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Differences in the Association of Hip Cartilage Lesions and Cam-type Femoroacetabular Impingement with Movement Patterns: A Preliminary Study

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Abstract

Objective—Preliminary study to investigate the differences in hip movement patterns during different daily and athletic activities in individuals with cam-type femoroacetabular impingement (FAI) with and without cartilage lesions compared with controls.

Design—Controlled laboratory study using a Cross-sectional design.

Setting—Research Institution with Tertiary Care Medical Center.

Participants—Fifteen subjects [M:F – 13:2, Age- 31.6±9.7 years (22-52), BMI- 24.9±4.6 (18.8-38.4), FAI: Control = 7:8].

Methods—All subjects had 3-Tesla MR imaging of the hip and also underwent 3-D motion capture during walking, deep-squat and drop landing tasks. Experienced radiologists graded cartilage lesions on clinical MR images.

Outcomes—Peak kinematic and kinetic variables were compared between those with and without FAI, and those with FAI and cartilage lesions compared to subjects without cartilage lesions.

Results—Subjects with FAI demonstrated no significant differences for walking or drop-landing compared to controls. However, during deep-squat, subjects with FAI adducted more and had greater internal rotation moment. Subjects with cartilage lesions in the presence of a cam-lesion demonstrated - no difference for walking; greater adduction, greater internal rotation moment and lower transverse plane range of motion during deep-squat; and greater adduction and lower internal rotation during drop-landing, compared to those without cartilage lesions.

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Conclusions—We observed differences in movement patterns between subjects with FAI compared to controls. However, the differences were more pronounced between subjects with FAI who had cartilage lesions compared to subjects who did not have cartilage lesions. These findings highlight the importance of understanding the complex interplay between bony morphology, cartilage lesions, and movement patterns in individuals with cam-type FAI.

Keywords

Kinematics; Kinetics; Gait; Squat; Drop-landing; Joint power

INTRODUCTION

Hip osteoarthritis (OA) is a major cause of pain and disability with 4.4 % of adults over the age of 55 years complaining of symptomatic hip OA [1]. Femoroacetabular Impingement (FAI) has been identified as a risk factor for development of hip OA [2-4]. FAI is primarily classified into cam- and pincer- types based on the morphological abnormalities of the femoral head-neck junction or the acetabulum respectively [5-7]. However, FAI with features of both cam-type and pincer-type FAI has also been reported [2]. Literature suggests that 66-75% of individuals with FAI present with the cam-type deformity [8]. Cam-type impingement is identified as a decreased offset at the antero-lateral femoral head-neck junction or a non-spherical extension of the femoral head [5, 9, 10]. It is thought that the cam-type lesion could be associated with abrasive damage as the femoral head translates over the acetabulum during the repetitive activities of flexion and internal rotation [2].

Symptomatic cam-type FAI clinically presents as groin pain and reduced internal rotation at the hip [5, 11-14]. It has been reported that up to 14% of asymptomatic adult men and 6 % of asymptomatic adult women have the cam-type lesion as well [6, 7]. Furthermore, a recent report showed that 24% of asymptomatic adults have cartilage defects [15]. Adding to the confusion, not all individuals with the cam-type FAI progress to hip OA [16-19]. Degree of deformity (size of lesion), soft-tissue morphology (presence, size and location of cartilage and labral tears), function (amount and types of physical activity) and other unknown factors are likely related to the risk of individuals with a cam-type lesion being symptomatic or progressing to OA [17-19]. Hence, it is critical to understand how morphology and function interact in patients with FAI to be able to selectively identify those at risk of further cartilage changes.

Abnormal hip movement patterns during daily activities like walking and squatting have been reported in patients with cam-type FAI [20, 21]. Repetitive excessive hip joint loading due to abnormal movement patterns could be associated with cartilage damage over a period time resulting in hip OA. Hence, it is critical to identify these cartilage defects early in the disease process so that surgical or non-surgical interventions can be implement before further damage occurs. Furthermore, it is important to characterize movement patterns in the setting of cartilage lesions so that movement retraining interventions can be developed and implemented. Earlier reports of kinematic and kinetic differences in individuals with FAI have focused on walking and squatting[20, 21]. Since FAI is commonly seen in athletes it

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would be important to characterize hip movement patterns during high demand tasks like drop landing, which has not been done.

Movement patterns are commonly characterized using kinematic and kinetic descriptors from a motion analysis evaluation [22]. During a motion analysis evaluation, data collected include segment motion and ground reaction force. These data are used to quantify the kinematic (for eg: measures of peak joint motion and excursions in the sagittal, coronal, and transverse planes) and kinetic (for eg: peak joint moments and powers in the 3 planes) patterns at the hip joint during different activities [23, 24]. Joint moments are an estimate of the loading across the hip joint and are reported as net moments (i.e. no information on muscle co-contraction). For instance, a net external flexion moment at the hip during early stance indicates that there is a moment tending to flex the hip which is countered by an equal and opposite net internal extension moment generated by muscles and other soft-tissues. Joint powers are calculated as the product of the joint moment and joint angular velocity [23]. A positive joint power indicates concentric work at the joint since the joint moment and joint motion are in the same direction. A negative joint power on the other hand indicates eccentric work at the joint since the joint moment and joint motion are in opposite directions. These techniques have not been used to explore the differences in the movement patterns of individuals FAI who may or may not have cartilage lesions with controls.

Hence, the aim of this preliminary exploratory study was to investigate the differences in movement patterns during walking, squatting and drop landing between individuals with FAI and controls, and also between individuals with FAI who have cartilage lesions compared to individuals without cartilage lesions.

MATERIALS AND METHODS

Subjects

Seven subjects with unilateral symptomatic FAI (Age = 36.6 ±9.7 years; BMI = 26.2 ± 6.9 kg/m^2) [25] and eight asymtomatic volunteers (Age = 27.3 ± 7.7 year; BMI = 23.9 ± 2.3 kg/m^2) participated in the study. All procedures were approved by an Institutional Committee on Human Research and all subjects signed informed consent prior to data collection. The FAI subjects were recruited from the orthopedic faculty practice at our Institution after having a positive anterior impingement test (pain accompanying hip flexion, adduction, and internal rotation), visual cam morphology on anteroposterior (AP) and frog-leg lateral radiographs, and an α angle greater than 55° on oblique axial MRI (a common diagnostic criteria for cam-type FAI) [10]. The control participants were recruited from the student population at our Institution and related community networks, and were included only if they had no lower limb pain, a clinical history negative for serious lower extremity injury or surgery and no radiologic features consistent with FAI. Subjects from either group were excluded if they had any neurologic disorders that would affect their ability to perform the motion analysis tasks, or any implanted metal devices that could interact with the magnetic field.

MR Image Acquisition

All imaging was performed with a 3-Tesla MR scanner (GE MR750, GE Healthcare, Waukesha, WI) and an 8 -channel cardiac coil (GE Healthcare, Waukesha, WI). Following our established standard operations manual, patient positioning aids were used to immobilize and support patients, resulting in a consistent, reproducible, and comfortable hip position during scanning. The lower extremities were fully extended with a foam lower leg immobilizer to maintain neutral rotation. The feet were comfortably taped together to minimize movement. Sagittal and coronal T_2-weighted fat-saturated fast spin-echo (TR/TE = 3678/60 msec, FOV = 14 cm, matrix = 288 × 224, slice thickness = 4 mm, no gap, echo train length = 16, bandwidth = 50 kHz, NEX = 4) were acquired for clinical grading of femoral and acetabular cartilage. Oblique T_2-weighted fat-saturated fast spin-echo images (TR/TE = 3678/60 msec, slice thickness = 3 mm, no gap, matrix= 288 × 224, FOV = 18 cm) were acquired for the measurement of alpha angle (Figure 1).

Alpha Angle

Alpha angle was measured on the oblique MR studies as shown in Figure 1 [10]. The measurements were performed by an experienced radiologist (LN). The inter-class coefficient (ICC) for inter-rater reproducibility of alpha angle has been reported to be 0.83 [26]. The ICC for intra-rater reproducibility has been reported to be between 0.96 – 0.98 [26].

Semi-quantitative Clinical Cartilage Grading

Experienced board-certified musculoskeletal radiologists (TML, LN) performed the clinical grading for cartilage lesions on the coronal and sagittal MR studies [27]. The radiologists were blinded to the group assignment of the subjects. The femoral and acetabular segments were divided into six subregions (4 femoral, 2 acetabular) on the coronal studies and 4 subregions (2 femoral, 2 acetabular) on the sagittal studies, for a total of 10 subregions (Fig 1). The mid portion of the femoral head was defined on the sagittal images and subdivided into four subregions on the coronal images, from lateral to medial (Fig 1 a,b). The landmark for division was lateral acetabular rim for lateral and superolateral, a vertical line from center of femoral head for superolateral and supermedial, and ligamentum teres for supermedial and inferior subregions. On the sagittal MR study, the anterior subregion represented the anterior 1 cm of the femoral head and the posterior subregion represented the posterior 1 cm of the femoral head (Fig 1 c,d). The division was based on a simplified version of the geographic zone method described by Ilizaliturri Jr. et al. for hip arthroscopy which showed superior inter-observer reproducibility compared to the clock-face method. [28] Cartilage defects were graded as 0 (no defect), 1 (partial thickness) and 2 (full thickness). Consensus readings were performed in case of a disagreement.

Intra and inter-rater reliability for the cartilage lesion grading was established by 2 radiologists on a cohort of 30 subjects not included in this study. Intra-reader percent agreement was 85% and the inter-rater percent agreement was 78%.

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Motion Capture

Motion capture was always performed after the MRI on the same day or on a different day within 2 weeks of the MRI. All subjects performed 3 tasks. During these tasks 3-D kinematic data (at 250 Hz) were collected from bilateral lower extremities using a passive 10-camera system (VICON, Oxford Metrics, UK). Kinetic data (at 1000 Hz) were concurrently collected from two embedded force platforms (AMTI, Watertown, MA, USA). Tasks recorded included – 1) Walking at 1.3 m/sec, 2) Deep-squat to 25% of the total body height, at a speed of 2 seconds for descent and 2 seconds for ascent and 3) Drop-landing from a 12” high platform, where the subjects were asked to step off and land synchronously with one foot on each force plate, and then jump as high as possible. During the deep-squat, the subjects were instructed to stand with feet parallel, facing anteriorly and arms outstretched. However, the distance between the feet was not controlled and they were not instructed to maintain heel contact. [21] Five trials were acquired for each task. For walking task, a trial was considered acceptable when there was clean foot-strike on either of the force platforms and the speed was within ± 5% of the first good trial. Fourteen millimeter spherical retro-reflective markers were placed on bony landmarks of bilateral lower extremities for identification of joint centers. These anatomical markers were placed on the sacrum, and bilaterally on the iliac crest, anterior superior iliac spine, greater trochanter, medial and lateral femoral condyles, medial and lateral malleoli, and 1st and 5th metatarsal head. Rigid marker clusters placed bilaterally on the lateral surface of the subject’s thighs, legs and heel shoe counters were used to track segment motions.

Motion Analysis Data Processing

Kinematic and kinetics were calculated using Visual3D (C-motion, Georgetown, MD, USA). All net joint moments are expressed as internal moments and normalized to body weight (BW) and height (Ht) (Nm/BW*Ht). In the convention used, flexion, abduction and internal rotation were positive. Peak kinematic and kinetic variables, as well as joint excursions, were calculated for the hip joint during the stance phase of each task in sagittal, coronal and transverse planes. The average of 5 trials during each task was calculated for each subject.

Statistical Analysis

Analyses were performed between FAI subjects and controls, stratified based on anatomical morphology as described earlier. In addition, the subjects with FAI who had cartilage lesions (a grade > 0 in any subregion) were compared to the rest of the cohort without cartilage lesions (a grade of 0 in all subregions). One-way ANOVA tests were to evaluate the differences in peak hip joint - moments, excursions, and powers during the 3 tasks for both comparisons.

RESULTS

Subject demographics

Group means for age, BMI and gender distribution for subjects stratified by bony morphology (FAI and Controls), as well as, those with cartilage lesion in presence of FAI and without cartilage lesions are shown in Table 1. Six of the FAI subjects had cartilage lesions and 9 subjects did not have any cartilage lesions (8 controls, 1 FAI). None of these cases required consensus readings. The differences in age, BMI and gender distribution between those with FAI and controls, and those with cartilage lesions in presence of FAI and without cartilage lesions were not statistically significant. Mean alpha angle for the FAI group was 74° (range 58-90), and for the control group was 42° (range 33-52).

Walking

Average kinematic and kinetic patterns during walking for all groups are shown in Figure 3. Hip powers are shown in Table 2. No significant differences in kinematics or kinetics were seen when comparing between subjects with and without FAI, or those with cartilage lesions and FAI compared to those without cartilage lesions (Fig 3).

Deep-squat

Average kinematic and kinetic patterns during deeps-squat for all groups are shown in Figure 4. Hip powers are shown in Table 2. Subjects with FAI performed the deep-squat with greater hip adduction ($P = .005$) (Fig 4b), and higher peak internal rotation moment ($P = .008$) (Fig 4f) when compared to the control group. When evaluating subjects stratified by cartilage lesions, the group with FAI and cartilage lesions also demonstrated greater peak hip adduction ($P = .038$) (Fig 4b) and a higher peak internal rotation moment ($P = .015$) compared to those without cartilage lesions (Fig 4f). However, this group also demonstrated less transverse plane ROM (CL = 9.9±4.0°, No-CL = 17.8±4.2°, $P = .006$).

Drop-landing

Average kinematic and kinetic patterns during drop-landing for all groups are shown in Figure 5. Hip powers are shown in Table 2. During the drop-landing task, subjects with FAI landed with their feet closer together (FAI = 0.30±0.05 m, Control = 0.37±0.04 m, $P = .029$). No other kinematic or kinetic differences were noted when comparing the FAI and control groups (Fig 5). In contrast, the group with FAI and cartilage lesion landed with a smaller base of support (CL = 0.29±0.03 m, Control = 0.37±0.04 m, $P = .001$), exhibited greater peak hip adduction ($P = .031$) (Fig 5b) and less peak hip internal rotation ($P = .033$) when compared with subjects without cartilage lesions (Fig 5c).

DISCUSSION

This preliminary exploratory study was aimed at investigating the influence of FAI and cartilage lesions on kinematics and kinetics of the hip during various tasks. We observed differences in movement patterns between subjects with FAI compared to controls. However, the differences were more pronounced between subjects with FAI who had cartilage lesions compared to subjects who did not have cartilage lesions. These findings highlight the importance of understanding the complex interplay between bony morphology, cartilage lesions, and movement patterns in individuals with cam-type FAI.

When comparing the movement patterns at the hip during walking between subjects with and without cam-type FAI, and between those with FAI and cartilage lesions, and without cartilage lesions, we did not observe any statistically significant differences. In an earlier study, Kennedy et al. showed lower sagittal ROM and hip abduction during walking in individuals with cam-type FAI compared to controls [20]. Our sample size (n = 7) was smaller compared to that of Kennedy et al. (n = 17), and they exclusively studied males, with an alpha angle cut-off of 50.5° for diagnosis of FAI. Also, their finding of lower hip abduction occurred during the swing phase, which we did not analyze since our aim was to understand the relationship of hip loading during stance with cartilage damage. These differences could explain the disparity in the findings. Walking is the most common daily activity and patients with FAI often complain of pain after walking [29]. Future studies would be needed to assess the long term implications of these kinematic asymmetries.

Lamontagne et al. performed [21] a study to quantify the effect of cam-type FAI on movement patterns during a deep-squat task. They did not find any significant differences in the hip motion between those with and without FAI but did report lower squat depth for individuals with FAI and differences in pelvic motion. For our subjects, we did not control the width between the feet at the start of the squat or restrict the heel to be in contact with the ground during the squat. However, our subjects were instructed to stand with feet parallel to each other facing anteriorly. Lamontagne et al. instructed their subjects to “stand with feet shoulder width apart, parallel to each other, and facing anteriorly”. They also instructed the subjects to maintain heel contact at all times. We wanted the subjects to perform the squats as naturally as possible. Hence, we used the Base of Support as one of the variables in our analyses. It is possible that the differences in the starting hip position across the subjects may have influenced our results. Lamontagne et al. did not control for squat depth but in our study, we controlled for the squat depth and compared the differences in movement patterns between groups. Using this strategy, we found that individuals with FAI, and those with FAI and cartilage lesions maintained their hips in more adduction and generated greater peak hip internal rotation moments. Reduced hip abduction during these activities may be a mechanism to reduce the demands on the musculature. An earlier study has shown that patients with FAI present with weakness of all hip muscle groups [30]. Maintaining the hip in more adduction is one strategy to reduce the demands on the hip musculature, as well as increase the internal moment arm for the hip abductor muscles, potentially providing more stability. These results suggest that presence of cartilage lesions with cam-lesion may could be associated with further abnormalities in functional movement patterns. Longitudinal studies would be needed to investigate the cause and effect relationship between movement patterns and cartilage lesions in individuals with cam-type FAI.

There are no previous reports comparing the hip kinematics and kinetics in individuals with FAI with controls during a drop-landing task. We chose to include a drop-landing task since it is a common athletic activity for this age group (eg. in basketball, gymnastics etc.), and entails rapid hip loading with significant hip motion, which is very different from the slow loading in deep-squat and the smaller range of motion during walking. Surprisingly, we did not find any statistically significant differences in hip kinematics and kinetics between those with and without FAI during this activity, except that patients with FAI landed with their feet closer together, again presumably to lower the demands on the hip musculature. In contrast, when we compared the subjects FAI and cartilage lesions with those without

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cartilage lesions, we observed patterns similar to the other tasks, where the subjects with FAI and lesions maintained a smaller base of support with greater hip adduction. We also found less hip internal rotation during this task in subjects with cartilage lesions, suggesting that subjects may have employed a compensatory strategy to avoid anterior impingement. These findings also suggest that the presence of cartilage lesions in individuals with cam-type FAI may further alter the loading patterns at the hip which needs to be confirmed in longitudinal studies.

It is important to note that only one subject with FAI did not have any cartilage lesions. Hence, the differences between the findings when the FAI group was compared to controls vs. when the FAI and cartilage lesion group was compared to no-cartilage lesion group, are driven by this subject. This subject was a 32 year old male with an alpha angle of 58°. Hence this subject, although symptomatic, indeed had the lowest alpha angle among the FAI subjects. It may be possible that larger magnitudes of cam-lesion are associated with cartilage damage. A cutoff of 55° is usually used to diagnose cam-type FAI along with presence of FAI related symptoms [10]. However, recent large scale cohort studies suggest that a radiographic alpha angle of 60° suggests presence of cam-lesion and a radiographic alpha angle of 78° indicates presence of a pathological cam-lesion [31].

One of the main difficulties in evaluating hip cartilage on MR is the thinness of the articular cartilage. Our cartilage grading is a simplified version of Outerbridge classification, a widely accepted cartilage lesion classification originally based on knee cartilage arthroscopy, with elimination of grades that would not be reliably discernible on hip MR. [28] MR arthrogram has been the modality of choice for identification of cartilage lesions at the hip. [32] However, optimized non-contrast hip MRI has been shown to have excellent ability to identify cartilage lesions at the hip. [33] The ability to visualize the cartilage in our study was enhanced by the use an optimized non-contrast hip MRI protocol, using a small field of view on a 3-Tesla scanner.

The limitations of this work relate to the facts that the sample size was small, we did not adjust for age, BMI and gender distribution, and the analyses were cross-sectional. The control group and the no-cartilage lesion groups were approximately 10 years younger than the FAI and cartilage lesion group respectively. Although this difference was not found to be statistically significant in our study, the P values were close to significance. Since the incidence of cartilage lesions increases with age and risk of OA, our findings would need to be confirmed in a larger cohort, and either group-matched for potential covariates or adjusted statistically in the data analysis. Given the small sample of the current investigation we were unable to adjust for these variables in our analyses, which may or may not confound the results. Future studies should also consider a longitudinal design as our data suggest a complex interplay between bony and cartilage morphology in this population and understanding this relationship is not possible given the cross-sectional nature of our study. Other hip abnormalities, including labral tears, bone marrow edema like lesions, hernation pits, tendinopathies etc. which all may be related to hip movement patterns, were not evaluated in our study and should be considered in future investigations. Finally, our findings are limited to cam-type impingement. Pincer or combination impingement may present very different than our cohort and caution should be taken when comparing our findings to other impingement cohorts.

CONCLUSION

In conclusion, the data show that patients with FAI have abnormal movement patterns during functional tasks when compared to controls. The differences are amplified when comparing those with and without cartilage lesions in the presence of a cam-lesion. These findings highlight the importance of understanding the complex interplay between bony morphology, cartilage lesions, and movement patterns in individuals with cam-type FAI.

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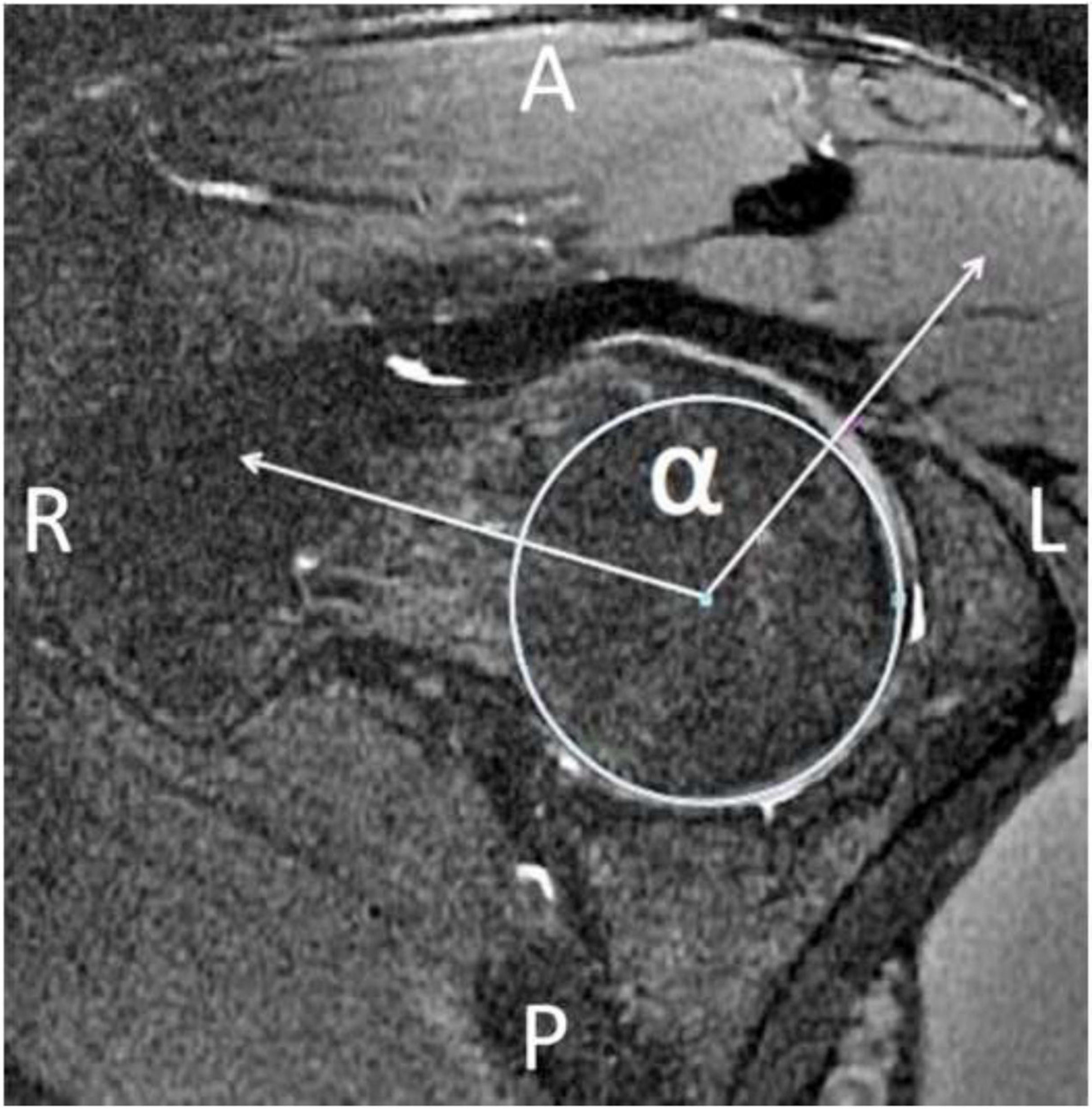

Figure 1.

The alpha angle measurement shown on an oblique axial T_2 FSE image.

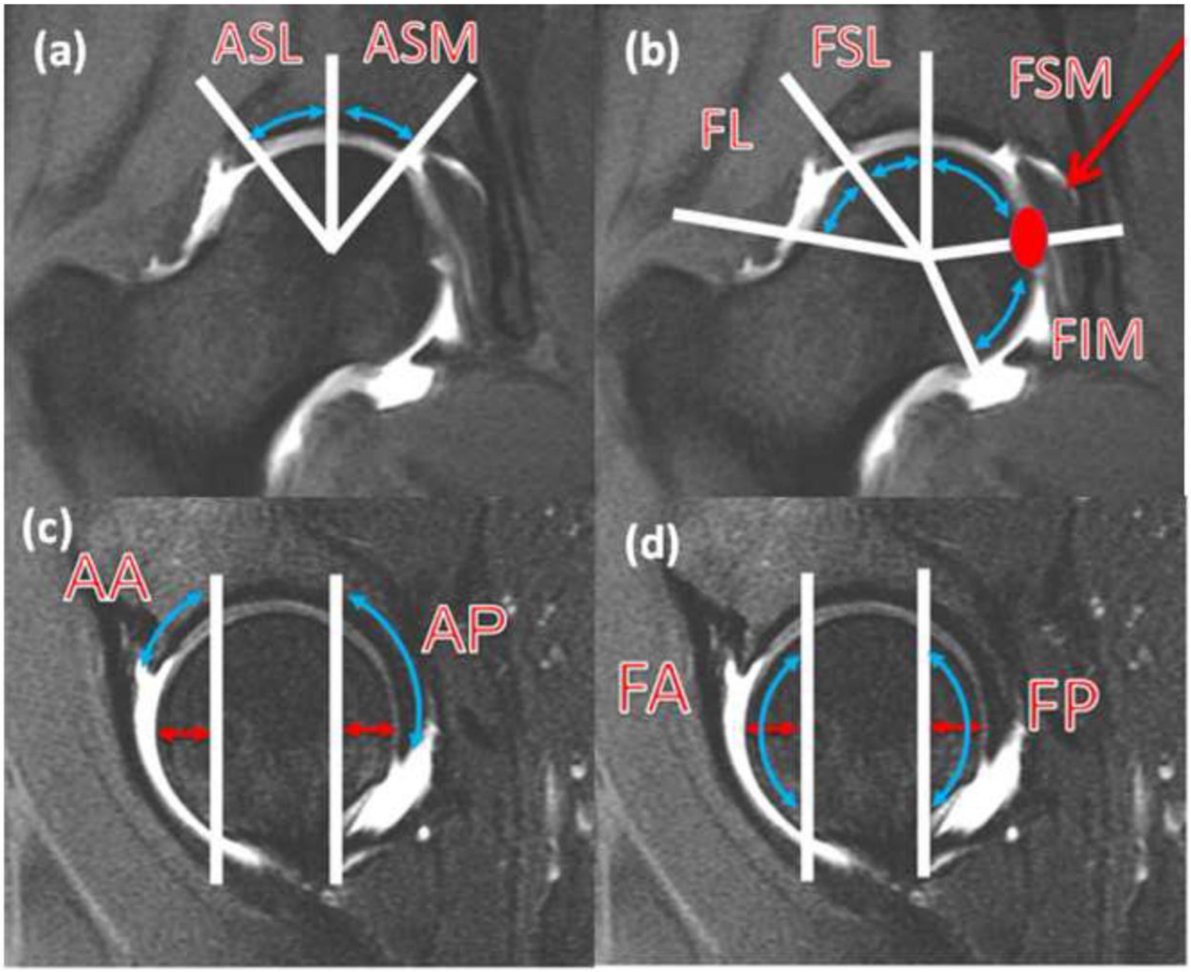

Figure 2.

Subregions of articular cartilage. for acetabulum on coronal (a) and sagittal (c) images. Subregions for femur on coronal (b) and sagittal (d) images. (a) coronal MR image demonstrating acetabular superolateral (ASL) and superomedial (ASM) subregions divided by vertical line extending from femoral head center.(b) coronal MR image demonstrating femoral lateral (FL), superolateral (FSL) and superomedial (FSM) and inferior (FIM) subregions divided by line extending from femoral head center, to the lateral acetabular rim, to straight vertical direction and to the ligamentum teres attachment . (c) sagittal MR image demonstrates acetabular anterior(AA) and posterior(AP) subregion, demarcated by vertical line 1 cm from the most anterior and posterior aspect of the femoral head. (d) sagittal MR image demonstrates femoral anterior (FA) and posterior (FP) subregion, demarcated by vertical line 1 cm from the most anterior and posterior aspect of the femoral head.

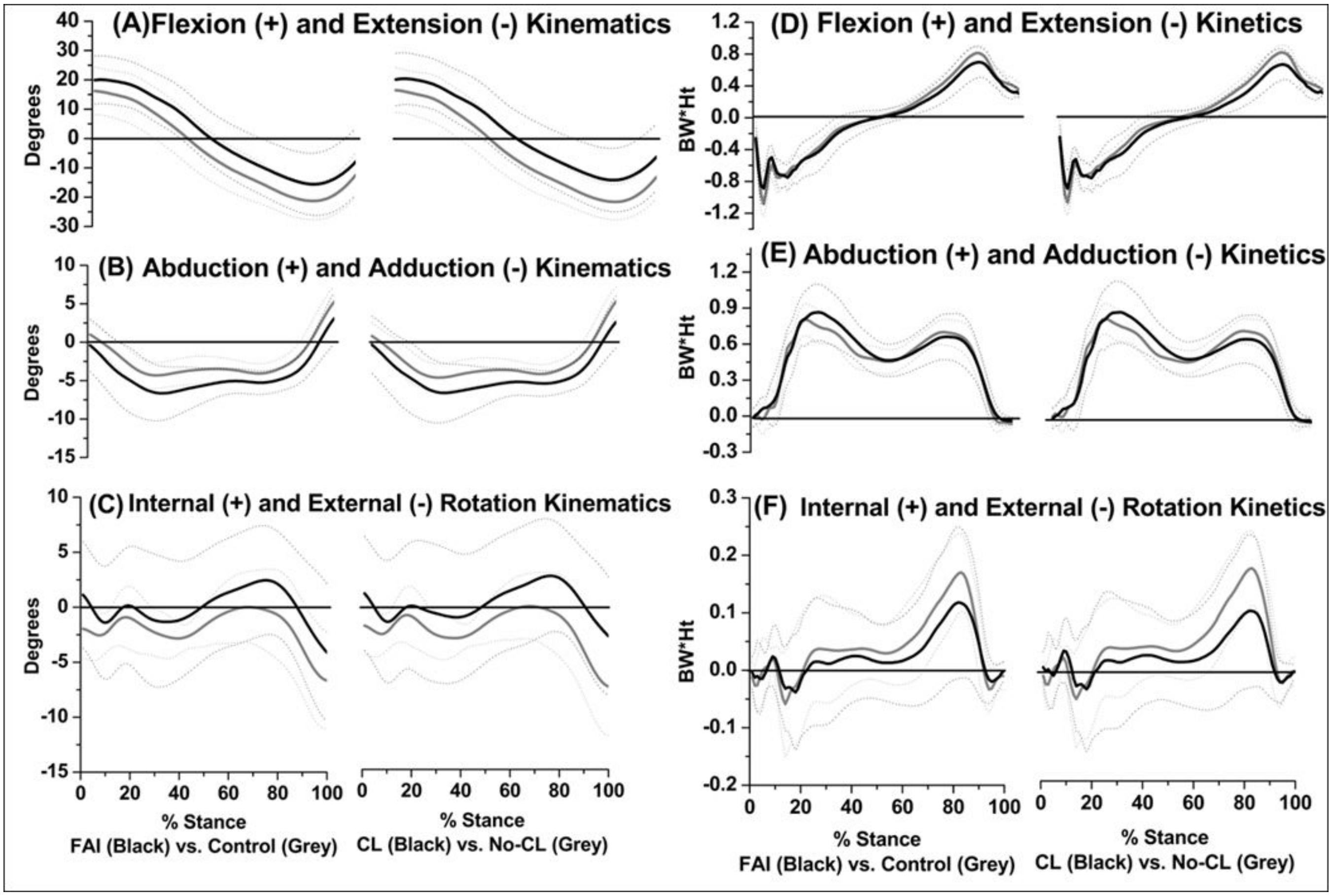

Figure 3.

Average (standard deviation) symptomatic hip kinematic (left panel) and kinetic (right panel) patterns for sagittal (A,D), frontal (B,E), and transverse (C,F) planes during walking gait. Femoroacetabular impingement (FAI: black) and control (grey) are shown in the first column. FAI + CL (CL: black) and no cartilage lesion (No-CL: grey) are in the second column. BW = body weight; Ht = height.

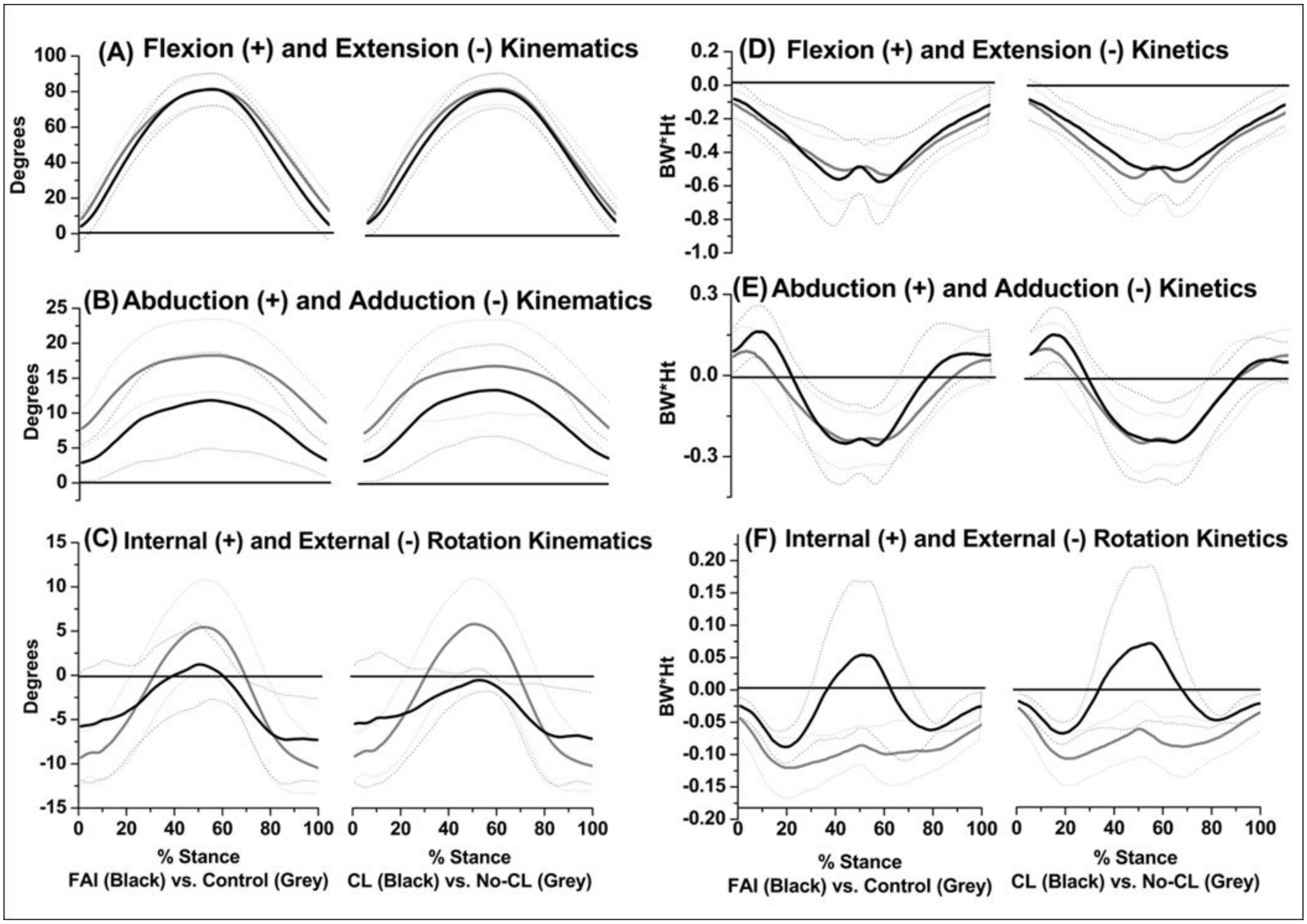

Figure 4.

Average (standard deviation) symptomatic hip kinematic (left panel) and kinetic (right panel) patterns for the sagittal (A,D), frontal (B,E), and transverse (C,F) planes during a deep squat. Femoroacetabular impingement (FAI: black) and control (grey) are shown in the first column. FAI + CL (CL: black) and no cartilage lesion (No-CL: grey) are in the second column. BW = body weight; Ht = height.

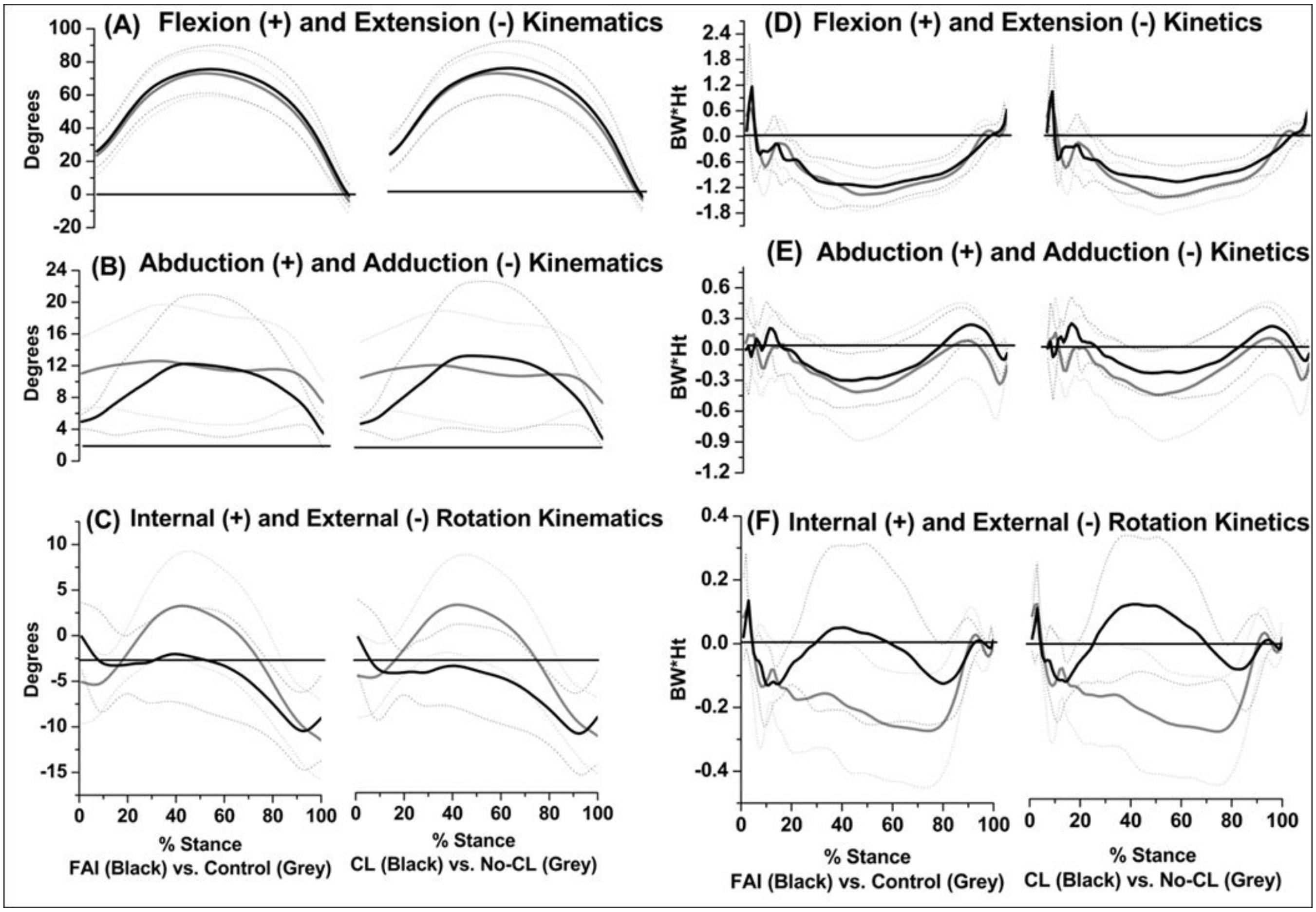

Figure 5.

Average (standard deviation) symptomatic hip kinematic (left panel) and kinetic (right panel) patterns for sagittal (A,D), frontal (B,E), and transverse (C,F) planes during drop jump. Femoroacetabular impingement (FAI: black) and control (grey) are shown in the first column. FAI + CL (CL: black) and no cartilage lesion (No-CL: grey) are in the second column. BW = body weight; Ht = height.

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Table 1

Subject age, BMI and gender distribution in patients with FAI and controls and those with and without cartilage lesions. Mean (standard deviation) reported for age and BMI.

	Controls (n =8)	**FAI (n = 7)**	***P***	**No Lesion (n = 9)**	**FAI + Lesion (n = 6)**	***P***
Age (years)	27.3 (7.7)	36.6 (9.7)	.059	27.8 (7.4)	37.3 (10.4)	.057
BMI (kg/m^2)	23.9 (2.3)	26.2 (6.9)	.400	24.2 (2.3)	26.1 (7.6)	.473
Male: Female	8:0	5:2	.104	0:9	2:4	.063
FAI: Controls	-	-	-	1:8	6:0	**.001**

FAI = Femoroacetabular Impingement

Table 2

Peak Positive and Negative Hip Powers (Mean and Standard Deviation) at the symptomatic hip for walking, deep-squat and drop-landing tasks

	Controls	FAI	*P*	No Lesion	FAI + Lesion	*P*
Walking (Watts)	88.5 (21.2)	72.9 (23.5)	.199	88.9 (19.9)	69.6 (23.9)	.112
	-33.1 (7.5)	-34.4 (14.5)	.824	-34.2 (7.8)	-32.9 (15.3)	.827
Deep-Squat (Watts)	35.2 (11.7)	44.9 (27.3)	.379	41.9 (22.9)	34.8 (12.9)	.542
	-33.1 (12.7)	-38.6 (22.5)	.574	-38.1 (19.0)	-30.8 (13.2)	.462
Drop-jump (Watts)	554.1 (72.6)	546.0 (204.6)	.919	582.1 (108.1)	493.9 (178.9)	.267
	-879.3 (417.8)	-665.1 (261.4)	.293	-911.8 (402.8)	-563.6 (91.0)	.085

FAI = Femoroacetabular Impingement