Hip morphology in elite golfers: asymmetry between lead and trail hips

Edward Dickenson,[1] Philip O'Connor,[2] Philip Robinson,[2] Robert Campbell,[3] Imran Ahmed,[1] Miguel Fernandez,[1] Roger Hawkes,[4] Hutchinson Charles,[5] Damian Griffin[1]

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[1]Warwick Medical School, Warwick, UK
[2]Leeds Musculoskeletal Biomedical Imaging Unit, Leeds Teaching Hospitals, Leeds, UK
[3]Radiology Department, Royal Liverpool University Hospital, Liverpool, UK
[4]European Tour Performance Institute, European Tour, Virginia Water, UK
[5]Department of Clinical Imaging, Warwick Medical School, Warwick, UK

Correspondence to
Professor Damian R Griffin, Warwick Medical School, Clinical Sciences Research Institute, University Hospitals Coventry and Warwickshire, Clifford Bridge Rd, Coventry, CV2 2DX, UK; damian.griffin@warwick.ac.uk

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ABSTRACT

Aim During a golf swing, the lead hip (left hip in a right-handed player) rotates rapidly from external to internal rotation, while the opposite occurs in the trail hip. This study assessed the morphology and pathology of golfers' hips comparing lead and trail hips.

Methods A cohort of elite golfers were invited to undergo MRI of their hips. Hip morphology was evaluated by measuring acetabular depth (pincer shape=negative measure), femoral neck antetorsion (retrotorsion=negative measure) and α angles (cam morphology defined as α angle >55° anteriorly) around the axis of the femoral neck. Consultant musculoskeletal radiologists determined the presence of intra-articular pathology.

Results 55 players (mean age 28 years, 52 left hip lead) underwent MRI. No player had pincer morphology, 2 (3.6%) had femoral retrotorsion and 9 (16%) had cam morphology. 7 trail hips and 2 lead hips had cam morphology (p=0.026). Lead hip femoral neck antetorsion was 16.7° compared with 13.0° in the trail hip (p<0.001). The α angles around the femoral neck were significantly lower in the lead compared with trail hips (p<0.001), with the greatest difference noted in the anterosuperior portion of the head neck junction; 53° vs 58° (p<0.001) and 43° vs 47° (p<0.001). 37% of trail and 16% of lead hips (p=0.038) had labral tears.

Conclusions Golfers' lead and trail hips have different morphology. This is the first time side-to-side asymmetry of cam prevalence has been reported. The trail hip exhibited a higher prevalence of labral tears.

INTRODUCTION

Golf is one of the most popular sports globally with an estimated 57 million participants worldwide and 4 million in the UK.[1] In 2016 golfers will complete at the Olympic Games.[2]

In order to generate power in an efficient golf swing, rapid hip rotation is required. The lead hip (left hip in a right-handed player) moves rapidly, with a peak velocity of 228°/s, from external rotation at the end of the back swing to maximal internal rotation at the end of the downswing.[3] Conversely, the trail hip rapidly rotates from internal rotation to external rotation with a peak velocity of 145°/s.[3] Rotational forces of this magnitude, in a closed kinetic chain (weightbearing), place the hip at risk of soft tissue injuries such as labral tears.[3] A recent systematic review reported the prevalence of hip injuries in golfers to be from 2% to 18%.[4]

Recently, there has been an increasing understanding of the role of subtle hip shape abnormalities in causing hip pain and injury, especially within athletic participants.[5–8] Femoroacetabular impingement (FAI), a condition characterised by cam, pincer and low femoral neck antetorsion hip morphologies, is associated with soft tissue injuries to the acetabular labrum and articular cartilage.[9–11] The morphologies associated with FAI syndrome and are known to limit hip internal rotation, which is required in an efficient golf swing.[12] The presence of these deformities in golfers has the potential to negatively affect performance as well as increase the probability of soft tissue injuries associated with FAI.[9]

There are a wide range of prevalence estimates for cam hip morphology in the general population.[13–15] Kang *et al*[16] reported a prevalence of 16% within the general population (cam defined as α angles >55° at 3 o'clock on CT). Some authors report a higher prevalence in certain groups of professional athletes such as soccer, ice hockey and American football players.[6 7 17 18] Some professional sportsmen have developed a joint morphology that is advantageous to their activity—for example, an increased humeral retroversion in the throwing arm of baseball pitchers, allowing greater external rotation at the glenohumeral joint.[19–21]

To date, no study has examined if golfers, who have asymmetrical athletic demands, have symmetrical hip morphology.

This study aims to determine the prevalence of femoral neck retrotorsion, cam and pincer hip shapes in elite golfers and to compare the morphology of golfers' lead and trail hips.

METHODS

Participants

After institutional ethical approval, a group of researchers attended the Scottish Hydro Challenge, Aviemore 2015, where the European Challenge Tour (the second-tier men's elite golf tour in Europe) was holding a golfing event. A cross-sectional observational study was conducted to assess this cohort of elite golfers.

When registering for the tournament, all elite golfers were invited to undergo MRI of both their hips. Players who agreed to undergo an MRI scan were allocated an appointment time until all appointments were filled and demographic data (age, years playing golf and hours of practice per week) collected.

MRI

A mobile 1.5 T MR scanner (Siemens, Erlangen, Germany) was used to assess players' hip morphology. Details of the MRI protocols can be found in the online supplementary appendix 1.

Imaging analysis

MR three-dimensional (3D) volume sequences were subsequently reconstructed using OsiriX DICOM viewer (V.6.0.1 32 bit) to assess hip morphology.[22] Femoral neck antetorsion was measured on axial slices of the hip, using slices through the posterior condyles of the femur as a reference.[23] Femoral neck morphology and the presence of cam deformity were assessed by measuring α angles (figure 1).[24] The α angles are a widely used and easily reproducible method for objectively detecting cam morphology.[24 25] When first described, α angles were measured on the anterior femoral neck on axial oblique MRI. However, cam deformities may be present in the superior, anterosuperior or anterior portion of the femoral head neck junction.[26] Therefore, α angles were measured around the axis of the femoral neck at 30° intervals with 12 o'clock being superior (relative to long axis of femur) and 3 o'clock representing the anterior neck (figure 2).[24]

Acetabular morphology was assessed by measuring the acetabular depth as described by Pfirrmann *et al*[27] (figure 3).

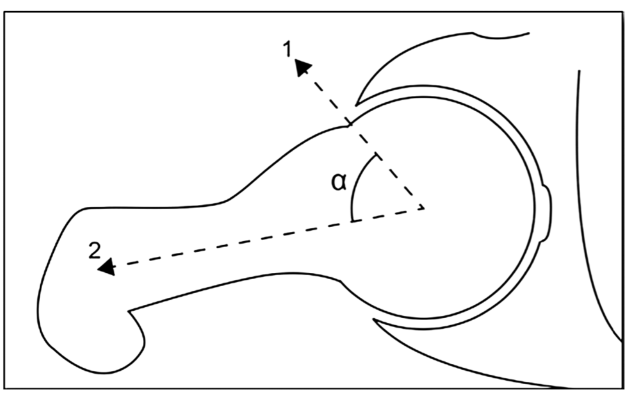

Figure 1 Diagrammatic representation of how to measure an α angle in a hip with a cam deformity. Line 1 is drawn between the centre of the femoral head and the anterior point where the bony contour exceeds the radius of the head. Line 2 is drawn along the axis of the femoral neck, between the narrowest point of the neck and the centre of the femoral head. The α angle is measured between lines 1 and 2. Diagram adapted from Notzli *et al*.[24]

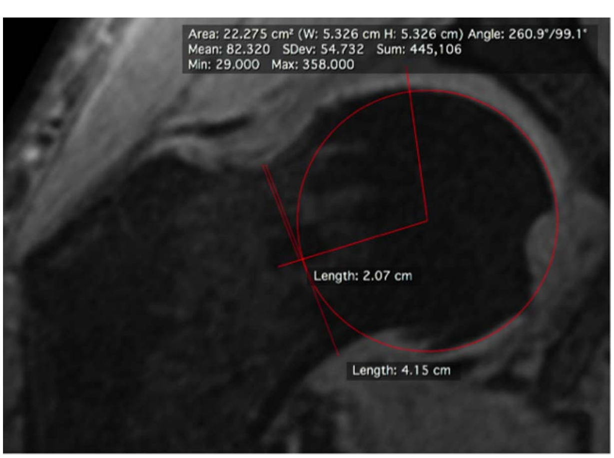

Figure 2 Right (trail) hip showing the 1 o'clock position on the femoral head neck junction. The α angle measures 99°.

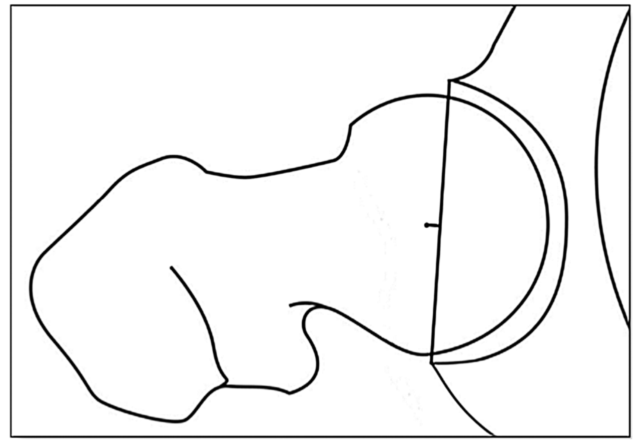

Figure 3 Diagrammatic representation of how to measure acetabular depth. The axial oblique image (in line of femoral neck) is used to draw line from the anterior to posterior rim of the acetabulum. A second line is drawn perpendicular from the first line to the centre of the femoral head. The length of the second line corresponds to the acetabular depth. Diagram adapted from Pfirrmann *et al*.[27]

The α angles, acetabular depth and femoral neck antetorsion were measured by ED (orthopaedic registrar), with repeated measurements made on 20 randomly selected cases independently by PR (consultant musculoskeletal radiologist) to establish inter-rater reliability.

Hips were referred to as lead and trail, where the lead hip is on the side of the golfer that faces the target. Typically, the lead hip is the left hip in a right-handed player and the right hip in a left-handed player.

There is currently no single definition of cam morphology, with different authors using different definitions.[13] Therefore, two separate definitions were used with results of each definition reported independently to allow comparisons:

1. A hip with an α angle >55° at 3 o'clock.[24 28 29]
2. A hip with an α angle >83° at any position around the femoral neck.[30]

A negative acetabular depth measurement was considered pincer morphology,[27] and a negative femoral neck antetorsion, representing retrotorsion, was considered abnormal.

Three experienced musculoskeletal radiologists each with >15 years of experience, blind double reported all MRI scans for signs of intra-articular pathology. The κ coefficients for inter-rater agreement between the raters were determined. Images for each hip were scored for acetabular labrum (normal, partial tear or complete tear, deformed/degenerate), acetabular cartilage (normal, partial irregularity, full thickness deficit), femoral cartilage (normal, partial irregularity, full thickness deficit) and the presence of an os acetabuli,[31] acetabular retroversion,[32] femoral neck herniation pits[9] and acetabular and femoral subchondral oedema. Where there was disagreement, the third observer blind scored the abnormality of concern with the majority score then taken as the consensus score.

Statistical analysis

Summary statistics were used to describe baseline player demographics and differences in α angles, acetabular depth, femoral neck antetorsion and markers of intra-articular pathology between the lead and trail hips. The prevalence of cam, pincer and femoral retrotorsion was described as the percentage of players and hips affected. Continuous data were assessed for

Table 1 Proximal femoral morphology

	α Angle/°											
Position on femoral neck (o'clock)	12	1	2	3	4	5	6	7	8	9	10	11
Trail hip median (IQR)	45 (42–49)	66 (55–80)	56 (48–68)	45 (40–52)	40 (37–44)	42 (40–44)	43 (41–45)	38 (36–41)	36 (36–38)	39 (36–42)	42 (39–45)	41 (39–42)
Lead hip median (IQR)	46 (44–48)	62 (52–73)	51 (46–57)	41 (38–46)	39 (37–43)	43 (40–45)	44 (42–46)	39 (37–43)	37 (35–40)	39 (36–42)	40 (38–43)	39 (38–42)
Wilcoxon signed-rank test p value	0.661	0.053	<0.001*	0.001*	0.885	0.094	0.006	0.069	0.027	0.584	0.016	0.075

*p Values that reached statistical significance.

normality with Shapiro-Wilk statistics. Dependent non-parametric continuous data were assessed for statistical significance with Wilcoxon signed-rank test, and dependent parametric data were assessed with paired Student's t-tests. For comparisons of α angles at different positions on the femoral neck between hips, a Bonferroni correction was applied (α=0.004).[33] Differences between hips in categorical outcomes were assessed for statistical significance with a χ^2 test.

RESULTS

A total of 55 elite male golfers underwent MRI with a mean age of 28 years (±5.5), having been playing golf for 21 years (±6.1) and practiced for a mean of 39 hours a week (±11.9). A total of 52 players swung with the left hip leading; three players led with their right hip.

Interclass correlation coefficients between the two readers for α angles, acetabular depth and femoral neck antetorsion measurements were 0.92 (0.85–0.96), 0.86 (0.69–0.93) and 0.85 (0.64–0.94) with SE of the measurement of 3.51, 1.29 and 2.34, respectively.

Around the femoral neck, α angles were higher in the trail compared with lead hips (p=0.001), with the greatest differences between lead and trail hips found between 1 and 3 o'clock (table 1).

Mean femoral neck antetorsion was 16.7° for lead hips and 13.0° in trail hips, (p<0.001). Mean acetabular depth was 11.5 (±3.9) and 11.6 (±4.0) for the lead and trail hip, respectively (p=0.81) (table 2).

Cam morphology (α angle >55° at 3 o'clock) was present in nine players (16%); in no player was the lead hip affected in isolation, the trail hip was affected in seven players and both hips were affected in two players. Cam morphology (α angle >83° at any position around the femoral neck) was present in 11 players (20%); the lead hip was affected in 1 player, the trail hip in 5 players and both hips in 5 players.

Femoral neck retrotorsion was present in two players (3.6%) with the trail hip affected in both. No player was found to have pincer morphology (negative acetabular depth measure).

The rate of partial or complete labral tears was greater in the trail hip compared with the lead hip (p=0.038). The MR signs of intra-articular pathology are described in table 3 (figures 4 and 5). Tables describing the results by left and right hip laterality can be found in the online supplementary appendix 2.

DISCUSSION

This is the first study describing hip morphology in elite golfers. We have demonstrated that elite golfers have a reduced α angle and antetorsion in their lead hips compared with trail hips and have an increased prevalence of labral tears and cam morphology in their trail compared with lead hips—findings that are statistically significant. We believe this is also the first study that demonstrates differences in morphology and pathology between hips in sportsmen where movement patterns are asymmetrical.

Table 2 Acetabular depth and femoral neck antetorsion

	Acetabular depth/mm	Femoral neck antetorsion/°
Trail hip mean	11.5 (±3.9)	13.0 (±7.2)
Lead hip mean	11.6 (±4.0)	16.7 (±7.5)
Paired Student's t-test p value	0.81	<0.001*

*p Values that reached statistical significance.

Table 3 Signs of intra-articular pathology

Pathology	Percentage of hips affected (n=55)													
	Acetabular retroversion	Femoral neck pits	Os acetabuli	Joint effusion	Paralabral cysts	Presence of labral tear (partial or complete)	Increased labral signal (deformed/degenerate)	Acetabular cartilage loss	Acetabular subchondral oedema	Femoral cartilage loss	Femoral subchondral oedema	Cam Morphology (AA>83 at any position around neck)	Cam morphology (AA>55 3 o'clock)	Femoral retrotorsion
Lead hip	2	14	2	10	2	16	24	8	8	4	12	11	4	4
Trail hip	0	12	2	8	2	37	27	12	12	2	14	18	16	0
κ Coefficient	1.00	0.85	1.00	0.68	1.00	0.76	0.78	0.67	0.85	0.66	0.80	NA	NA	NA
χ^2 Test p value	1.00	1.00	1.00	1.00	1.00	0.038*	1.00	0.74	0.74	1.00	1.00	<0.001*	0.024*	0.495

*p Values that reached statistical significance.
AA, α angle; NA, not applicable.

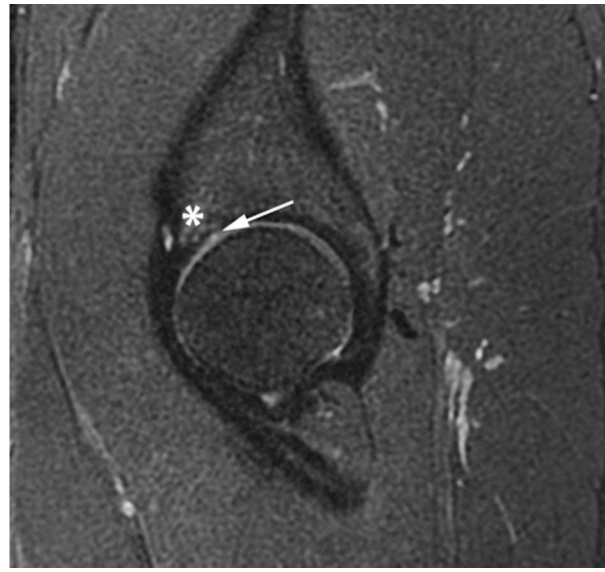

Figure 4 Sagittal proton density fat-saturated MRI showing acetabular subchondral oedema (*) and irregularity and clefting of the acetabular cartilage.

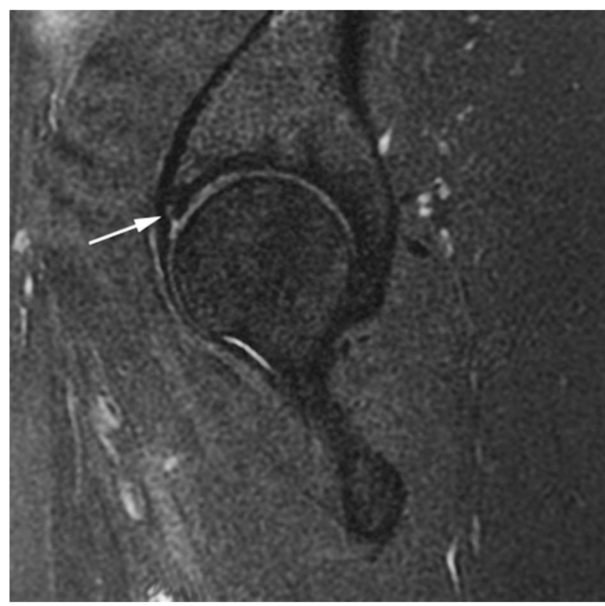

Figure 5 Sagittal proton density fat-saturated MRI showing partial high-grade labral tear.

Differences in α angles between hips

Mean α angles around the femoral neck were greater in trail compared with lead hips (p=0.001). In the anterosuperior portion of the femoral head neck junction (1–3 o'clock), where cam morphology is most frequently identified,[26] median α angles were higher in the trail hips (66°, 56° and 45° vs 62°, 51° and 41°) reaching statistical significance at 2 and 3 o'clock. Other studies assessing hip morphology in athletes have not demonstrated differences in head neck offset between hips.[7 28 29 34–37] In the general population, Hack *et al* measured α angles in the hips of 200 volunteers. Although not tested for statistical significance, Hack reported a slight difference in the α angles of the left and right hips (left 40.6° (95% CI 39.6°–

41.6°) and 50.1° (48.9°–51.2°) vs right 40.9° (39.9°–41.9°) and 50.2° (49.1°–51.4°) at 1:30 and 3 o'clock, respectively).[15] These differences were far smaller in magnitude than those reported in this study.

Differences in femoral neck torsion between hips

Mean femoral neck antetorsion was 16.7° in lead compared with 13.0° in trail hips of golfers ($p<0.001$). The clinical significance of this finding is questionable as previous studies have demonstrated a similar phenomenon within the general population.[10] Sutter *et al*[10] found that asymptomatic volunteers had 14.8° of left hip antetorsion compared with 11.0° in the right hip.

The differences described in lead and trail hip morphology in golfers represent an interesting phenomenon. Golfers require rapid lead hip internal rotation when driving. Theoretically, reduced α angles and greater femoral neck antetorsion should increase the hip internal rotation,[10 38] which could translate to a competitive advantage in elite golfers. However, we report the range of motion in the same cohort of golfers in another manuscript in this journal and found no difference in clinical rotational range of motion between hips.[39] Despite no clinically detectable difference in the rotational range of motion between hips, the presence of these morphologies does appear to be associated with a reduced incidence of lead hip intra-articular soft tissue injuries such as labral tears and cartilage delamination.[10 11] The lack of a clinically detectable difference may be because the real differences lie within the SEs of the measurement.[40]

Differences in intra-articular pathology between hips

The observed rate of partial and complete labral tears (figure 5) was found to be greater in trail hips (37%) compared with the lead hips (16%) of elite golfers ($p=0.038$). This may be due to the increased prevalence of cam morphology and reduced antetorsion in trail hips, as labral tears are associated with FAI morphology.[11] However, it has also been suggested that labral tears are more likely to occur when the hip experiences external rotation and extension, as the trail hip does during downswing.[41] These two factors are likely to contribute to the increased prevalence of labral tears in trail hips.

Prevalence of FAI morphology

In this study we determined, using the 55° at 3 o'clock definition, that cam morphology was present in 16% of players (10% of hips) and that pincer morphology was absent. Using the same diagnostic criteria used in this study, Kang *et al* and Omoumi *et al*[16 42] reported the prevalence of cam morphology in the general population to be 12 and 30% of participants, respectively. Other research assessing hip morphology in various groups of athletes has reported a wide range of prevalence estimates from 2% to 92% of hips affected.[13] It has been reported that cam hip morphology is more common in athletes compared with the general population.[14 43] However the methods used to report the prevalence of cam morphology vary between studies, making direct comparisons between subpopulations and between sports impossible.[15 30 34 44] Studies of soccer and track and field competitors that used the same case definition used in this study reported higher prevalence rates of cam morphology —50% and 59%, respectively.[28 29] This may reflect that these sports involve more vigorous loading of the hip during training, which may promote the development of cam morphology.[17]

Reporting of pincer morphology prevalence suffers from similar problems of case definition as cam morphology. This makes comparisons with the general population and other athletic populations difficult. Laborie *et al*[45] reported that 9% of the general population had an increased acetabular depth. The absence of pincer morphology in golfers may reflect the fact that pincer morphology restricts hip rotation, reducing the player's ability to swing.[12]

Why do golfers have this morphology?

What remains to be established is whether this hip morphology develops during adolescence in response to a certain pattern of loading and asymmetrical movements or whether the asymmetry is due to elite golfers being self-selected as individuals with these bony characteristics. It has been suggested that cam morphology (a reduction in head neck offset) develops in response to vigorous loading of the hip during adolescence.[17 46] The different prevalence of cam morphology between golfers lead and trail hips, where there are asymmetrical movement patterns, adds weight to the concept that cam morphology develops prior to skeletal maturity in response to certain loading patterns. Trail hips in golfers have an external rotation moment as golfers drive.[3] Roels *et al*[47] used finite element models to demonstrate that increased external rotation of the hip during adolescence stresses the anterosuperior portion of the femoral neck; promoting bone formation in the area that corresponds to where cam morphology is found in adults.

Similar differences in bony morphology that are advantageous within a sport have been demonstrated in baseball pitchers. Several studies have shown pitchers' develop greater humeral head retroversion compared with their non-throwing arms and to control participants.[19 20 21] These studies hypothesised that this was the result of a bony adaptation to the sport, although we are not aware of any prospective studies that observed participants through development.[19 20 21] With respect to femoral neck antetorsion in golfers, it is plausible that a similar mechanism occurs where the reduction in antetorsion that occurs during growth is less marked in lead hips in response to repetitive golf swings.[21 48] However, the differences of antetorsion between hips found in this study were similar to those identified in one study of the general population.[10] Longitudinal studies assessing adolescent golfers and controls would be required to demonstrate this, particularly given that similar patterns of antetorsion have been observed in the general population in one other study.[10]

Strengths and limitations

The strength of this study is the inclusion of a relatively large group of elite golfers who were representative of the golfers on the European Challenge Tour.

A limitation of this study is the lack of female golfers and general population controls that would have allowed comparisons between male and female golfers and between golfers and the general population. Furthermore, due to difficulties in imaging such a large field (156 golfers) in a short space of time only 35% of players at the event could be imaged. As outlined in the methods, steps were taken when inviting players to participate to reduce responder bias. The reported rates of intra-articular pathology were subject to weaknesses in the imaging methods, with a non-contrast 1.5 T MR scanner being used.[49] Further studies that assess adolescent golfers over time would help to establish why elite golfers develop the characteristic hip shapes identified.

CONCLUSION

Elite golfers' lead hips have significantly lower α angles (and so lower prevalence of cam morphology) and greater femoral neck antetorsion than their trail hips, and the prevalence of labral tears is significantly less in the lead hips. While one other study in a general population also suggested a left to right difference in antetorsion, this is the first study to show a left to right difference in the prevalence of cam morphology. It raises the possibility that asymmetrical hip movements result in development of asymmetrical hip morphology. We would encourage future research to report left and right differences in hip morphology.

What are the findings?

- Elite golfers have significantly greater head neck offset and femoral neck antetorsion in their lead compared with trail hips.
- The prevalence of cam morphology is greater in trail than lead hips.
- The prevalence of labral tears is greater in trail than lead hips.

How might it impact on clinical practice in the future?

- Understanding the morphological differences in golfers' hips will help in the clinical diagnosis of conditions such as femoroacetabular impingement.
- Although previous research using the same cohort of golfers demonstrated a lack of difference in clinical examination between hips, understanding the morphological and pathological characteristics may influence how injured golfers' hips are evaluated and treated.
- Other research groups examining athletes with asymmetrical loading patterns can explore and report side-to-side morphological differences.

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Competing interests None declared.

Patient consent Obtained.

Ethics approval University of Warwick, Biomedical & Scientific Research Ethics Committee, REGO-2015-1570.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Farrally MR, Cochran AJ, Crews DJ, *et al*. Golf science research at the beginning of the twenty-first century. *J Sports Sci* 2003;21:753–65.
2 Committee IO. International Golf Federation. Secondary International Golf Federation. 2015. http://www.olympic.org/igf
3 Gulgin H, Armstrong C, Gribble P. Hip rotational velocities during the full golf swing. *J Sports Sci Med* 2009;8:296.
4 Cabri J, Sousa JP, Kots M, *et al*. Golf-related injuries: a systematic review. *Eur J Sport Sci* 2009;9:353–66.
5 Philippon MJ, Ho C, Briggs KK, *et al*. Changes in the Hip of Youth Hockey Players over 3 Seasons as Seen on MRI and Physical Exam. *Orthopaedic J Sports Med* 2014;2.
6 Philippon MJ, Ho CP, Briggs KK, *et al*. Prevalence of increased alpha angles as a measure of cam-type femoroacetabular impingement in youth ice hockey players. *Am J Sports Med* 2013;41:1357–62
7 Larson CM, Sikka RS, Sardelli MC, *et al*. Increasing alpha angle is predictive of athletic-related "hip" and "groin" pain in collegiate National Football League prospects. *Arthroscopy* 2013;29:405–10
8 Nepple JJ, Brophy RH, Matava MJ, *et al*. Radiographic findings of femoroacetabular impingement in National Football League Combine athletes undergoing radiographs for previous hip or groin pain. *Arthroscopy* 2012;28:1396–403
9 Ganz R, Parvizi J, Beck M, *et al*. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 2003;417:112–20.
10 Sutter R, Dietrich TJ, Zingg PO, *et al*. Femoral antetorsion: comparing asymptomatic volunteers and patients with femoroacetabular impingement. *Radiology* 2012;263:475–83.
11 Beck M, Kalhor M, Leunig M, *et al*. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of osteoarthritis of the hip. *J Bone Joint Surg Br* 2005;87:1012–18.
12 Audenaert EA, Peeters I, Vigneron L, *et al*. Hip morphological characteristics and range of internal rotation in femoroacetabular impingement. *Am J Sports Med* 2012;40:1329–36.
13 Dickenson E, Wall PD, Robinson B, *et al*. Prevalence of Cam hip shape morphology: a systematic review. *Osteoarthr Cartil* 2016;24:949–61.
14 Frank JM, Harris JD, Erickson BJ, *et al*. Prevalence of femoroacetabular impingement imaging findings in asymptomatic volunteers: a systematic review. *Arthroscopy* 2015;31:1199–204.
15 Hack K, Di Primio G, Rakhra K, *et al*. Prevalence of cam-type femoroacetabular impingement morphology in asymptomatic volunteers. *J Bone Joint Surg Am* 2010;92:2436–44
16 Kang AC, Gooding AJ, Coates MH, *et al*. Computed tomography assessment of hip joints in asymptomatic individuals in relation to femoroacetabular impingement. *Am J Sports Med* 2010;38:1160–5
17 Agricola R, Heijboer MP, Ginai AZ, *et al*. 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;42:798–806.
18 Siebenrock KA, Ferner F, Noble PC, *et al*. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. *Clin Orthop Relat Res* 2011;469:3229–40
19 Crockett HC, Gross LB, Wilk KE, *et al*. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med* 2002;30:20–6.
20 Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med* 2002;30:347–53.
21 Yamamoto N, Itoi E, Minagawa H, *et al*. Why is the humeral retroversion of throwing athletes greater in dominant shoulders than in nondominant shoulders? *J Shoulder Elbow Surg* 2006;15:571–5.
22 Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. *J Digit Imaging* 2004;17:205–16.
23 Dandachli W, Ul Islam S, Tippett R, *et al*. Analysis of acetabular version in the native hip: comparison between 2D axial CT and 3D CT measurements. *Skeletal Radiol* 2011;40:877–83.
24 Nötzli H, Wyss T, Stoecklin C, *et al*. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br* 2002;84:556–60.
25 Mast NH, Impellizzeri F, Keller S, *et al*. Reliability and agreement of measures used in radiographic evaluation of the adult hip. *Clin Orthop Relat Res* 2011;469:188–99.
26 Rakhra KS, Sheikh AM, Allen D, *et al*. Comparison of MRI alpha angle measurement planes in femoroacetabular impingement. *Clin Orthop Relat Res* 2009;467:660–5.
27 Pfirrmann CW, Mengiardi B, Dora C, *et al*. Cam and pincer femoroacetabular impingement: characteristic MR arthrographic findings in 50 patients. *Radiology* 2006;240:778–85.
28 Lahner M, Bader S, Walter PA, *et al*. Prevalence of femoro-acetabular impingement in international competitive track and field athletes. *Int Orthop* 2014;38:2571–6.
29 Lahner M, Walter PA, von Schulze Pellengahr C, *et al*. Comparative study of the femoroacetabular impingement (FAI) prevalence in male semiprofessional and amateur soccer players. *Arch Orthop Trauma Surg* 2014;134:1135–41.
30 Gosvig K, Jacobsen S, Palm H, *et al*. A new radiological index for assessing asphericity of the femoral head in cam impingement. *J Bone Joint Surg Br* 2007;89:1309–16.
31 Klaue K, Durnin C, Ganz R. The acetabular rim syndrome. A clinical presentation of dysplasia of the hip. *J Bone Joint Surg Br* 1991;73:423–9.
32 Dora C, Leunig M, Beck M, *et al*. Acetabular dome retroversion: radiological appearance, incidence and relevance. *Hip Int* 2006;16:215–22.
33 Holm S. A simple sequentially rejective multiple test procedure. *Scand J Stat* 1979;6:65–70.
34 Kolo FC, Charbonnier C, Pfirrmann CW, *et al*. Extreme hip motion in professional ballet dancers: dynamic and morphological evaluation based on magnetic resonance imaging. *Skeletal Radiol* 2013;42:689–98

35 Mariconda M, Cozzolino A, Di Pietto F, *et al*. Radiographic findings of femoroacetabular impingement in capoeira players. *Knee Surg Sports Traumatol Arthrosc* 2014;22:874–81.
36 Tak I, Weir A, Langhout R, *et al*. The relationship between the frequency of football practice during skeletal growth and the presence of a cam deformity in adult elite football players. *Br J Sports Med* 2015;49:630–4.
37 Johnson AC, Shaman MA, Ryan TG. Femoroacetabular impingement in former high-level youth soccer players. *Am J Sports Med* 2012;40:1342–6
38 Kennedy M, Lamontagne M, Beaule P. The effect of cam femoroacetabular impingement on hip maximal dynamic range of motion. *J Orthop* 2009;1:41–50.
39 Dickenson E, Ahmed I, Fernandez M, *et al*. Professional golfers' hips: prevalence and predictors of hip pain with clinical and MR examinations. *Br J Sports Med* 2016;50:1077–81.
40 Reichenbach S, Jüni P, Nüesch E, *et al*. An examination chair to measure internal rotation of the hip in routine settings: a validation study. *Osteoarthr Cartil* 2010;18:365–71.
41 Mason JB. Acetabular labral tears in the athlete. *Clin Sports Med* 2001;20:779–90.
42 Omoumi P, Thiery C, Michoux N, *et al*. Anatomic features associated with femoroacetabular impingement are equally common in hips of old and young asymptomatic individuals without CT signs of osteoarthritis. *AJR Am J Roentgenol* 2014;202:1078–86.
43 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;43:2833–40.
44 Nepple JJ, Prather H, Trousdale RT, *et al*. Diagnostic imaging of femoroacetabular impingement. *J Am Acad Orthop Surg* 2013;21(suppl 1):S20–6.
45 Laborie LB, Lehmann TG, Engesæter I, *et al*. Prevalence of Radiographic findings thought to be associated with femoroacetabular impingement in a population-based cohort of 2081 healthy young adults. *Radiology* 2011;260:494–502.
46 Agricola R, Bessems JH, Ginai AZ, *et al*. The development of Cam-type deformity in adolescent and young male soccer players. *Am J Sports Med* 2012;40:1099–106
47 Roels P, Agricola R, Oei EH, *et al*. Mechanical factors explain development of cam-type deformity. *Osteoarthr Cartil* 2014;22:2074–82.
48 Fabry G, MacEwen GD, Shands AR Jr. Torsion of the femur. A follow-up study in normal and abnormal conditions. *J Bone Joint Surg Am* 1973;55:1726–38.
49 Smith TO, Hilton G, Toms AP, *et al*. The diagnostic accuracy of acetabular labral tears using magnetic resonance imaging and magnetic resonance arthrography: a meta-analysis. *Eur Radiol* 2011;21:863–74.