**TITLE PAGE**

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

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**ABSTRACT**

**Aim**

During a golf swing the lead hip (left hip in right handed player) rotates rapidly from external into 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**

An cohort of elite golfers were invited to undergo magnetic resonance imaging (MRI) of their hips. Hip morphology was evaluated by measuring acetabular depth (pincer shape= negative measure), femoral neck antetorsion (retrotorsion= negative measure) and alpha angles (cam morphology defined as alpha 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 28years, 52 left hip lead) underwent MRI. No player had pincer morphology, two (3.6%) had femoral retrotorison and nine (16%) had cam morphology. Seven trail hips and two lead hips had cam morphology ($p=0.026$). Lead hip femoral neck antetorsion was 16.7° compared to13.0° in the trail hip ($p<0.001$). Alpha angles around the femoral neck were significantly lower in the lead compared to trail hips ($p<0.001$), with the greatest difference noted in the anterio-superior portion of the head neck junction; 53° versus 58° ($p<0.001$) and 43° versus 47° ($p<0.001$). 37% of trail and 16% of lead hips ($p=0.038$) had labral tears.

**Conclusion**

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.

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**What are the new findings?**

- Elite golfers have significantly greater head neck offset and femoral neck antetorsion in the their lead compared to 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 near future?**

- Understanding the morphological differences in golfers hips will help in the clinical diagnosis of conditions such as FAI.
- 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.

## 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°/sec, from external rotation at the end of the back swing, to maximal internal rotation at the end of the down swing.[3] Conversely the trail hip rapidly rotates from internal rotation into external rotation with a peak velocity of 145°/sec.[3] Rotational forces of this magnitude, in a closed kinetic chain (weight bearing), 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 subjects.[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 10] [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 increasing 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 reported a prevalence of 16% within the general population (cam defined as alpha [α] angles >55° at 3'oclock on CT).[16] 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 gleno-humeral 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 magnetic resonance (MR) imaging of both their hips. Players who agreed to undergo an MR scan, were allocated an appointment time until all appointments were filled and demographic data (age, years playing golf and hours of practice per week) was collected.

### MR Imaging

A mobile 1.5 Tesla MR scanner (Siemens, Erlangen, Germany) was used to assess players' hip morphology. Details of the MR imaging protocols can be found in Appendix 1.

### Imaging Analysis

MR 3D volume sequences were subsequently reconstructed using Osirix DICOM viewer (version 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 was assessed by measuring $\alpha$ angles (Figure 1).[24] $\alpha$ angles are a widely used and easily reproducible method for objectively detecting cam morphology.[24 25] When first described $\alpha$ angles were measured on the anterior femoral neck on axial oblique MR images. However cam

deformities may be present in the superior, anterio-superior 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 3).[24]

Acetabular morphology was assessed by measuring the acetabular depth as described by Pfirrmann et al (Figure 2).[27]

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 2 separate definitions were used with results of each definition reported independently to allow comparisons:

1. A hip with an α angle greater than 55° at 3o'clock, [24 28 29]
2. A hip with an α angle greater than 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 more than 15 years experience, blind double reported all MR scans for signs of intra articular pathology. Kappa 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 was assessed for normality with Sapiro-Wilk statistics. Dependent non-parametric continuous data was assessed for statistical significance with Wilcoxon Signed rank test and dependent parametric data was assessed with paired T tests. For comparisons of α angles at different positions on the femoral neck between hips a Bonferroni correction was applied ($\alpha = 0.004$).[33] Differences between hips in categorical outcomes were assessed for statistical significance with a Chi squared test.

**RESULTS**

55 elite male golfers underwent MR imaging 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). 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 standard error of the measurement of 3.51, 1.29 and 2.34 respectively.

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

**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

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 ($p=0.81$) (see table 2).

**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 T testing P value | 0.81 | <0.001* |

* = p values that reached statistical significance

Cam morphology (α angle >55° at 3 o'clock) was present in 9 players (16%); in no player was the lead hip affected in isolation, the trail hip was affected in 7 players and both hips were affected in 2 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 retrotosion was present in 2 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 to the lead hip (p=0.038). The MR signs of intra-articular pathology are described in Table 3(see also Figure 4 and 5). Tables describing the results by left and right hip laterality can be found in Appendix 2.

**Table 3 Signs of intra-articular pathology**

| | % of hips affected (n=55) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pathology | Acetabular retroversion | Femoral neck pits | Os acetabuli | Joint effusion | Para-Labral 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 |
| Kappa coefficient | 1.00 | 0.85 | 1.00 | 0.68 | 1.00 | 0.76 | 0.78 | 0.67 | 0.85 | 0.66 | 0.80 | n/a | n/a | n/a |
| Chi squared 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

## DISCUSSION

This is the first study describing hip morphology in elite golfers. We have demonstrated that elite golfers have a reduced $\alpha$ angles and antetorsion in their lead hips compared to their trail hips and have an increased prevalence of labral tears and cam morphology in their trail compared to lead hips, findings which 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.

*Differences in alpha angles between hips*

Mean α angles around the femoral neck were greater in trail compared to lead hips (p=0.001). In the anterio-superior 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 versus 62, 51, and 41°) reaching statistical significant 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 statistically 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] versus right 40.9 [39.9-41.9] and 50.2° [49.1-51.4] at 1:30 and 3o'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 to 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 phenomenum within the general population.[10] Sutter et al found that asymptomatic volunteers had 14.8° of left hip antetorsion compared to 11.0° in the right hip.[10]

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 alpha 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 and labral tears and cartilage delamination.[10 11] The lack of a clinically

detectable difference may be because the real differences lays within the standard errors 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 to 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 reported the prevalence of cam morphology in the general population to be 12 and 30% of subjects respectively.[16 42] 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 to the general population.[14 43] However the methods used to report the prevalence of cam morphology vary between studies, making direct comparisons between sub-populations 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 reported that

9% of the general population had an increased acetabular depth.[45] The absence of pincer morphology in golfers may reflect the fact that pincer morphology restricts hip rotation, reducing the players 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 used finite element models to demonstrate that increased external rotation of the hip during adolescence stresses the anterio-superior portion of the femoral neck; promoting bone formation in the area that corresponds to where cam morphology is found in adults.[47]

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 to their non-throwing arms and to control subjects.[19-21] 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 subjects through development.[19-21] 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 1.5T MR scanner being used.[49 50] 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 alpha 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. Whilst 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.

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**Competing Interests:**

The authors have no competing interests to declare

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