 13/3 |
| Estimated age of adolescent growth spurt (yr) | 13.9 ± 1.9 | 14.2 ± 1.4 |
| Age started playing (yr) | 7.2 ± 2.8 | 8.5 ± 2.5 |
| Total years playing (yr) | 14.8 ± 3.2 | 18.1 ± 2.9* |
| Professional baseball games played (games) | —— | 181 ± 89 |
| Professional baseball innings pitched (innings) | —— | 616 ± 334 |

[a]Data are mean ± SD, except for frequencies.

[b]Drive leg is on the same side (i.e., ipsilateral) to the preferred throwing arm

*p<0.001 compared to Run (unpaired t-test)

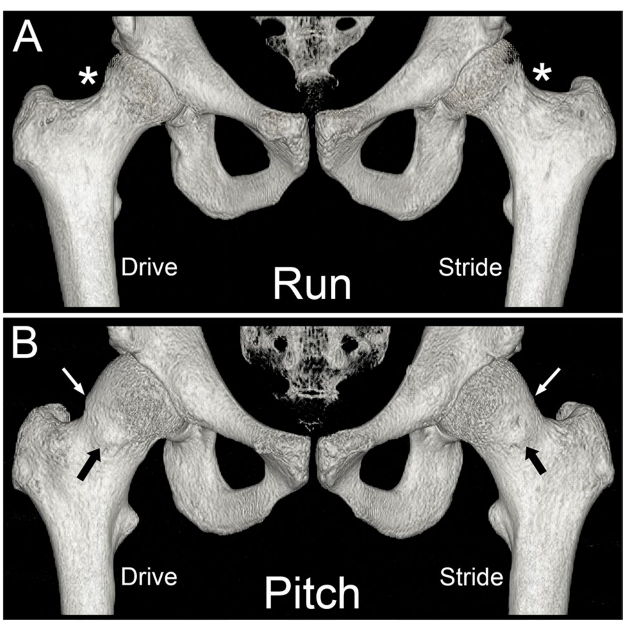


**Fig. 2** Three-dimensionally reconstructed CT scans in a runner (**A**) and baseball pitcher (**B**). Alpha angles bilaterally at the femoral head-neck junction (*) in the runner ranged from 33.3° to 40.1°, depending on clock position. In the baseball pitcher, bilateral cam morphologies (alpha angles ≥ 60°) were present superiorly (white arrows) and anteriorly (black arrows) with larger defects in the drive leg. Alpha angle in the drive leg was 82.4°, 84.7°, 68.2°, and 67.5° at the 12, 1, 2, and 3 o-clock position, respectively. In the stride leg, alpha angle at the 12, 1, 2, and 3 o-clock position was 77.9°, 77.6°, 71.2°, and 65.6°, respectively

and age) in Run did not differ between their Drive (55.2°; 95%CI, 39.3° to 71.2°) and Stride (50.0°; 95%CI, 35.1° to 64.8°) legs ($q = 0.15$).

There was a significant interaction between sport (Pitch vs. Run) and leg (Drive vs. Stride) for alpha angle at each clock position (all $p = 0.001$ to 0.05) (Fig. 3A-D). The interaction at the 2 and 3 o'clock positions resulted from the Drive leg in Pitch having a greater alpha angle than in the Stride leg (all $q = 0.01$ to 0.04). There were no Drive vs. Stride leg differences at any clock position for alpha angle in Run (all $q = 0.15$ to 0.90) or differences between Pitch and Run for alpha angle in either the Drive or Stride leg at any clock position (all $q = 0.16$ to 0.94). There was no significant interaction or main effects for sport (Pitch vs. Run) and leg (Drive vs. Stride) for acetabular version or LCEA (all $p = 0.16$ to 0.61) (Fig. 3E, F).

Eleven-out-of-16 pitchers (69%) had an alpha angle ≥ 60° at one or more clock positions within either hip, with six (38%) having bilaterally increased alpha angles. Having an alpha angle ≥ 60° at one or more clock positions within either hip was 8.8 (95%CI, 1.7 to 45.8) times more prevalent in Pitch compared to Run (3-out-of-15 individuals [20%]) ($p = 0.01$) (Fig. 4A). The odds ratio decreased to 2.2 (95%CI, 0.1 to 53.5) when adjusted for body mass and age ($p = 0.63$). Pitch had a greater frequency of an alpha angle ≥ 60° at the 3 o'clock position in Drive compared to Stride ($p = 0.01$) (Fig. 4B). No differences were observed at the other clock positions (all $p = 0.08$ to 0.17). Drive in Pitch had a greater frequency of an alpha angle ≥ 60° at one, two, or three clock positions compared to Stride (all $p = 0.01$ to 0.03) (Fig. 4C). Pitch had a higher frequency of LCEA ≥ 40° in Stride vs. Drive ($p = 0.03$) (Fig. 4D). There was no Drive-to-Stride difference in the likelihood of having acetabular version ≥ 20° in Pitch ($p = 0.08$, *data not shown*).

## Discussion

Asymptomatic professional baseball pitchers in this study exhibited an elevated prevalence of cam morphology compared with running controls. Over two-thirds of players had an alpha angle ≥ 60° at one or more clock positions within either hip. This prevalence rate matches that reported in other athlete groups who multidirectionally load their hips, including American and Australian football, soccer and ice hockey players [2, 10] The prevalence rate also matches that reported by Uquillas et al. [15] who found 71% of 80 prospective professional baseball players exhibited radiological evidence of a cam morphology (alpha angle > 55°). In contrast, 1-in-5 cross-country runners in the current study had an elevated alpha angle within either hip, matching the 22–23% prevalence rate reported in the general population [2, 9]. The later observation supports the inclusion of runners an asymptomatic athletic control group. Overall, having

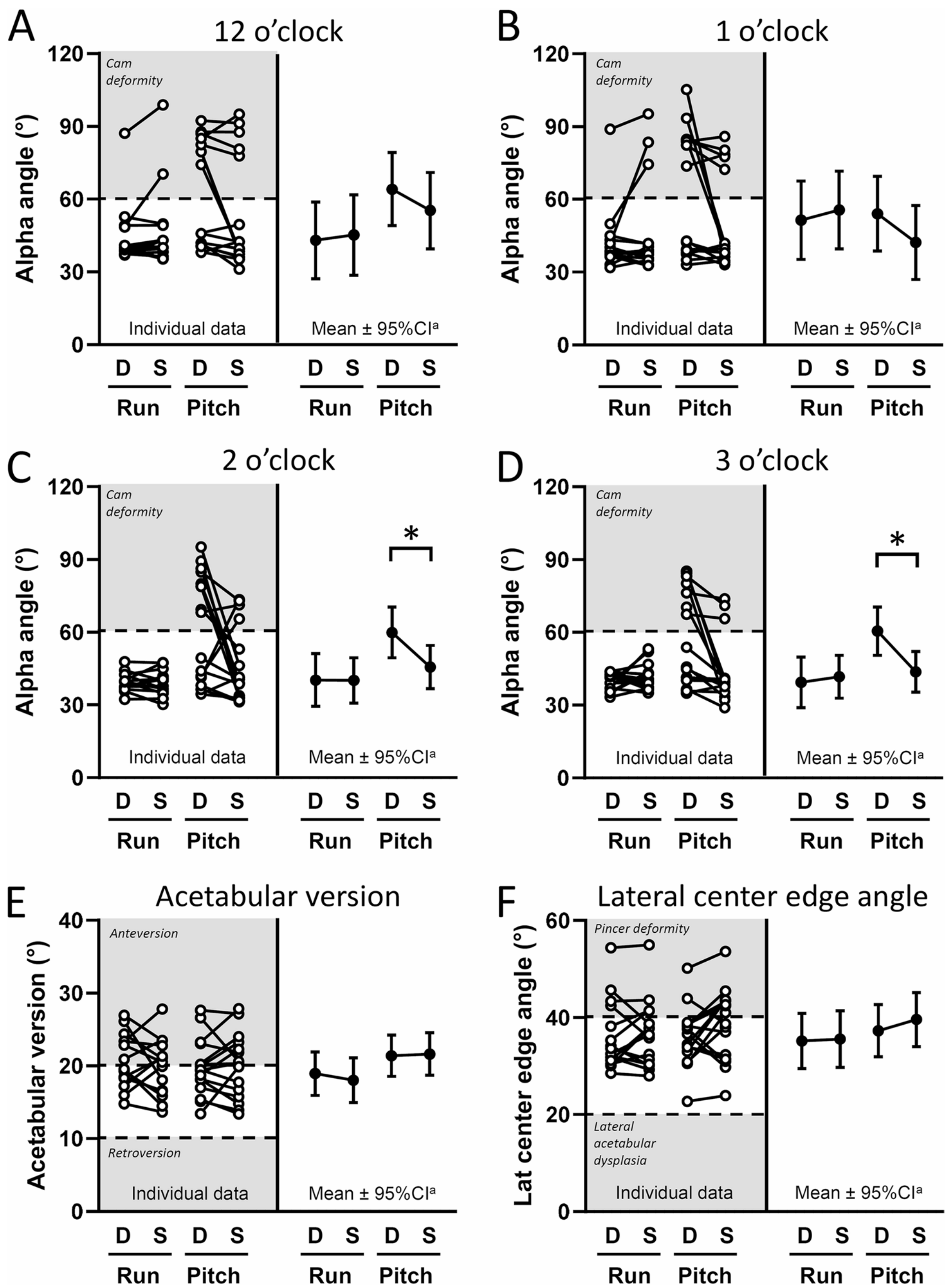


**Fig. 3** Alpha angle (°) in the proximal femur at the: (**A**) 12, (**B**) 1, (**C**) 2, and (**D**) 3 o'clock positions and (**E**) acetabular version and (**F**) lateral center edge angle in the drive ('D') and stride ('S') legs of baseball pitchers ('Pitch') and cross-country runners ('Run'). The left side of each graph shows the paired data for each individual participant, with the shaded area indicating altered morphology. The right side of each graph shows the group mean and 95% confidence interval (CI). [a]Adjusted for body mass and age. *$q < 0.05$ for leg (Drive vs. Stride) in pitchers

an alpha angle ≥ 60° at one or more clock positions was 8.8 (95%CI, 1.5 to 36.6) times more prevalent in baseball pitchers compared to the cross-country runners.

Cam morphology in the baseball pitchers likely resulted from elevated loading across the hip during throwing, particularly to loads introduced prior to and across skeletal maturation. Cam morphology appears to develop prior to skeletal maturity in response to mechanical loading introduced across the growth plate at the femoral head-neck junction [28–30]. Pitchers in the current study started playing well prior to their adolescent growth period (8.5 ± 2.5 yrs vs. 14.2 ± 1.4 yrs, respectively) and pitchers repetitively load their lower extremities, with vertical ground reaction forces equivalent to 1.2–1.5 times body weight generated during each pitch [31–33]. The cross-country runners also started their sport prior

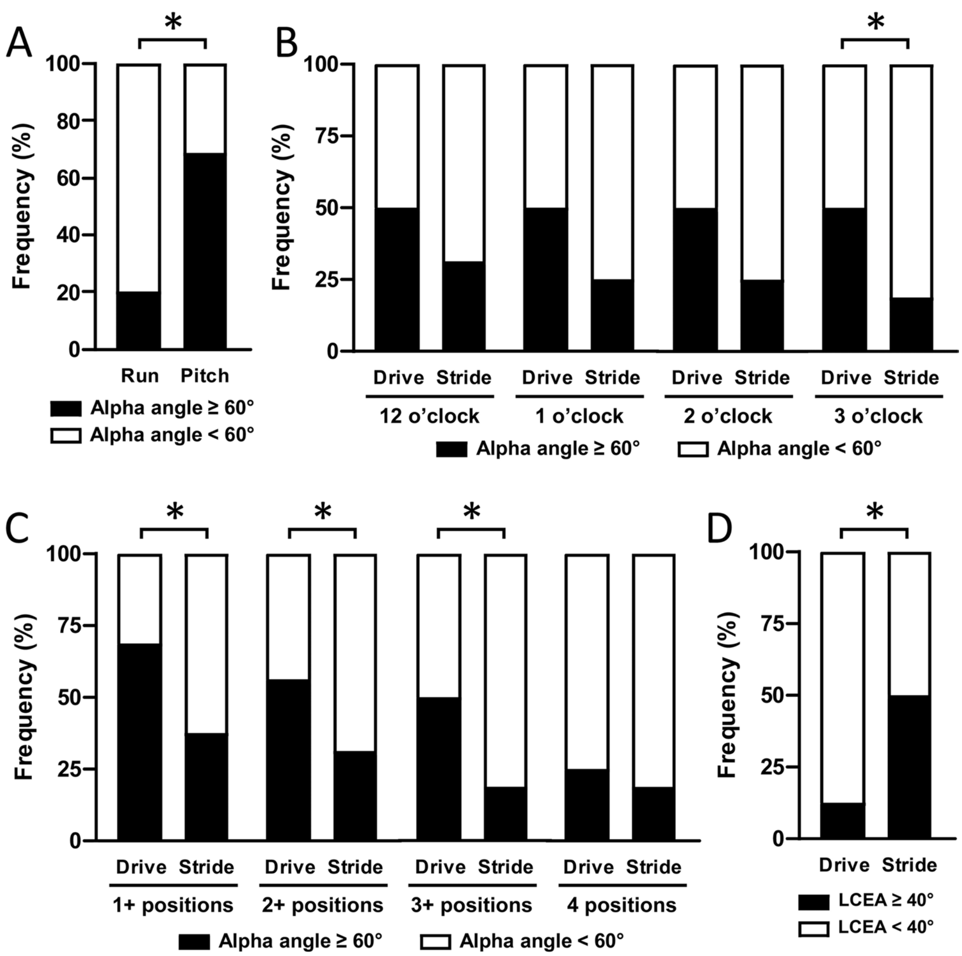


**Fig. 4** Frequencies of elevated alpha angle and lateral center edge angle (LCEA). **A** Frequency of alpha angle ≥ 60° in either leg of baseball pitchers ('Pitch') and cross-country runners ('Run'). **B** Occurrence of an alpha angle ≥ 60° at each clock position in the Drive and Stride legs of baseball pitchers. **C** Occurrence of an alpha angle ≥ 60° at 1, 2, 3 or 4 clock positions in the Drive and Stride legs of baseball pitchers. **D** Frequency of LCEA ≥ 40° in the Drive and Stride legs of baseball pitchers. *$p < 0.05$

to their adolescent growth period (7.2 ± 2.8 yrs vs. 13.9 ± 1.9 yrs, respectively), and running also repetitively loads the lower extremities and with higher numbers of cycles and ground reaction forces relative to body weight than pitching [34]. However, ground reaction forces do not quantify internal loads which are greater than foot-ground impacts due to muscle generated forces [35].

Baseball pitchers weighed more than cross-country runners in the current study so absolute loads across the hip experienced by the pitchers were likely greater. Adjusting the odds ratio between pitchers and runners for age and current body mass diminished the group differences. However, we do not know whether the mass of the pitchers differed from runners during adolescence when cam morphology is thought to develop. Baseball pitchers also load their hips in positions and directions thought to be consequential with regards to the development of cam morphometry—namely, hip flexion, rotation and adduction [30]. In particular, baseball pitchers approach the extremes of hip rotation during pitching [11].

Baseball pitchers in the current study exhibited asymmetry between their drive (i.e., leg on the same side of the pitching arm) and stride legs. During pitching, the drive leg pushes the body forward while the front leg serves as a stable base for the pelvis and the trunk to rotate over and transform forward and vertical momentum into rotational components [32, 36]. Based on the greater rotation and ground reaction forces experienced by the stride leg during pitching [16, 17] and our previous findings of greater proximal femur bone density and estimated strength in this leg, [18, 19] we anticipated the stride leg would have a higher prevalence of cam morphology. The opposite was observed. Compared to the stride leg, the drive leg had a greater alpha angle at each clock position, had a higher prevalence of cam morphology, and a had more extensive cam morphology (indicated by a greater prevalence of morphology at three or more clock positions).

Few studies have reported on the development of asymmetrical bony hip morphology in sports with asymmetrical loading. Dickenson et al.[37] reported a higher prevalence of cam morphology in the trail legs of elite golf players; however, the overall prevalence of cam morphology was very low (8.2%; 9-out-of-110 hips). Soccer players have been reported to have a higher prevalence of cam morphometry and be more likely to undergo arthroscopic treatment of FAI syndrome on their dominant lower extremity (i.e., preferred kicking leg); [38, 39] however, this observation has not been supported by others [40]. Consistent with the current study, Uquillas et al. [15] reported cam morphology was twice as prevalent in the drive leg (71%) compared to the stride leg (48%) of right-handed pitchers ($n$ = 62). Interestingly, Uquillas et al. [15] did not find the same in left-handed pitchers ($n$ = 18) who had equal side-to-side prevalence of cam morphology (56% prevalence in both legs). In the current study, all of the three left-handed pitchers had a cam morphology in their drive leg (100%) and only one had a cam morphology in the stride leg (33%). In right-handed pitchers, the prevalence rates were 62% and 38% in the drive and stride legs, respectively.

The greater prevalence and larger cam morphology in the drive leg of baseball pitchers supports our recent study in female softball pitchers where we found a greater prevalence of cam morphology at three or more clock positions in the drive leg compared to the stride leg [20]. In that study, we also found the drive leg to have elevated T1ρ and T2 relaxation times in the superior femoral cartilage compared to the stride leg. Longer relaxation times suggest higher water content, lower glycosaminoglycan content and/or reduced integrity of the collagen network which may indicate early cartilage degeneration [41, 42]. While underarm windmill-style softball pitching differs from overhand baseball pitching, these cumulative data suggest that the drive leg undergoes greater adaptation to the loading associated with pitching and throwing.

The cause for the greater prevalence and larger cam morphology in the drive leg of baseball pitchers remains unknown. The contralateral stride leg is exposed to greater ground reaction forces during pitching, but the drive leg experiences more time under load and generates most of the forward linear and angular impulse [43, 44]. Combining these factors with differences in ranges of motion between the hips during pitching may impact the growth plate at the femoral head-neck junction during skeletal maturation. The hip in the drive leg of baseball pitchers has been reported to possess greater range of motion compared to the stride leg; [45] however, this observation is not supported by other studies [46–48]. It is also possible that activities outside of throwing (e.g., hitting) play a role in the greater prevalence of cam morphology in the drive leg. Uquillas et al. [15] reported that right handed hitters had greater prevalence of cam morphology in their back (i.e., drive) leg compared to their front (i.e., stride) leg (73% vs. 42%).

The current study had several strengths including the use of CT to assess alpha angles at multiple clock positions, inclusion of a physically active control group, and study of high-level pitchers. However, the study also possesses limitations. The study was cross-sectional in asymptomatic individuals and, thus, cannot inform causality with regards to future pain or pathology without longitudinal follow-up. The study had a small sample size in a specific population which limits generalizability. We did not assess the reproducibility of our scanning procedure because of radiation exposure considerations, and we did not assess the consequences of altered hip bony morphology on range of motion and function.

In summary, the current study provides preliminary evidence that professional Minor League Baseball (Triple-A level) baseball pitchers exhibit an elevated prevalence of cam morphology. All of the pitchers were asymptomatic, consistent with studies showing that cam morphology is prevalent in asymptomatic populations. Whether the observed morphological variations occur in pitchers competing at other levels and have consequences in terms of the development of asymmetrical symptoms and joint changes requires further investigation.

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Not applicable.

**Authors' contributions**
RKF and SJW contributed to study conception and design, and provided study materials and participants, statistical expertise, and drafting of the article. All authors contributed to the collection, assembly, analysis, and interpretation of data, provided critical revision of the article for important intellectual content, and provided final approval of the article.

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**Data availability**
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The study was performed in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board and Machine Produced Radiation Safety Committee of Indiana University (study ID#1503934363). All participants provided written informed consent.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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