Effect of Capsulotomy on Hip Stability—A Consideration During Hip Arthroscopy

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Abstract

We conducted a study to further understand the effect of capsulotomy on hip joint stability using an in vitro cadaver model. Thirteen fresh-frozen cadaveric hip specimens were subjected to an external rotation torque of 0.588 Nm. The experimental kinematics, post-process translation, and rotation data for each specimen were tested under 4 conditions: neutral flexion with capsule intact; neutral flexion with transverse capsulotomy; maximum flexion with capsule intact; and maximum flexion with transverse capsulotomy. A segmented 3-dimensional model of the femur was used to evaluate femoral head translation after application of external rotation torque.

In maximum flexion, hips with intact capsules rotated less than hips with capsulotomy in the y (abduction) and z (external rotation) planes (y-plane, $P = .01$; z-plane, $P = .02$). After capsulotomy, there was a qualitative observation of increased distal, lateral, and anterior translation of the femoral head in neutral position, and a qualitative observation of increased medial, posterior, and distal translation of the femoral head in flexion. Qualitatively, after capsulotomy, hips tested in neutral position demonstrated more translation than rotation, whereas hips tested in flexion demonstrated more rotation than translation.

Capsulotomy appears to permit increased rotation in maximum flexion. Hips tested in neutral trended toward more translation than rotation, whereas hips in flexion trended toward more rotation than translation.

Judicious capsular management is indicated during arthroscopic hip procedures.

Hip arthroscopy is an increasingly popular procedure with steadily expanding utility and broadening indications. For arthroscopic procedures of the hip, a capsulotomy is often performed, as it helps the surgeon achieve intra-articular visualization, facilitates instrument exchange, and enhances maneuverability within a highly constrained joint. As such, an appropriate capsulotomy is a necessity for arthroscopic procedures in the central compartment. In addition, capsulotomy improves visualization of the peripheral compartment for the treatment of cam lesions and other extra-articular pathology. Consequently, interest in the contribution of capsular structures to hip stability has increased.

The role of the hip joint capsule on hip joint stability or kinematics is relatively unknown. Martin and colleagues[1] conducted the initial biomechanics study of the role of the iliofemoral, ischiofemoral, and pubofemoral ligaments. The triangular iliofemoral ligament (Y ligament of Bigelow) is the strongest of the capsular ligaments. It arises from the anterior inferior iliac spine of the pelvis and extends distally and laterally along the femoral neck to attach to the intertrochanteric line of the anterior femur. The iliofemoral ligament is taut in positions of extension and external rotation of the hip and loose in flexion and internal rotation.[2] Martin and colleagues[1] found that the iliofemoral ligament was determined to resist anterior translation of the femoral head from within the acetabulum, with its lateral arm limiting internal rotation in extension. The pubofemoral ligament was shown to control external rotation in extension. The ischiofemoral ligament was found to be the most significant resistor of internal rotation forces of the hip as well as resistor to adduction forces.

Using this in vitro model, we conducted a study to further understand the effect of a transverse capsulotomy (often performed during hip arthroscopy) on the rotational and translational kinematics of the hip. We hypothesized that increased rotational and translational femoroacetabular motion would be observed after capsulotomy.

Materials and Methods

We obtained 13 fresh-frozen cadaveric hip specimens consisting of the hemipelvis, the femur, and the overlying soft-tissues. All specimens were screened by computed tomography (CT) examination to assess acetabular and femoral version and to

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confirm the absence of bony pathology. Two inclusion criteria were hip center-edge angle 25° or less and Tönnis grade 1 or less. Two exclusion criteria were hip center-edge angle more than 25° and Tönnis grade more than 1. After thawing for 24 hours, all muscle and soft-tissue were removed from each specimen by careful dissection, leaving the hip capsule and labrum intact. The femur was transected at the junction of the proximal and distal thirds to allow for potting in polymethylmethacrylate (PMMA) in a cylindrical polyvinyl chloride mold. The iliac wing of the hemipelvis was placed in a 4 × 4-in mold to allow for potting in PMMA. The acetabular seal was vented placing a 20-gauge needle between the labrum and the bony acetabulum. Each specimen was placed into a modified version of the loading apparatus described by Provencher and colleagues.[3] The apparatus allowed for adjustment of flexion, extension, and axial rotation of the femur around a static ilium and acetabulum.[3]

Figure 1. Motion tracking system with loading apparatus mounted on x-y displacement table.

Six reflective markers were rigidly attached to the specimens to allow for 3-dimensional (3-D) position tracking. A motion-tracking system (Eagle4 cameras and EVaRT analysis software; Motion Analysis Corp., Santa Rosa, California) was used to record the experimental kinematics, post-process translation, and rotation data. The loading apparatus holding each specimen was mounted on an x-y displacement table (modified Provencher frame; **Figure 1**).[3] An external rotation torque of 0.588 Nm was applied by static load and held while data were recorded for 10 seconds for each loading condition. This torque magnitude was chosen because pilot testing demonstrated that 0.588 Nm was sufficient to cause full external rotation of the femur without causing impingement of the greater trochanter on the acetabulum at terminal rotation.

Each hip was tested under 4 conditions: neutral flexion with capsule intact; neutral flexion with transverse capsulotomy; maximum flexion with capsule intact; and maximum flexion with transverse capsulotomy. The transverse capsulotomy was performed on the anterior aspect of the femoral neck, 1 cm from the acetabular rim. It was continued distally, parallel to the labrum, involving the entire iliofemoral ligament.

The 3-D position of the markers in space was analyzed using Euler angle calculation in order to obtain translational and rotational parameters. CT scan was obtained of each specimen, and a virtual model was segmented using Mimics software (Materialise, Leuven, Belgium). In the model, the femoral and pelvic bones were separately extracted at the neutral position. These were superimposed over the images of each different position using voxel-based registration to evaluate

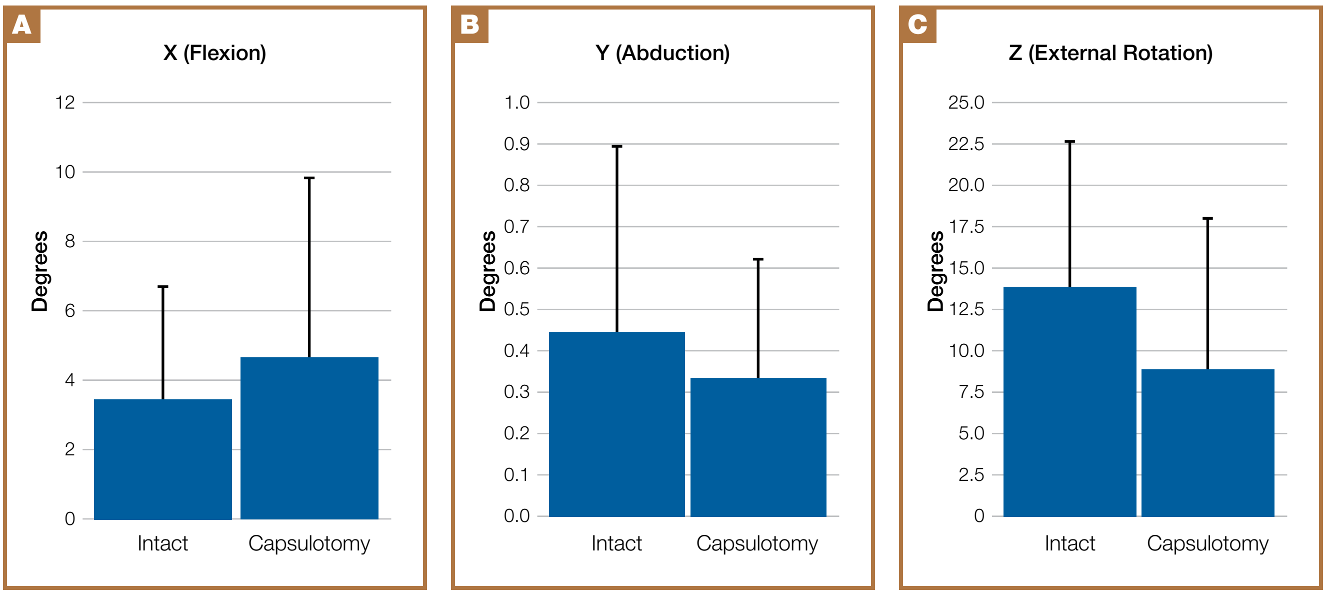

Figure 2. Rotation in neutral flexion. (A) Rotation in the x (flexion) plane. (B) Rotation in the y (abduction) plane. (C) Rotation in the z (external rotation) plane.

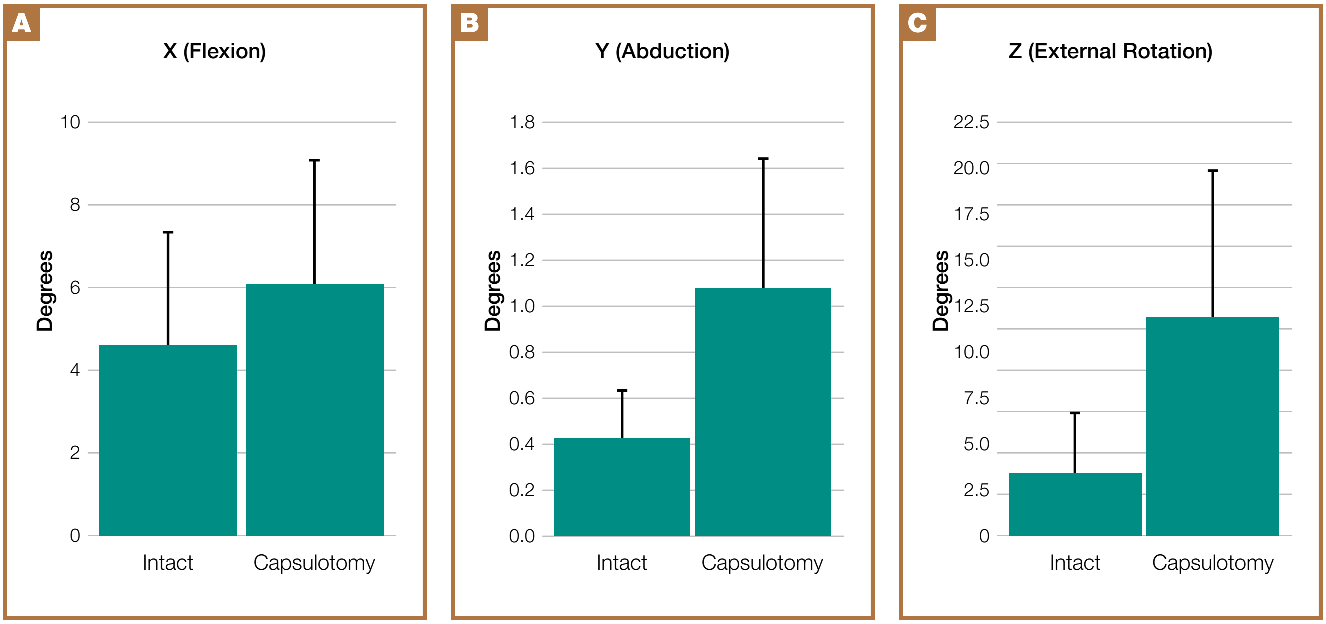

Figure 3. Rotation in maximum flexion. (A) Rotation in the x (flexion) plane. (B) Rotation in the y (abduction) plane. (C) Rotation in the z (external rotation) plane.

femoral head translation after application of the external rotation torque. Differences between experimental groups were assessed with both analysis of variance and nonparametric analysis. Level of significance was set at $P < .05$.

Results

We compared femoroacetabular motion caused by applied external rotation torque for each testing condition in terms of translation and rotation. The vector components of the rotation observed for each applied torque were analyzed in the x, y, and z axes. These equated to flexion, abduction, and external rotation components, respectively. During testing in neutral flexion, there was no significant difference in rotation in any plane between the hips with intact capsules and the hips with capsulotomy (**Figure 2**). However, for hips tested in maximum flexion, there was a significant difference in rotation in the y and z axes after capsulotomy (y-axis, 0.4° before capsulotomy, 1° after capsulotomy, $P = .01$; z-axis, 0.30° before capsulotomy, 1.20° after capsulotomy, $P = .02$). This equated to a 0.6° increase in abduction after capsulotomy and a 0.9° increase in external rotation after capsulotomy (**Figure 3**).

There were no statistically significant differences for displacement of the femoral head after torque application (**Table**). However, displacement vectors were plotted in a Cartesian coordinate system to visualize any changes in femoral head translation after torque application in the distal/proximal, anterior/posterior, and medial/lateral planes. Several qualitative changes in directionality were observed: Femoral head translation for hips tested in neutral was likely more distal, anterior, and lateral. This was true for hips with intact capsules and hips after capsulotomy. Femoral head translation for hips tested in flexion was inclined mostly to be distal, posterior, and lateral. However, after capsulotomy, hips tested in flexion leaned toward distal, posterior, and medial translation (**Figure 4**).

To better understand these qualitative observations, we plotted the mean displacement of all specimens in each testing condition. Again, there was no statistically significant difference in displacement of the femoral head after applied torque. Only qualitative directional tendencies were observed. In general, specimens tested in neutral rotation were likely to demonstrate anterior displacement of the femoral head both before and after capsulotomy (0.17 mm anterior before, 0.22 mm anterior after). This anterior displacement was greater after capsulotomy (0.17 mm anterior before, 0.22 mm anterior after). Specimens tested in flexion had a predisposition to demonstrate posterior displacement of the femoral head both before and after capsulotomy. This posterior displacement was also greater after capsulotomy (0.23 mm posterior before, 0.61 mm posterior after) (**Table**).

There was increased qualitative distal displacement af-

Table. Displacement

		Mean (SD), mm		
		ML	AP	PD
Neutral	Intact	1.64 (0.75)	0.17 (1.11)	−0.20 (0.48)
	Capsulotomy	1.68 (1.81)	0.22 (0.73)	−0.87 (1.29)
Flexed	Intact	0.09 (1.14)	−0.23 (0.55)	−0.23 (1.50)
	Capsulotomy	−0.75 (2.11)	−0.61 (1.95)	−1.05 (1.32)

Abbreviations: ML, medial negative, lateral positive; AP, anterior positive, posterior negative; PD, proximal positive, distal negative.

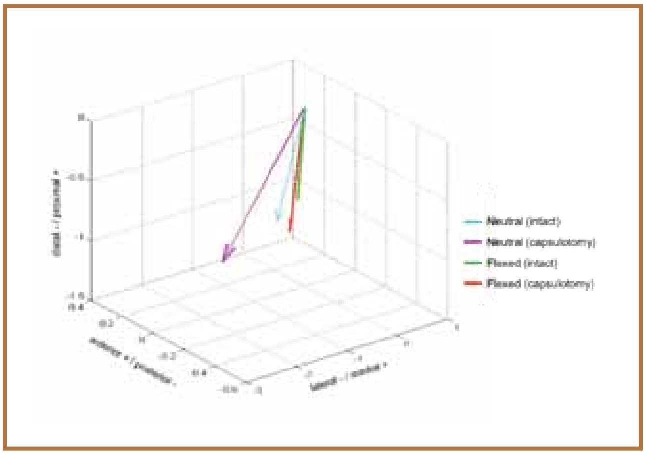

Figure 4. Mean displacement.

ter capsulotomy in neutral and flexed hips. This was a more marked difference for hips tested in flexion (neutral, 0.20 mm before capsulotomy, 0.87 mm after capsulotomy; flexed, 0.23 mm before capsulotomy, 1.05 mm after capsulotomy). There was an observation of greater qualitative lateral displacement after capsulotomy in specimens tested in neutral (1.64 mm laterally before capsulotomy, 1.68 mm laterally after capsulotomy). Similarly, there was greater qualitative medial displacement after capsulotomy for hips tested in flexion (0.9 mm laterally before, 0.75 mm medially after).

Discussion

With use of nonarthroplastic intra-articular hip procedures continuing to increase rapidly, more attention is being paid to the capsular structures of the hip. The question of how to perform the associated capsular sectioning that is required for these procedures becomes increasingly more relevant. Furthermore, there have been several reports of hip instability after hip arthroscopy.[4,5] Few studies have examined the contribution of the capsule to the stability of the hip joint.[1,6-8]

The objective of our experimental study was to demonstrate the effect of a transverse capsulotomy on hip stability by evaluating its effect on rotational and translational hip kinematics. Myers and colleagues[8] observed increased rotation after iliofemoral ligament sectioning for hips experiencing torque while in a flexed position. The larger increase in external rotation (mean, 12.9°, SD, 5.2°)[9] in their study is likely due to their use of larger torque (5 Nm vs 0.588 Nm). There is no consensus regarding what loads should be used for this type of cadaver study.

Transverse capsulotomy may also permit greater distal, lateral, and anterior displacement of the femoral head within the acetabulum in neutral, and increased medial, posterior, and distal translation of the femoral head in flexion. Data suggest that the overall trend in motion after application of external rotation torque is such that, after capsulotomy, hips that sustain the torque in neutral rotation tend to experience more translation than rotation. In contrast, hips that sustain the torque in flexion trend toward more rotation than translation (**Figure 5**).

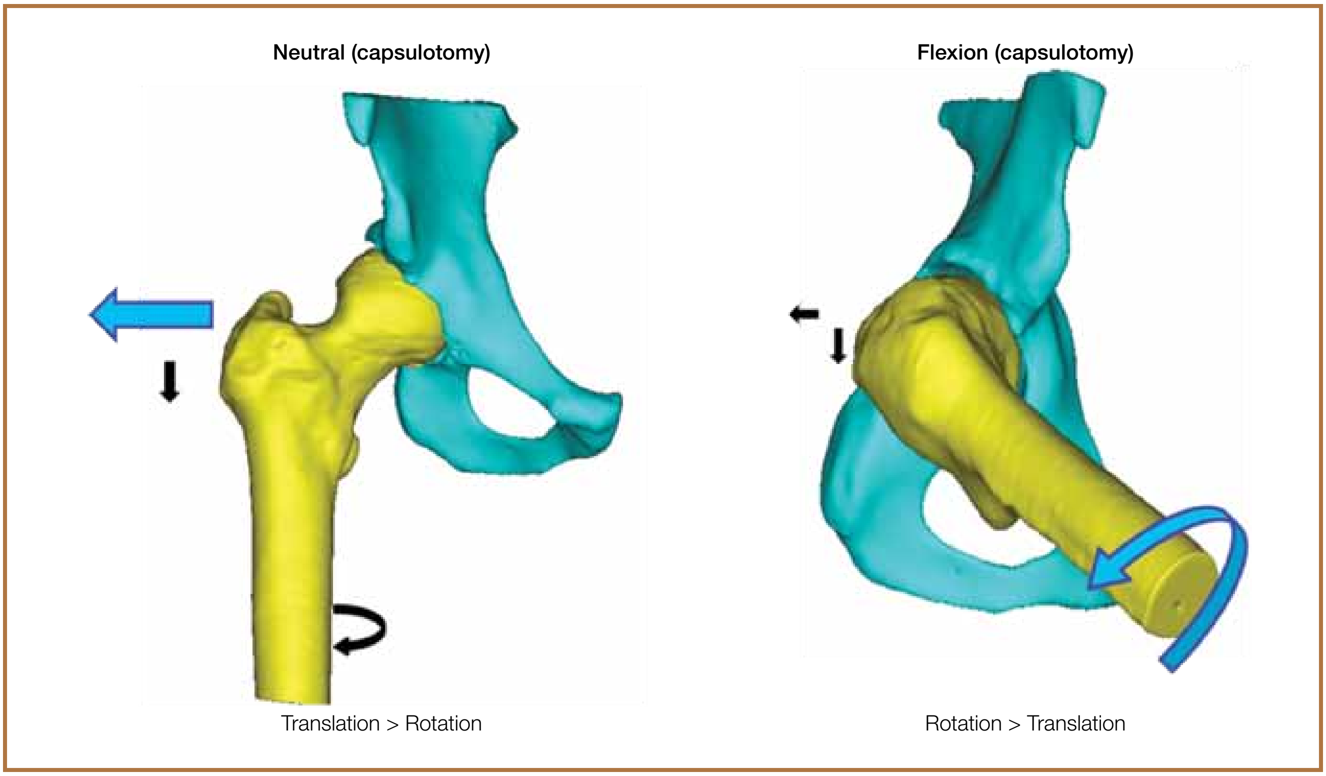

Figure 5. Overall motion trends after capsulotomy.

We believe that these observations are largely attributable to the relationship between the femoral head and the acetabulum with certain range of motion and the anatomical location of the transverse capsulotomy.

In this study, we tried to duplicate the capsulotomy generally used for hip arthroscopy. The arthroscopic transverse capsulotomy typically begins 1 cm from the acetabular rim and continues parallel to the labrum, connecting the anterior and anterolateral portals. It principally involves the iliofemoral ligament. In addition to contributing to the resistance of internal and external rotation in extension, the lateral arm of the iliofemoral ligament has also been shown to limit external rotation in flexion.[1] It is this latter function that we believe explains the increase in rotation observed after application of torque for hips tested in flexion. With transverse capsulotomy, the iliofemoral ligament loses its ability to resist rotation in flexion, and an increase in external rotation is observed.

Perceived increases in anterior displacement of the femoral head after capsulotomy in neutral are also likely due to iliofemoral ligament compromise, as it has been shown to resist anterior translation of the femoral head.[1] The inability of the ligament to perform this function after capsulotomy ostensibly permits greater anterior translation of the femoral head from within the acetabulum and explains our observed trends.

After capsulotomy, the increased qualitative lateral and distal displacement in neutral and the increased qualitative medial and distal displacement in flexion likely result from the bony congruency of the femoroacetabular joint. This translation likely represents the normal path that the femoral head traverses when moving against the inferior aspect of the acetabulum with rotation. Without the contribution of the iliofemoral ligament to anterior capsular restraint, the femoral head set into motion after an external rotation torque presumably follows the contours of the acetabulum as it rotates. As it continues, it likely translates laterally and distally when the hip is in neutral and medially and distally when the hip is in flexion.

After torque with the hip in flexion, there is more rotation and less translation because the femoral head is more engaged in the acetabulum. In neutral position, the femoral head is less engaged, and more translation than external rotation is observed.

Of note, specimens tested in flexion qualitatively demonstrated posterior displacement of the femoral head both before and after capsulotomy. This may explain the "contrecoup" pattern of cartilage damage over the femoral head and corresponding acetabulum often observed during hip arthroscopy. Flexed and rotated hips in the presence of capsular or labral damage may lever off the anterior acetabulum and impact the posterior acetabulum, causing posteroinferior acetabular cartilage injury.

We describe a novel approach for the analysis of native, cadaveric hip motion. Accurate quantification of positional changes of cadaver tissue in capsular studies is difficult.[10,11] Previous work ranges from use of the photoelastic coating method to measure strain in cadaver knee ligaments[10] to elaborate roentgen stereo photogrammetry (RSA) models that need artificial nominal-strain states that might not be physiologic but that are warranted from an engineering testing perspective.[11] More recently, use of biplanar fluoroscopy with RSA to study cadaver femoroacetabular motion has provided some initial results, but there are concerns because of the large number of repetitions for each condition (n = 20) with regard to tissue quality.[8] Myers and colleagues[8] also observed increased rotation in flexion after iliofemoral ligament sectioning.

To our knowledge, this is the first study to analyze hip kinematics after capsular sectioning using motion-capture analysis. Crawford and colleagues[12] evaluated hip kinematics after labral venting and sectioning using motion-capture analysis. With their data, they concluded that a breach in labral integrity decreases femoral stability. The biomechanics laboratory at Rush University Medical Center (Chicago, Illinois) has expertise in using motion-capture methods to quantify joint mechanics in cadaver tissue.[13-15] The post-processing method developed in our laboratory makes use of CT-based models to accurately determine the spatial relationships between marker position and bone geometry to define the trajectory of the rigid body centroid tracked by the motion-analysis system, making it a more robust approach. Conversely, biplanar fluoroscopy and RSA depend on accurate calibrations to remove distortion artifacts, and often image registration is performed by hand to evaluate changes in rigid body kinematics. As such, motion-capture analysis can theoretically minimize human error.

Furthermore, this is the first capsular hip motion study to analyze native femoral head rotation in its component axes (abduction, flexion, external rotation) as a consequence of torsion, and to examine the direction of translation of the native femoral head in its component vector planes (anterior/posterior, medial/lateral, proximal/distal).

This study had several limitations. First was the small sample size. Prior cadaveric hip motion model studies have used between 6 and 24 hips.[1,8,12] A related limitation was that only qualitative tendencies, not statistical differences in translation, were observed after capsulotomy. Larger studies are needed to further examine how capsular integrity affects hip stability. Another limitation of this study was the effect of bony morphology on hip kinematics. We attempted to minimize variability by controlling for hips without evidence of acetabular dysplasia or arthritis. However, it is unknown how variations in hip morphology and orientation may affect rotational and translational motion. Last, as this was a cadaveric study, the femoroacetabular joint kinematics were evaluated only in vitro.

At present, the clinical significance of our observed differences in rotation and qualitative observational tendencies in translation is unknown. As we evaluated only the static stabilizers of the hip, this study did not account for dynamic sources of stability, including the surrounding musculature. Furthermore, we were able to evaluate data only from immediately after the capsulotomy. Behavior of the hip joint over time after the capsulotomy is unknown. Simulation studies may be able to provide an answer if the appropriate constitutive equations are developed.

The literature includes very few studies on hip capsule instability and even fewer analytical models. A Pubmed search using the phrase *hip capsule instability* found only 52 articles as of May 2012. The vast majority of those articles were clinical reports. The search found only one finite-element study, by Elkins and colleagues,[6] and it innovated in this area, but the focus of its instability investigation was on a total hip arthroplasty model, not femoroacetabular impingement. As such, the capsular ligament elastic anisotropy and spatial variation in capsule-tissue thickness were not included in the model because of the added computational expense and complexity.[6] Knowledge of these properties will also help to describe how the kinematics are affected by capsular healing. However, we believe that the observations made in this study are motivating and warrant further investigation.

Conclusion

Our results suggest that transverse capsulotomy permits increased rotation in maximum flexion compared with hips with intact capsules. Capsulotomy may also allow greater translation of the femoral head in both neutral and flexion. Therefore, we believe judicious capsular management is indicated during arthroscopic hip procedures.

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