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What is This?

Hip Morphological Characteristics and Range of Internal Rotation in Femoroacetabular Impingement

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Background: Radiographic features specifically related to the occurrence of femoroacetabular impingement (FAI) appear to be highly prevalent in the asymptomatic population. It remains unclear, however, how these incidental findings should be interpreted clinically and which other variables might differentiate between true incidental findings and preclinical patients.

Purpose: To study the association between cam and overall hip morphological characteristics and range of motion in impingement patients, asymptomatic patients (healthy patients with radiographic features specific to FAI), and healthy controls.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Morphological parameters describing cam and overall hip anatomy were obtained from 30 patients (10 per subgroup) with use of 3-dimensional computational methods. In addition, the range of internal rotation in high flexion activities was evaluated, and its relation to hip morphological variables was analyzed in a multivariate regression model.

Results: Size of the cam lesion and range of motion significantly differed between groups ($P < .05$). The range of internal rotation on impingement testing was found to average 27.9° in the healthy control group compared with 21.1° in the asymptomatic control group with radiographic features specific to FAI ($P < .001$) and 12.3° in the patient group ($P < .001$). Cam size, acetabular coverage, and femoral version appeared to be predictive variables for the range of internal rotation. Seventy-five percent of variance between patients could be attributed to the combined effect of these 3 variables ($R = .86$). The range of motion was decreased in cam patients and asymptomatic patients, and early femoroacetabular conflict was not restricted to the area of the cam lesion but involved the entire anterior femoral head-neck junction.

Conclusion: Decreased range of motion, as found in FAI, is not solely dependent on the size or even the occurrence of a cam lesion but should be interpreted by taking into account the overall hip anatomy, specifically femoral version and acetabular coverage. Decreased femoral anteversion and increased acetabular coverage add to the risk of early femoroacetabular collision during sports and activities of daily living and therefore appear to be additional predictive variables, besides the finding of a cam lesion, for the risk of clinical hip impingement development. In addition, the findings suggest that surgical osteochondroplasty to restore a normal range of motion may necessitate more excessive bone resection than what simply appears to be a bump on imaging.

Keywords: hip; range of motion; femoroacetabular impingement; hip anatomy

Femoroacetabular impingement (FAI) has increasingly been recognized as a cause of painful and decreased range of motion (ROM) of the hip joint. In particular, motions requiring high flexion in combination with adduction and/or internal rotation are most frequently affected among symptomatic patients.[9,11] The anterior impingement test is based on this finding and has been reported as having a positive result on clinical examination in 90% to 100% of hip impingement cases.[8,9,25] Patients typically report a history of pain in the groin or in the greater trochanter region, extending to the lateral side of the thigh, with activities of daily living requiring substantial hip flexion (eg, sitting, stair climbing, squatting, driving, changing clothes) and with sports (eg, soccer, swimming, cycling, rowing).[9,27]

Despite the growing awareness of the condition and the exponential growth of the literature on FAI, recent reviews have shown that, so far, only little information is available about the cause and natural history of the condition,[10] and

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many discrepancies and controversies still remain.[25] One of these controversies is the question of whether radiographic findings such as loss of femoral head sphericity, reduced anterior offset, and signs of acetabular overcoverage are pathognomonic of the condition or merely represent common anatomic variations.[27] Recent epidemiological studies have demonstrated that these radiographic features appear far more frequently in healthy and asymptomatic cohorts than previously anticipated, with reported incidences between 30% and 76%.[13,15,21] Conversely, clinical studies on impingement patients and early osteoarthritis (OA) patients have clearly shown a very strong association between these radiographic features and disease onset.[18] To date, the diagnosis is usually only based on the co-occurrence of radiological features and clinical signs such as a painful impingement test finding and a decreased ROM. It remains unclear how the incidental finding of a cam lesion should be interpreted. Is it indicative of preclinical impingement patients, and should these undergo more stringent preclinical monitoring? Are they at risk for development of early OA? Should participation in specific sports or specific positions (eg, baseball catcher or hockey goalie) be discouraged?

In an attempt to improve the diagnostic accuracy and understanding of FAI, 3-dimensional (3-D) methods have been developed and validated using collision detection for the evaluation of hip ROM and the detection of abnormal motion patterns between the femur and pelvis.[14] These methods have proved to be powerful tools for the identification of abnormal motion patterns in impingement patients and can also be used for preoperative planning of FAI surgery.[2,4] Theoretically, they also allow for an evaluation of how ROM differs between FAI patients and asymptomatic patients and to what extent this can be attributed to differences in features considered specific to FAI (eg, α angle, femoral offset) and features describing overall hip morphology (eg, caput-collum-diaphyseal [CCD] angle, femoral and acetabular anteversions).

In the present study, we simulated ROM in cam-type impingement patients, asymptomatic controls with radiographic features specific to FAI, and healthy controls and evaluated how this related to radiographic variables used for the identification of cam-type impingement and to general variables commonly used in the description of hip anatomy. We hypothesized that (1) the ROM would be different between the 3 groups; (2) in the collision analysis, collisions would most likely occur at the site of the cam lesion, if present; and (3) asymptomatic cases would differ from symptomatic cases in terms of range of internal rotation during high flexion activities, cam, and overall hip structure.

MATERIALS AND METHODS

The study was approved by the local ethics committee, and all participants signed an informed consent form. The study population consisted of 30 patients, prospectively recruited between April 1, 2010 and March 31, 2011. All were male patients aged between 18 and 35 years.

The population was composed of 3 equally represented subgroups (n = 10 each): cam patients, asymptomatic volunteers, and healthy controls. A minimum sample size of 8 patients was calculated as needed to be enrolled in each subgroup to identify a clinically relevant difference in the primary outcome measure: the range of internal rotation. The power analysis was based on the following parameters: type II error rate (β = .2) and type I error rate (α = .05, μ = 12°-18°-24°, σ = 8°). Patients were recruited from FAI patients scheduled for arthroscopy of the hip. Simultaneously, healthy controls and asymptomatic controls with radiographic features specific to FAI were recruited from a cohort of healthy volunteers. Criteria for inclusion were a negative history of groin pain, the absence of clinical signs on anterior impingement testing at 90° of flexion, and an α angle of either <50° (healthy controls) or >55° (asymptomatic patients) on anteroposterior (AP) and Dunn views (45° of hip flexion, neutral rotation, and 20° of abduction). Patients and controls with solitary pincer-type impingement or hip dysplasia were excluded. Screening for inclusion was performed by means of fluoroscopy to decrease radiation exposure. Upon inclusion, the presence or absence of a cam-type deformity was confirmed by automated 3-D evaluations of the α angle and possible cam deformity using data from a computed tomography (CT) scan.[11] A total of 34 volunteers had to be screened by fluoroscopy to select 10 asymptomatic patients and 10 healthy controls fulfilling the inclusion criteria. All of the 14 excluded cases failed to fulfill the radiographic inclusion criteria on screening because of α angle measures between 50° and 55° on either AP or Dunn views. Preferentially, the dominant leg was chosen for analysis.

In all patients, CT was performed in a standardized fashion. Helical multislice CT scanning (64-slice Lightspeed VCT, General Electric, Fairfield, Connecticut) with 0.625-mm helical thickness and 0.969-mm rotation pitch including the pelvis and proximal femur was performed. Appropriate lead shielding of the genitals was applied. Additional imaging of the distal femur including the condyles was obtained for description of the anatomic position of the femur relative to the pelvis.

Different radiographic parameters describing FAI or parameters that might have an influence on the condition were measured in each patient.[‖] Reconstructed images of the pelvis were used to reproduce a standardized 2-dimensional image as defined by Siebenrock and coworkers,[24] representing the AP pelvis view used for evaluation of the center edge angle, crossover sign, and ischial spine projection. Semiautomated analysis of the 3-D CT images by means of a custom-written software application in Matlab (MathWorks, Natick, Massachusetts) was used for evaluation of the CCD angle, α angle according to the radial plane protocol and height of cam, anterior offset ratio, femoral version, and acetabular version. The technique for semiautomated 3-D analysis of the cam structure has previously been validated in a cohort of over 100 femurs. We refer to the original work for a full description

[‖]References 7, 12, 17, 19, 22, 23, 28, 30.

TABLE 1
Parameters Used to Describe Variation in Hip Joint Morphology Among Patients

Parameter	Definition	Reference	Normal Value
Caput-collum-diaphyseal angle	Angle formed by the axis of the femoral neck and the proximal femoral diaphyseal axis	Tönnis and Heinecke[29]	>125°, <135°
Femoral anteversion	Angle between the axis through the femoral neck with reference to the tangent to the posterior border of the femoral condyles	Rippstein[23]	Relative retroversion <15°, absolute retroversion <0°
Acetabular anteversion	Angle between a line between the anterior and posterior acetabular ridges and a reference line drawn perpendicular to a line between the posterior pelvic margins at the level of the sciatic notch	Murray[17]	15°-20°
Center edge angle	Angle formed by a line parallel to the longitudinal pelvic axis and by the line connecting the center of the femoral head with the lateral edge of the acetabulum	Wiberg[30]	>25°
Cross-over sign	Present if the anterior rim runs more laterally in the most proximal part of the acetabulum and crosses the posterior rim distally	Reynolds et al[22]	Anterior rim line projects medially to the posterior wall line
Ischial spine projection	Projection of the ischial spine into the pelvic cavity on an anteroposterior pelvic radiograph	Kalberer et al[12]	No projection
α angle	Angle formed by the femoral neck axis and a line connecting the center of the femoral head with the point of beginning asphericity	Nötzli et al[19]	<55°
Anterior offset ratio	Ratio between the anterior offset and the maximal diameter of the femoral head; anterior offset is the difference in the radius between the anterior femoral head and the anterior femoral neck on a cross-table lateral image	Eijer et al[7]	0.21 ± 0.03 in healthy patients, 0.13 ± 0.05 in cam patients

of the technical aspects.[3] A detailed overview of the morphological parameters evaluated is provided in Table 1.

Segmentation and reconstruction of the 3-D models of the femur and pelvis were performed using the Mimics software package (Materialise NV, Heverlee, Belgium). To compare the kinematics of the different patients and subgroups, the 3-D femur and pelvis models were positioned in the hip joint local coordinate system defined by the International Society of Biomechanics (ISB).[31] The center of rotation of the femur and the pelvis was evaluated by defining the best-fitting sphere on the femoral and acetabular joint surfaces using the 3-matic software package (Materialise NV). The anterior and posterior iliac spines, as well as the femur epicondyles, were digitally marked on the 3-D reconstructed images of the bones by a clinical expert. Centers of rotation of the femur and pelvis were matched in the ISB coordinate system. Range of motion was simulated using our own routines implemented with the open-source library Visualization ToolKit (www.vtk.org). A distance map of the pelvis was computed to detect collision between the femur and the pelvis. Evaluation of the range of internal rotation during high flexion hip positions was based on the protocol described by Kubiac-Langer et al[14] and consisted of calculating the remaining internal rotation for flexion between 70° and 110° and abduction between –20° and 20° in 2° increments. In total, 441 positions were evaluated in each case, with the classic impingement test being one of these positions (Figure 1). It was further considered that these positions would be representative of activities of daily living requiring substantial hip flexion, such as cycling, sitting, car driving, putting on shoes, toilet sitting, and so on.

Statistical Analysis

Statistical analysis was performed using the SPSS software package (v18, SPSS Inc, Chicago, Illinois). To evaluate differences in kinematics and morphological characteristics between the 3 subgroups, 1-way analysis

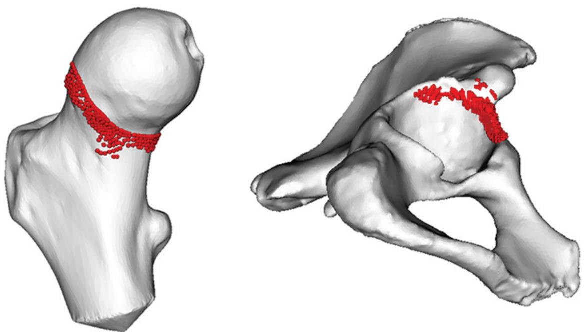

Figure 1. Representation of all the collisions between the femur and acetabulum in maximal internal rotation for 441 high flexion positions of the hip.

of variance (ANOVA) was performed. The necessary basic assumptions for the ANOVA analysis were evaluated by means of the Levene test for homogeneity of variances and the Kolmogorov-Smirnov test for normality of distribution. Where relevant, post hoc evaluation was performed using the Sheffé and Bonferroni tests. Variables describing the cam structure that were only present in patients and asymptomatic participants were evaluated using independent-samples t tests.

To quantitatively investigate the relation between the range of internal rotation in high flexion activities or during impingement testing, and morphological parameters describing the proximal femur and pelvis, a multivariate regression analysis was performed. Before inclusion in the multivariate regression model, possible intercorrelation of the variables was investigated by means of the Pearson correlation coefficient. Dichotomous variables were evaluated using the Mann-Whitney U test. The level for significance was set at .05.

RESULTS

Differences in Morphological and Kinematic Variables Between Subgroups

Center edge angle, CCD angle, femoral anteversion, or acetabular anteversion were not found to differ between groups. The ANOVA, however, demonstrated that significant differences were present between subgroups for the range of internal rotation during high flexion activities and impingement testing, the α angle, and the anterior offset ratio. A priori analysis was therefore necessary to identify which groups statistically differed and for which parameters.

Post hoc testing showed healthy controls differed significantly from both FAI patients and asymptomatic controls with radiographic features specific to FAI in terms of the range of internal rotation during high flexion activities and impingement testing, the α angle, and the anterior offset ratio. The mean α angle, determined on 3-D analysis, in the healthy control group was 49.4° compared with 65.2° in the asymptomatic control group with radiographic features specific to FAI ($P < .001$) and 74.5° in the patient group ($P < .001$). The mean anterior offset ratio in the patient group was 0.15 compared to 0.17 in the asymptomatic control group with radiographic features specific to FAI ($P = .05$) and 0.21 in the healthy control group ($P < .001$). The range of internal rotation on impingement testing was found to average 27.9° in the healthy control group compared with 21.1° in the asymptomatic control group with radiographic

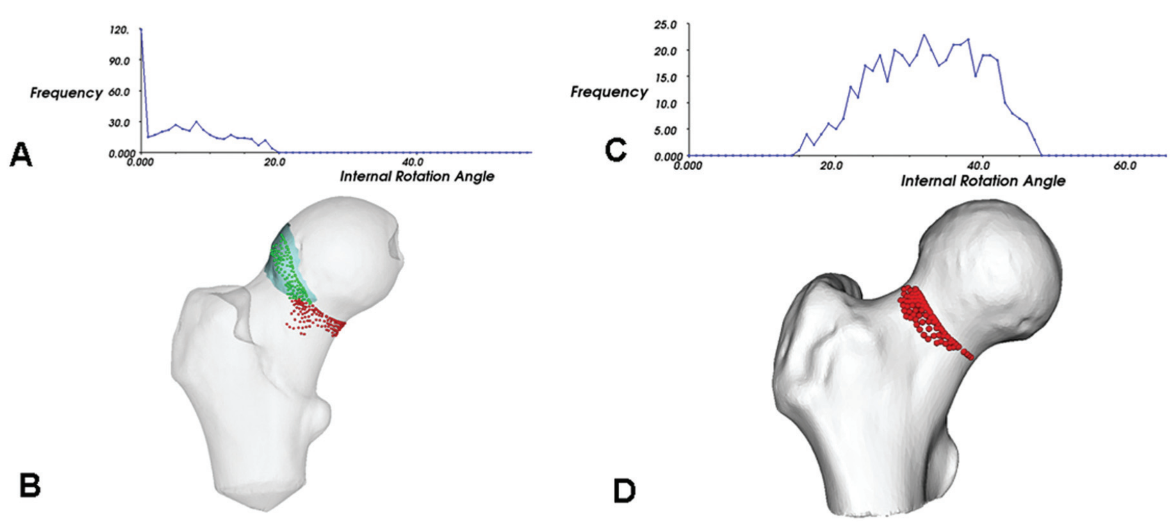

Figure 2. Results from the collision analysis evaluating range of internal rotation for 441 high flexion positions of the hip in a cam patient (A) and healthy control (C). Collision points are visualized on the patient's 3-dimensional model. The green area represents the cam lesion. The individual points are the collisions themselves, with the green dots occurring on the cam lesion and the red ones outside the cam lesion. (B) Symptomatic cam corresponding with the motion profile described in A. (D) Healthy control corresponding with the motion profile described in C.

TABLE 2
Differences in Morphological and Kinematic Variables Between Cam Patients, Asymptomatic Patients, and Controls[a]

	Cam Patients (n = 10)	Asymptomatic Patients (n = 10)	Controls (n = 10)
Caput-collum-diaphyseal angle, deg	128.3 ± 4.5	127.9 ± 4.7	128.23 ± 4.5
Femoral anteversion, deg	8.7 ± 9.3	10.1 ± 9.3	10.5 ± 8.3
Center edge angle, deg	35.2 ± 7.3	32.7 ± 5.5	35.4 ± 4.6
Acetabular anteversion, deg	16.2 ± 3.4	15.74 ± 2.6	16 ± 3.1
Positive cross-over sign, n	5	2	0
Positive ischial spine projection, n	5	2	0
α angle, deg	74.5 ± 6.1[b]	65.24 ± 7.4[b]	49.4 ± 5.5[b]
Anterior offset ratio	0.15 ± 0.02[b]	0.17 ± 0.01[b]	0.21 ± 0.02[b]
Average range of internal rotation in high flex activities, deg	12.9 ± 6.4[b]	20.9 ± 9.1[b]	27.8 ± 7.6[b]
Range of internal rotation on impingement testing, deg	12.3 ± 6.5[b]	21.1 ± 8.8[b]	27.9 ± 7.4[b]
Collisions on cam, %	63.82 ± 28[c]	56 ± 25[c]	NA
Depth of cam, mm	4.21 ± 0.8[c]	3.55 ± 0.6[c]	NA

[a]Values are expressed as difference ± standard deviation unless otherwise indicated. NA, not applicable.
[b]Observed differences between subgroups are significant at the .01 level.
[c]Observed differences between subgroups are significant at the .05 level.

TABLE 3
Correlations Between Variables and Their Significance Level (N = 30 Patients)[a]

	Internal Rotation	CCD Angle	CE Angle	α Angle	Anterior Offset	Femoral Anteversion	Acetabular Anteversion
Internal rotation							
Pearson correlation	1	.009	−.430[b]	−.650[c]	.624[c]	.505[c]	.053
Significance (2-tailed)		.962	.018	.000	.000	.004	.782
CCD angle							
Pearson correlation	.009	1	.224	.056	−.046	.297	.088
Significance (2-tailed)	.962		.234	.769	.809	.111	.644
CE angle							
Pearson correlation	−.430[b]	.224	1	−.003	.040	−.303	−.417[b]
Significance (2-tailed)	.018	.234		.989	.833	.104	.022
α angle							
Pearson correlation	−.650[c]	.056	−.003	1	−.777[c]	−.032	.121
Significance (2-tailed)	.000	.769	.989		.000	.865	.525
Anterior offset							
Pearson correlation	.624[c]	−.046	.040	−.777[c]	1	−.044	−.067
Significance (2-tailed)	.000	.809	.833	.000		.817	.726
Femoral anteversion							
Pearson correlation	.505[c]	.297	−.303	−.032	−.044	1	−.164
Significance (2-tailed)	.004	.111	.104	.865	.817		.387
Acetabular anteversion							
Pearson correlation	.053	.088	−.417[b]	.121	−.067	−.164	1
Significance (2-tailed)	.782	.644	.022	.525	.726	.387	

[a]CCD angle, caput-collum-diaphyseal angle; CE angle, center edge angle.
[b]Correlation is significant at the .05 level (2-tailed).
[c]Correlation is significant at the .01 level (2-tailed).

features specific to FAI ($P < .001$) and 12.3° in the patient group ($P < .001$).

When comparing patients with asymptomatic controls with radiographic features specific to FAI, significant differences were found for the range of internal rotation during high flexion activities and impingement testing ($P = .02$), the α angle ($P = .01$), and the height of the cam lesion ($P = .05$). The difference in anterior offset ratio, however, was not statistically significant ($P = .13$). A detailed overview of the findings is provided in Table 2.

Morphological Variables Affecting the Range of Internal Rotation

To quantitatively analyze the relationship between hip morphological characteristics and the degree of internal rotation during impingement testing, a multivariate regression was performed. To select the relevant parameters for inclusion in the model, the correlations between the variables in the observed range of internal rotation on impingement testing were determined. The

TABLE 4
Coefficients, Standard Errors, and Significances of Coefficients of a Multivariate Regression Model Predicting the Range of Internal Rotation During Impingement Testing

	β	Standard Error	*P*
Constant	60.91	7.22	<.001
α angle	−.45	.07	<.001
Femoral anteversion	.38	.10	<.001
Center edge angle	−.46	.15	.005

correlations are presented in Table 3. Crossover sign or positive ischial spine projection was not found to significantly affect ROM.

Because a significant intercorrelation was observed between the α angle and the anterior offset ratio (P = .78), only the α angle was included in the regression model. Of all other parameters, only femoral anteversion and acetabular coverage showed a moderate correlation with the dependent variable: internal rotation. Therefore, a multiple regression model was developed with internal rotation as the dependent variable and the α angle, center edge angle, and femoral anteversion as independent variables.

The multivariate regression model showed an R value of .86 and an R^2 value of .75 ($P < .01$), indicating that 75% of variance in internal rotation during high flexion activities can be attributed to variations in α angle, acetabular coverage, and femoral version between patients. Internal rotation was shown to decrease by 0.45° with each degree of increase in α angle or acetabular coverage and to increase by 0.38° with each increase in femoral anteversion. Significance of regression was below .01 for all regression coefficients. Coefficients, standard errors, and significances are presented in Table 4.

Analysis of Collision in Internal Rotation During High Flexion Activities

When analyzing the location of collisions in internal rotation between the femur and pelvis for 441 high flexion positions, it appeared that the entire anterior femur neck could be involved. Qualitative and quantitative analyses of the data demonstrated that the overall range of internal rotation in high flexion activities was compromised for all motions analyzed in the impingement patients compared with the healthy controls and asymptomatic patients. Interestingly, an important number of these early collisions occurred outside the actual cam lesion, more specifically at the medial femur neck. In the patient group, 36.2% ± 28.2% of early collisions occurred outside the actual cam lesion. Figure 2 demonstrates the differences in range of internal rotation during high flexion activities in a patient versus a control participant and shows the locations of the bony collision points at the femoral head-neck junction for both cases.

DISCUSSION

In the present study, we evaluated how morphological and kinematic variables differ between cam patients, asymptomatic patients, and healthy controls using volumetric imaging, semiautomated 3-D computational analysis, and kinematic analysis based on collision detection. The relationships between joint structure and range of internal rotation in high flexion activities were also evaluated. Both the range of internal rotation and the variables describing cam deformity were found to differ significantly between subgroups. Cam size, acetabular coverage, and femoral anteversion were the main determinants for predicting differences in internal rotation during impingement testing. Finally, data suggested that a femoroacetabular conflict might occur at the anteromedial head-neck junction distant from the actual cam lesion during activities of daily living requiring high flexion positions of the hip. This observation might be of importance to the surgical management of an FAI patient. It specifically suggests that osteochondroplasty or reshaping of the proximal femur to restore a normal ROM should include the entire anterior neck and not only what seems to be a bump on imaging.

About a decade ago, when the concept of FAI was first introduced as a mechanical cause of OA, the estimated prevalence was 10% to 15% in the general population.[16] In recent epidemiological studies, radiographic findings that were considered specific to the condition appeared to have a much higher prevalence in healthy and asymptomatic study populations than previously anticipated. Kang et al[13] showed that 39% of 100 asymptomatic patients had at least one morphological aspect predisposing to FAI. Laborie et al[15] found cam-related radiographic features in 35% of the male participants and 10.2% of the female participants in a population-based cohort of 2081 healthy young adults. Pollard et al[21] more specifically investigated the α angle and anterior offset ratio in normal hips, without symptoms or signs of OA on radiographic imaging, and showed that 95% reference intervals for these parameters contained values that previously were considered "abnormal." Using a different approach, Allen et al[1] showed that of 88 patients with a cam deformity, only 26.1% had bilateral symptoms of impingement. From these studies, it appears that quite a number of people have cam deformities not causing any symptoms. On the other hand, some people with only minimal osseous abnormalities do have complaints typical of impingement. The incidental finding of a cam lesion, in the absence of clinical complaints, therefore remains challenging to deal with, and the findings from the present study do not allow us to make general statements. Both on morphological and kinematic analyses, these asymptomatic cases seem to differ not only from normal controls but also from clinical cases. Whether actual cartilage damage occurs in these cases could not be determined in the present study. Interestingly, however, a recent study by Pollard et al,[20] investigating acetabular glycosaminoglycan content, showed signs of localized cartilage damage in asymptomatic cam patients compared with healthy controls. An even more recent study by the same group, evaluating the 20-year risk of hip OA, showed a significant association between the α angle, anterior offset ratio, and hip OA development.[18] In the present study, the α angle and anterior offset ratio were found to be strongly correlated and to also correlate significantly with the patients' ROM. Because both parameters are established variables for describing asphericity of the femoral head, this finding is not surprising, and the correlation between the α angle and the anterior offset ratio has been documented before.[21,27]

The average internal rotation on impingement testing in the symptomatic group was only 12.88°, whereas the controls reached 27.9°. This difference in ROM is consistent with the findings of Kubiak-Langer et al[14] and Ecker et al[6] and has a strong effect on activities of daily living and sports. It provides immediate evidence for the clinical usefulness of the anterior impingement test for the detection of possible impingement.[25] The findings also show a clear link between the radiographic variables, indicating asphericity, and the clinical test, indicating possible impingement.

In the literature, similar studies have been published in which different variables relating to FAI were examined and used in predictive models, usually OA development.[6,18] Ecker et al[6] investigated internal rotation, center edge angle, and α angle, among many other variables. They compared a healthy group with a group with early OA degeneration of the hip and found these 3 factors to be strong predictions of the development of OA. This is an interesting finding because in combination with our results, it indicates a direct link with the OA process. Adding to these available models, the present study also demonstrated the importance of overall hip morphological characteristics, specifically femoral anteversion and acetabular coverage, as independent variables to predict hip ROM on impingement testing. The multivariate model showed that every increase in femoral anteversion and decrease in acetabular coverage were accompanied by a 0.38° and 0.46° increase in internal rotation, respectively. This is in agreement with Bedi et al,[5] who hypothesized that a possible collision between the femur and acetabulum might occur earlier in people with greater femoral retroversion. However, these authors also hypothesized that varus/valgus could have a similar effect. We were unable to confirm this statement probably because of the small sample size.

Considering the described discrepancy in imaging findings and the limited number of FAI cases, it seems important to make a clear difference between "specific" radiographic parameters for asphericity and the impingement process itself. Our data strongly suggest that, in agreement with Bedi et al, the overall 3-D joint structure should be taken into account when evaluating the presence of FAI or risk of FAI development.[5] The extreme case of a retroverted, overcovered cam deformity might therefore represent the unhappy triad of the hip. The possible association between decreased femoral version and the occurrence of groin pain and early OA signs in adolescents and young adults, as found in the present study, is not completely a new finding, as it has already been described 2 decades ago by Tönnis and Heinecke.[29]

It seems unlikely that parameters such as CCD angle and acetabular anteversion would not relate to a patient's ROM. The small group size might have been responsible for not detecting the contribution of these parameters to the prediction of internal rotation in high flexion activities. However, studies on larger populations already suggested their involvement in the impingement process.[5,22] It therefore seems essential that these variables remain included in future similar research on larger populations. A second limitation is the fact that evaluating patients through computational analysis is time consuming and technically challenging and will always remain an abstraction of reality. However, considering that surgery is the preferred treatment method for FAI, a customized approach would be most desirable, especially in cases with diagnostic uncertainties. Furthermore, observer-related errors are definitely minimized by standardized and automated computational methods. It should be kept in mind, however, that any predictive model is only useful if validated in further prospective studies. A final but relevant limitation of the present study relates to the design of the impingement model, which simplifies FAI to a purely bony restrained problem. Obviously, soft tissues are relevant anatomic structures that can interfere with motion or themselves be part of the impingement problem. Previous studies on range of internal rotation upon impingement testing, however, have shown that these movements are mainly bony restrained and that their ranges can reliably be predicted by bony restrained simulations.[4,26]

CONCLUSION

Asymptomatic cam patients significantly differ from patients and healthy controls in terms of hip morphological and kinematic variables. Cam deformity, as described by the α angle or anterior femoral offset, and hip structure, specifically femoral version and acetabular coverage, significantly add to hip ROM and the possible occurrence of abnormal femoroacetabular contact. In addition, in impingement patients, abnormal contact patterns are not exclusively observed at the site of the cam lesion but also in the entire anterior head-neck area, possibly necessitating more extensive osteochondroplasty than previously anticipated. To further support these findings, studies on larger populations are mandatory and have already been initiated.

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