Etiology and Severity of Impingement Injuries of the Acetabular Labrum: What Is the Role of Femoral Morphology?

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abstract

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Injuries to the acetabular labrum have been seen in association with femoroacetabular impingement, but recent studies have reported labral pathology in patients with normal hip morphology. The hypothesis of the current study was that labral lesions could occur without femoroacetabular impingement but that labral pathology would occur more commonly and more severely in hip joints that exhibit reduced head–neck offset. The presence, location, and severity of labral injury were recorded in 22 cadaveric specimens. Computed tomography was used to define the anatomic parameters of proximal femoral morphology. Three-dimensional modeling was used to simulate hip positions that typically cause labral impingement, including high flexion and internal rotation. Femoral morphology was compared between specimens with and without labral pathology using descriptive statistics. Labral pathology was seen in 15 of 22 specimens and was located in the anterosuperior portion of the labrum. No difference existed in age, femoral neck shaft angle, anteversion, acetabular depth, head diameter, alpha angle, or beta angle between specimens with and without labral pathology. The severity of labral pathology correlated with the alpha angle of the proximal femur. This study demonstrates that damage to the labrum may occur in hips with normal proximal femur morphology. However, the findings also indicate that the presence of morphologic features that increase the risk of impingement may predispose the hip joint to a characteristic pattern or severity of labral pathology. The results confirm the importance of considering both femoral morphology and athletic-type activities of the hip when determining the mechanism responsible for injury of the acetabular labrum.

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Figure: Photographs of stage 2 damage of the acetabular soft tissues with a defined labral tear and intact acetabular cartilage (A), stage 3B damage with a labral tear and focal adjacent chondral pathology (B), and stage 4 damage with diffuse labral and chondral damage (C).
The acetabular labrum is a fibrocartilagenous rim of tissue that enhances the stability of the hip joint. The labrum encases the femoral head within the acetabulum and restricts hip motion, particularly in the extremes of activity. By providing a partial seal of the hip joint, the labrum limits the biomechanical stress placed on the soft tissues of the joint. Previous investigation by the authors showed labral damage to negatively effect the biomechanical environment of the hip joint, with subluxation of the femoral head occurring in extremes of joint motion when the labral seal is disrupted. This finding, coupled with observational studies depicting a significant association between labral and chondral pathology, illustrates the potential for further irreversible joint degeneration after an initial injury to the acetabular labrum.

Although the exact mechanism of damage to the labrum has not yet been delineated, recent investigations have identified specific maneuvers of the hip and morphologic variants of the hip joint as factors involved in labral injury. McCarthy et al hypothesized that labral injury may occur from a mechanism in which the anterior labrum is subjected to substantial mechanical demands during pivoting or twisting of the hip in moderate amounts of flexion or extension. This hypothesis has been supported by the current authors’ work, which demonstrated the substantial tensile strains that are developed within the labrum during these activities and by motion capture analysis showing impingement during extreme ranges of motion experienced by dancers with morphologically normal hips.

Alternatively, Ganz et al implicated morphologic variants of femoral and acetabular anatomy as causative of nontraumatic labral pathology. Cam-type femoroacetabular impingement, in which reduced head-neck offset of the femur exists, is thought to be more damaging to the labrum than pincer-type femoroacetabular impingement, in which excessive deepening of the acetabulum exists. In cam-type femoroacetabular impingement, labral injury occurs secondary to internal rotation of the abnormal femur in flexion angles of approximately 90°. The shearing forces created during internal rotation are thought to damage the cartilage, separating it from the overlying labrum in the anterosuperior segment of the acetabular rim.

Although the mechanisms of labral injury proposed by McCarthy et al and Ganz et al appeared to be plausible and could coexist, Ganz et al concluded that nearly all nontraumatic labral lesions occur secondary to femoroacetabular impingement. The current authors’ previous work does not completely agree with this conclusion and, for this reason, further investigation of the relationship between labral pathology and femoroacetabular impingement is warranted. This investigation is of particular merit because of the potentially damaging consequences of labral damage and the more common and successful use of surgical techniques for early treatment of femoroacetabular impingement.

The current study investigated the effect of femoral morphology on the occurrence, severity, and location of labral pathology. The hypothesis was that labral lesions could occur in the absence of femoroacetabular impingement but that labral pathology would occur more commonly and more severely in hip joints that exhibited reduced head-neck offset. In addition, the authors evaluated whether the site of labral pathology was concordant with the impingement location of the femur along the acetabular rim during high deep flexion of the hip joint.

**Materials and Methods**

Twenty-two fresh-frozen cadaveric specimens consisting of a hemipelvis and hip joint with capsule and labrum intact were obtained from willed body programs for use in this study. Details of age and sex were available for 16 of the 22 donors (9 men and 7 women; average age, 74 years). The soft tissues surrounding the femoroacetabular joint were sequentially removed, and the joint was disarticulated in a controlled and careful manner to avoid damage to the labral and chondral surfaces of the acetabulum. The articular surfaces of the acetabulum and femoral head of each specimen were carefully inspected for pathologic changes.

The severity of labral pathology was classified using the staging system described by McCarthy, with modifications for use with cadaveric specimens. Specimens with no sign of labral or chondral pathology were classified as stage 0. Specimens with a discrete tear of the labrum at its free margin were classified as stage 1. Specimens with a defined labral tear, intact acetabular cartilage, and focal damage to the subjacent area of the femoral head were classified as stage 2 (Figure 1A). Specimens with a labral tear and an adjacent focal acetabular chondral lesion were classified as stage 3. Further subdivision of stage 3 was based on the size of the chondral lesion: specimens with chondral lesions <1 cm were classified as stage 3A and those with larger chondral lesions as stage 3B (Figure 1B). Specimens with a diffuse labral tear with associated diffuse articular cartilage degeneration were classified as stage 4 (Figure 1C). The locations of the labral and chondral lesions around the acetabular margin were identified using a clockface system, with the middle of the inferior acetabular notch designated as 6 o’clock.

**Evaluation of Femoral Morphology**

The femur and hemipelvis of each specimen were scanned by computed tomography scanned, and 3-dimensional (3-D) computer models of each specimen were reconstructed using customized software (Mimics 9.1; Materialise, Ann Arbor, Michigan). Computer analysis was used to describe the morphology of each femur by representing each bone as an assembly of discrete anatomic objects cor-
responding to the head, neck, and shaft of the femur. The procedure for describing the morphology of each femur consisted of initially segmenting each 3-D model of the femur into its anatomic objects and then defining the reference origin, anatomic axes, and surface shape of each object. It was then possible to define, in mathematical terms, the relative displacement of each object with respect to any other (eg, posterior slip of the femoral head on the neck), as well as dysmorphic changes in the inherent size and shape of each object itself (eg, coxa magna). The following morphologic parameters were derived using this method:

1. The diameter of the femoral head, defined by the sphere of best fit to the subchondral surface of the head.

2. The femoral neck axis, defined by the line of best fit to the centroids of a series of 20 cross sections through the femoral neck.

3. The anterior head–neck offset, measured using the method described by Eijer et al by calculating the distance between 2 lines parallel to the neck axis, the first along the anterior cortex of the femoral neck and the second along the apex of the anterior femoral head (Figure 2).

4. The normalized anterior head–neck offset ratio, defined by Eijer et al as the anterior offset of the femoral head divided by the head diameter. A vector was drawn between the center of the femoral head and the point at which the surface of the anterior half of the femoral head deviated from a sphere.

5. The extent of the spherical surface of the femoral head, as described by:
   - The alpha angle, defined as the angle between the femoral neck axis and a line connecting vector from the center of the femoral head to the anterior boundary of sphericity. This angle was recorded after positioning the femur to simulate the Dunn view in 45° flexion, a view shown by Meyer et al to be the most sensitive projection for detecting a large alpha angle. Recent analysis of asymptomatic individuals showed the mean alpha angle to be 48°, with 1 SD being 8°. The specimens were stratified according alpha angle cutoff levels of 55° (1 SD above mean) and 63° (2 SD above mean) for further analysis.
   - The beta angle, defined as the angle between the posterior interruption of sphericity and the femoral neck vector.

6. Femoral anteversion in specimens with intact femoral condyles (16 of 22 specimens) using a simula-
tion of the table-top examination of the angle of the femoral head and neck relative to the frontal plane of the body.

7. The neck–shaft angle between the femoral neck vector and the shaft of the femur.

Computer Simulation of Labral Impingement

Virtual simulation of the motion of each hip joint to the point of labral impingement was performed with the computer model of each specimen using kinematic routines (Unigraphics 4.0; EDS, Plano, Texas). The virtual model of each pelvis was positioned such that a plane tangent to the anterior surfaces of both anterior superior iliac spines and the pubic symphysis was oriented vertically. The horizontal axis of the pelvis was defined by a vector joining the anterior superior iliac spines and the posterior superior iliac spines. The femur was initially oriented in (1) neutral adduction, defined by orienting the epicondylar axis parallel to the horizontal plane; (2) neutral flexion/extension, defined by aligning the vertical axis and the tangent line to the posterior cortex at the midlength of the diaphysis; and (3) neutral axial rotation, defined by aligning the posterior condyles and the coronal plane. To represent the acetabular labrum, a curve fit was made to the rim of the acetabulum and extruded 5 mm, corresponding with the spatial location of the predicted surface of the labral margin.

Because it is generally appreciated that femoroacetabular impingement occurs in positions of high flexion with internal rotation, each hip joint model was placed in a range of flexion angles from 70° to 110°. At each flexion angle, the hip joint was internally rotated until the surface of the anterior femoral neck impinged with the simulated surface of the labrum (Figure 3). This was done to examine maneuvers that would be potentially painful in a clinical setting, as previous work has described nociception in the labrum. Once this position was recorded, additional internal rotation was added to the point of bone-on-bone impingement, as simulated by other authors. The internal rotation angle and clockface segment at which the lesion passed underneath the labrum was recorded for each case. The clock-face location of impingement following internal rotation in 90° flexion was also determined for each specimen to specifically investigate the mechanism proposed by Ganz et al and Tannast et al for damage of the labrum in femoroacetabular impingement and is hereafter referred to as the impingement zone.

Statistical Analysis

Specimens were separated into 2 groups based on the presence or absence of labral pathology. The morphologic parameters, predicted location of impingement between the femur and the acetabular margin in flexion/internal rotation maneuvers, and staging and location of labral pathology were compared between the 2 groups using the Mann-Whitney U test. The association of femoral morphology with the occurrence and severity of labral pathology was evaluated individually using Spearman’s rank correlation test. Fisher’s exact test was used to determine any difference in the probability of labral lesions between the morphologically normal and abnormal cohorts. The impingement zone and lesion location were compared using the paired Wilcoxon signed rank test (SPSS version 15.0 software; SPSS, Inc, Chicago, Illinois). Nonparametric tests were used in the absence of a normal distribution within the small sample size. Statistical significance was defined as $P<.05$.

RESULTS

Labral pathology was identified in 15 (68%) of the 22 hip joint specimens examined. Donors of specimens with labral lesions were predominantly men (70%), compared with donors of normal specimens, 33% of whom were men, but this difference was not statistically significant ($P = .09$). No significant difference existed in age, femoral neck–shaft angle, femoral anteverision, acetabular depth, acetabular index, anterior offset ratio, alpha angle, or beta angle between the 2 groups (Table). No difference existed in the likelihood of the specimens having labral pathology when the femora were classified morphologically using alpha angle thresholds of 55° (1 SD above the mean) and 63° (2 SDs above the mean). Some degree of labral pathology was
observed in 15 of the 22 specimens: 2 specimens had stage 1 pathology, 5 had stage 2, 6 had stage 3 (1 stage 3A and 5 stage 3B), and 2 had stage 4. The most common lesion consisted of a circumferential separation of the labrum and the acetabular articular cartilage within the anterior-superior quadrant. The average location of the largest labral lesion in each specimen was at $2.4\pm0.3$ o’clock and ranged from 12:30 to 4 o’clock. No significant difference existed between the normal and abnormal femora in terms of the prevalence of labral pathology, depth of the acetabulum, femoral anteversion, or neck–shaft angle (Table).

The amount of internal rotation permitted at each flexion angle was compared between the morphologically normal and abnormal cohorts and between the groups with and without labral pathology. When the specimens were compared according to an alpha angle threshold of 55o, no significant difference existed between permitted internal rotation in 90° of flexion in normal ($\alpha<55^\circ$) and abnormal femora ($\alpha>55^\circ$) ($16.4^\circ\pm3.4^\circ$ vs $13.7^\circ\pm2.8^\circ$, respectively; range: $0^\circ$-$38^\circ$; $P=.54$). When the specimens were compared according to the pathologic status of the labrum, those with labral lesions permitted an average of $8.3^\circ$ more internal rotation at 90° of flexion than the normal specimens ($17.5^\circ\pm2.6^\circ$ vs $9.2^\circ\pm2.8^\circ$, respectively; $P=.03$ (Table).

The mean lesion location was approximately 2:30 on the clockface, and the mean impingement zone location was approximately 1.8 o’clock. In specimens with labral pathology, the severity of the lesion was significantly correlated with the alpha angle ($r=0.504$; $P=.02$) but was not significantly associated with any other measurement of femoral morphology. Fisher’s exact test revealed no significant correlation between head–neck morphology (alpha and beta angles) and the location of the impingement zone. However, the neck–shaft angle was directly and significantly correlated with the impingement zone location ($r=0.442$; $P=.049$), indicating that impingement on internal rotation in 90° of flexion occurs at more anterior locations as the neck–shaft angle increases.

### Discussion

The identification of labral pathology as an early event in the progression of joint disease underscores the need for a better understanding of the pathomechanical processes leading to injury. Several factors, including hip joint morphology and specific maneuvers of the hip, have been proposed as being responsible for labral damage.1-3,5,20 The current study was designed to understand the femoral morphologic factors associated with the occurrence of labral lesions, the location of the lesions, and the characteristics of the maneuvers required for impingement.

The findings do not support the conclusion that labral pathology is predominantly associated with patients whose hip anatomy (such as those with cam or pincer lesions) prevents motion beyond a threshold value of range of motion. The results showed no difference between the amount of permitted internal rotation at 90° of flexion between specimens with alpha angles $<55^\circ$ and $>55^\circ$. This finding is contradictory to that of Ganz et al5 that a value of $<20^\circ$ of internal rotation in end-range degrees of flexion is indicative of femoroacetabular impingement and a high risk for labral pathology.5

In the current study, specimens with labral pathology exhibited significantly higher amounts of permitted internal rotation at 90° of flexion than those without labral pathology, despite no significant difference in alpha angle or anterior offset
The findings of McCarthy et al. and of the current study further support the hypothesis that labral pathology can occur from forceful impaction of the femoral neck into impinging positions during maximal range of motion, even in morphologically normal hips. The current study’s findings do not refute the significance of cam lesions in contributing to labral pathology, given that the alpha angle was directly correlated with the severity of labral pathology. This finding supports the rationale for surgical osteochondroplasty to increase the anterior offset and subsequently decrease impinging forces on the acetabular labrum. The current study joins other recent studies in showing engagement of cam lesions at the anterosuperior labrum and the relationship between asphericity and the severity of subsequent acetabular soft tissue injury. Although the importance of considering femoroacetabular impingement in the evaluation of young patients with hip pain is acknowledged, labral or chondral pathology can occur in patients with morphologically normal hips. Conversely, bony characteristics suggestive of femoroacetabular impingement may be present in asymptomatic patients.

The current study investigated the effect of various femoral morphology factors on the occurrence of labral lesions and related hip motion parameters. The approach used had several distinct strengths. The identification and testing of specimens with labral lesions allowed for a standardized and controlled evaluation of the hip joint. In addition, the use of 3-D computer modeling permitted the standardized measurement of femoral morphology factors. The protocol used for testing labral impingement allowed efficient determination of the postural maneuvers required to cause impingement at specific locations along the acetabular rim, a task that would be difficult to accomplish in a clinical or surgical setting. Previous models have shown the usefulness and validity of 3-D computed tomography-based methods to evaluate hip range of motion. However, conducting joint motion tests with computed tomography-based model reconstructions does not account for the dynamic stabilization effect of the surrounding soft tissues and the presence of intracapsular soft tissues such as the labrum. This is a limitation acknowledged by Kubiak-Langer et al., who justified this shortcoming by referring to Ganz et al.’s intraoperative findings that motion of the hip joint with femoroacetabular impingement is restricted by bony contact.

In addition, the maneuvers investigated in the current study were limited to internal rotation of the flexed femur. This was done to focus on a mechanism of impingement specifically described as related to femoral morphology. The findings of the current study are also limited by the tests selected to evaluate morphology of the femur. Other measurements or evaluations of femoral morphology may also be useful, but current assessment protocol was limited to measures used in the clinical setting and reported in the published literature. Femoral version may influence the amount of internal rotation permitted prior to impingement, regardless of whether a cam lesion is present. No difference existed in the femoral version between specimens with and without labral pathology. Because the scope of the current study was confined to the effect of femoral morphology on chondral and labral damage, evaluation of acetabular morphology was limited to measurement of each specimen’s acetabular depth and index. This limitation was accepted because Ganz et al.’s suggestion that cam-type femoroacetabular impingement is “clearly more dangerous” to the acetabular labrum than pincer-type femoroacetabular impingement.

Additional limitations of the current study include those inherent to cadaveric investigations, particularly the lack of a clinical history of the presence or absence of hip joint symptoms. Donor age of the specimens was substantially greater than the age of patients who generally present with labral lesions. It is plausible that degenerative labral lesions may have been present in these older specimens. This limits the direct clinical applicability of the findings because degenerative lesions in older patients are not equivalent to acute soft tissue trauma in younger, active patients often evaluated for femoroacetabular impingement. Ideally, this study would be replicated in a series of younger cadaveric specimens to strengthen the potential clinical correlations. However, obtaining a sufficient number of specimens in a younger age range is challenging. In addition, damage to the soft tissues of the hip was classified with a staging system originally designed for use during arthroscopic examination. This limitation was accepted in exchange for the ability to standardize and categorize the level of pathology present in the cadaveric specimens.

Despite these limitations, the current study was an objective assessment of the influence of femoral morphology on the potential for lesions of the acetabular labrum. Future clinical studies of the effect of femoral morphology factors on the occurrence and characteristics of labral lesions are warranted based on the findings of the current study.

**Conclusion**

The importance of the acetabular labrum in maintaining joint integrity is emphasized by the recent increase in interest in its normal function, the factors leading
to its injury, and the consequences of its pathology. The current study demonstrated that damage to the labrum may occur in hip joints with normal morphology of the proximal femur. However, the findings also indicate that decreased femoral head–neck offset may predispose the hip joint to a characteristic pattern or severity of labral pathology. Although further investigation is needed to apply the findings of the current study in the clinical setting, the results confirm the importance of considering femoral morphology and athletic-type activities of the hip when determining the mechanism responsible for injury of the acetabular labrum.

REFERENCES


