Preoperative Three-dimensional CT Predicts Intraoperative Findings in Hip Arthroscopy

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Abstract

Background Currently, plain radiographs and MRI are the standard imaging modalities used for diagnosing femoroacetabular impingement (FAI) and preoperative planning for arthroscopic treatment of FAI. The value of three-dimensional (3D) CT for these purposes is unclear.

Questions/purposes We therefore determined the reliability of CT assessment of FAI and whether CT findings of hip disease predict arthroscopic findings.

Methods We retrospectively assessed the preoperative CT scans of 118 patients who underwent primary hip arthroscopy. Intraoperative findings, including size of the cam

lesion, presence of an acetabular labral articular disruption lesion, and one of four types of labral tear were recorded and compared with the retrospectively read CT findings.

Results Agreement analysis between CT and intraoperative detection of FAI yielded kappa values of 0.48 for cam lesions and 0.16 for pincer lesions. Increasing values for the CT-based alpha angle correlated with increasing severity of arthroscopically assessed acetabular labral articular disruption grade. Each pattern of FAI predicted a specific labral tear type.

Conclusions Our data suggest CT has moderate value in predicting mechanically based labral tear patterns, although better parameters for assessment of pincer lesions are needed. Diagnostic assessment of patients with suspected FAI may be improved with use of 3D CT.

Level of Evidence Level III, diagnostic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Hip arthroscopy has an evolving spectrum of techniques and indications for use in orthopaedic surgery. Although

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many of the earliest applications of the technique were designed to address soft tissue lesions in the joint such as labral tears, cartilage lesions, and loose bodies [21, 23, 27, 37, 39, 41], a growing body of literature has suggested specific patterns of underlying bony morphologic features of the hip may be responsible for the chondrolabral disorders historically treated by arthroscopy [4, 14, 34, 42]. As a result, there has been a relative shift in the focus of hip arthroscopists toward these bony abnormalities, chief among them the cam and pincer lesions that comprise femoroacetabular impingement (FAI). FAI is one of the most common conditions leading to hip pain in young adults [4, 13, 25]. As understanding of the condition has continued to progress, arthroscopic bony recontouring procedures such as osteochondroplasty of cam lesions and rim trimming of pincer lesions have emerged to become common techniques used in hip arthroscopy.

Currently, MRI and MR arthrography are the established gold standards for advanced diagnostic imaging workup of hip pain in young patients, particularly when a labral tear is suspected [16, 22, 29, 32]. Despite its value in assessing the status of intraarticular and periarticular soft tissue structures about the hip, there are clear limitations in the ability of MRI to evaluate bony morphologic features. Although the value of three-dimensional (3D) CT imaging for hip pain is less well-studied [12, 18, 20, 30], CT has long been the best imaging modality for assessment of bony abnormalities, and its inherent advantages over MRI have been further advanced with the introduction of 3D reformatting of CT images. Thus, with expanding appreciation of FAI as a causative factor in labral and cartilaginous hip disorders, CT may have an underappreciated role as a preoperative imaging modality before arthroscopic hip procedures.

We therefore determined: (1) the reliability of specific CT-based measurements of bony geometry and pathologic features related to FAI; (2) the agreement between CT findings and findings of bony disorders on arthroscopic inspection; (3) whether the presence and size of a cam lesion predicts the presence or grade of an acetabular cartilage lesion; and (4) whether the presence or absence of a cam or pincer lesion predicts the type of labral tear.

Patients and Methods

We retrospectively assessed medical records and preoperative CT scans of all 118 patients who had CT, obtained for clinical purposes, and underwent primary hip arthroscopy by one surgeon (BTK) at one institution between June 2007 and February 2008. Indications for surgery included one of the following three diagnoses, the symptoms of which were refractory to a minimum of 6 months of nonoperative therapy (including physical therapy, NSAIDs, and activity

modification) in all cases: FAI, acetabular labral tear, or snapping hip syndrome with psoas impingement syndrome. Demographics and basic descriptive statistics of patients were collected and analyzed, including age, sex, and laterality. The mean age of patients included in this study was 30.3 years (range, 15–51 years). There was no major difference between the mean age of females ($n = 41$ [35%]) and males ($n = 77$ [65%]). Of the hips studied, 75 were right (64%) and 43 were left (36%).

Preoperative CT scans were performed at one facility with the following standardized imaging and reformatting protocol: slice thickness, 2.5 mm retrospectively reconstructed to 0.625 mm; pitch, 0.531:1; resolution, 512×512 ; kVp, 120; mAs, 400; acquisition algorithm, bone; and reformation algorithm, standard. The average dose of radiation for the CT scan was 16.48 mGy, and the national average 2010 Medicare reimbursement for CT Hip was \$241.73 (CPT 73700). Four radiologists (GLD, RL, DD, SA), each with greater than 8 years of experience evaluating hip CTs, each performed readings on a set of 60 of the scans. No two radiologists read the same group of 60 images, however there was overlap between the sets of scans given to any two radiologists. This algorithm was established so that at least two independent readings were generated for each of the 118 images to account for potential variations in assessment approaches or techniques between the radiologists. Standard protocols and definitions for CT measurements used for this study were selected from recent peer-reviewed literature [1–3, 7, 11, 24, 32] (Table 1). The beta angle used in this study is to be distinguished from that described by Beaulé et al. [3], which is essentially equivalent to an alpha angle at the posterior, rather than anterior, head-neck junction. Before recording any formal measurements, the radiologists also were asked to assess the 3D reconstructed image and grossly determine by visual assessment if a cam or pincer lesion was present or absent.

Intraoperative findings were assessed in one session by the primary surgeon (BTK) by reviewing the following three items, which were presented to the surgeon in a randomized fashion void of any patient identification: arthroscopic digital images, procedure sections of operative reports, and intraoperative findings data forms which had been filled out immediately after the surgery. With all surgeries having been performed at least 6 months before the time of assessment, the described approach was done to enhance relative blinding of the assessor. The assessment consisted of a description of the labral tear type based on a four-type classification system modified from the two-type system originally described by Seldes et al. [38] (Table 2). The location of the tear was described using clock-face geometry, as used by others [4, 26, 35, 40] and supported by reliability studies [7, 15]. The presence or absence, size,

Table 1. Standard protocols and definitions for CT measurements

CT measurement	Protocol/definition
Femoral version	The angle of rotation of the femoral neck relative to the posterior femoral condyles in the axial plane. (Kudrna [24])
Neck-shaft angle	The angle that the femoral neck makes with the shaft in the coronal plane. (Abel et al. [1])
Range of cam lesion	The location of the cam lesion described as a range on a clock face (eg, 2–4 o'clock) as assessed from three-dimensional volume-rendered reconstructions (3 o'clock always anterior, regardless of laterality). (Blankenbaker et al. [7])
Acetabular version	Obtained in the axial plane by measuring the angle between the line connecting the anterior and posterior rims of the acetabulum with a vertical line extending anteriorly from the posterior rim perpendicular to the plane of the pelvis.* (Dandachli et al. [11])
Sagittal center edge angle	Measured on the image that represents the midsagittal cut and is defined as the angle between the line drawn from the center of the femoral head to the most anterior point of the acetabular rim and the line drawn directly superiorly from the center of the femoral head directed superiorly at 90° to the transverse axis of the pelvis. (Anderson et al. [2])
Alpha angle	The angle derived from the oblique axial reformatted image that is associated with the largest bony offset and represents the angle between a line drawn along the center of the femoral neck to the center of the femoral head and a second line drawn from the center of the femoral head to the anterior head/neck junction or the point at which the head falls out of sphericity. (Notzli et al. [32])
Beta angle**	Derived from the oblique axial reformatted image that is associated with the largest bony offset and represents the angle of the line from the center of the head to the anterior rim of the acetabulum and the line drawn from the center of the femoral head to the anterior head/neck junction or the point at which the head falls out of sphericity. (Notzli et al. [32])

* The axial level chosen corresponds to the 1, 2, or 3 o'clock position of the femoral head in the coronal plane and is corrected for pelvic tilt;

**This beta angle is to be distinguished from that described by Beaulé et al. [3] which is essentially equivalent to an alpha angle at the posterior, rather than anterior, head-neck junction.

and location of cam and pincer lesions also were recorded, based on arthroscopic inspection and probing of the acetabular rim and femoral head-neck junction, with hip flexion and internal and external rotation performed within the limits of a hip arthroscopy traction table. The presence of an acetabular labral disruption (ALAD) lesion was assessed [22], indicating the state of the acetabular cartilage, and was divided into five types (Table 2). The radiologists' assessment was performed in three ways: (1) a gross assessment of the 3D CT in all planes for cam and pincer lesions; (2) alpha angle assessment from the axial CT slice with the greatest diameter of the femoral head with greater than 50° representing a positive cam lesion as described by Meyer et al. [28]; and (3) acetabular version assessment from three different axial CT scan slices, which were cross-referenced to the 1 o'clock, 2 o'clock, and 3 o'clock points on the sagittal images with any acetabular version value less than 15°, which we also defined as acetabular retroversion [36] and which some believe to be consistent with a positive pincer lesion [12]. These three points on the clock face were chosen to correspond with the most common sites of actual impingement, based on prior studies [5, 41]. Finally, assessment of the cartilage of the femoral head was performed using the Outerbridge classification [33] (Table 2).

Eight of the 10 patients with no bony lesions had labral lesions from psoas impingement with the other two having

isolated labral lesions with normal bony morphologic features of the hip. Of the labral injuries diagnosed arthroscopically, 10 patients (8.5%) had tears characterized as Type 0 lesions with each of these having the appearance of a focal erythematous contusion lesion in the non-detached anteroinferior region of the labrum, although two of the patients had concurrent labral tears of another type in an additional location on the labrum. Twenty-two patients (19%) had Type 1 tears with labral separation or detachment and transitional zone cartilage injury, whereas 13 patients (11%) had Type 2 tears with labral fraying and intrasubstance degeneration. The majority of patients ($n = 75$ [64%]) had Type 3 tears, in which detachment and transitional zone injury, fraying, and intrasubstance degeneration were observed.

To address the first question, interrater reliability testing was performed for each of the radiographic observations of the radiologists using an intraclass correlation coefficient (ICC) assessment. We assessed agreement of CT-diagnosed FAI lesions with intraoperatively diagnosed FAI lesions using kappa values.

To address the third question, a linear trend test was used to assess if a linear trend existed with increasing ALAD lesion severity based on the presence and size of cam lesions. A Kendall Tau rank correlation coefficient then was calculated to describe the magnitude of the association.

Table 2. Labral tear, acetabular cartilage, and femoral head cartilage classifications

Type	Labral tear type description	Acetabular cartilage description	Femoral head cartilage description
0	Either no labral tear, mild fraying, or an erythematous lesion found at the anteroinferior portion of the labrum corresponding to 3 o'clock	Normal, intact cartilage (low grade)	Normal, intact cartilage
1	Labral detachment with primary injury to the transition zone of the cartilage	Bubbling or separation of the cartilage from the subchondral bed but intact superficial articular surface (low grade)	Superficial fraying of the cartilage
2	Substantial fraying or intrasubstance degeneration consistent with a chronic crushing or shearing-type injury	Presence of bubbling and fissuring or damage to the superficial articular cartilage surface (high grade)	Fissuring or damage of the cartilage less than 50% of its thickness
3	A combined lesion with presence of findings inherent in Type 1 and Type 2 lesions	Presence of a cartilage flap or full thickness tear (high grade)	Fissuring or damage of the cartilage greater than 50% of its thickness but less than 100%
4	Not applicable*	Exposed bone/absent cartilage (high grade)	Exposed bone/absent cartilage

* The proposed labral tear classification system is limited to Types 0, 1, 2, and 3. There is no Type 4.

Table 3. Interrater reliability for CT variables

Measurement	Number	Intraclass correlation coefficient	Lower 95%	Upper 95%
Alpha angle	118	0.722	0.6	0.807
Beta angle	118	0.681	0.541	0.778
Posterior beta angle	118	0.73	0.611	0.812
Acetabular version (1 o'clock)	118	0.852	0.787	0.897
Acetabular version (2 o'clock)	118	0.728	0.609	0.811
Acetabular version (3 o'clock)	118	0.685	0.547	0.781
Midsagittal center-edge angle	118	0.87	0.813	0.91
Coronal center-edge angle	118	0.782	0.686	0.848
Femoral version	116	0.94	0.913	0.958
Neck-shaft angle	118	0.536	0.333	0.677
Cam presence	115	0.4	0.106	0.694
Pincer presence	118	0.159	-0.029	0.347

Finally, a chi-square analysis was used to evaluate whether higher proportions of labral tear types were found with particular FAI patterns (ie, cam versus pincer, isolated versus combined)

However, because the CT-based assessment of pincer lesions had relatively low value in this analysis, intraoperative assessment of the presence or absence of a pincer lesion was used as a proxy for CT-based assessment, whereas the standard of an alpha angle less than 50° was used for the presence of cam or absence of a cam lesion.

Fig. 1 The mean (horizontal line) alpha angle and 95% confidence interval bars, as measured from CT, are shown for each of the grades of acetabular labral articular disruption (ALAD) lesions, as seen intraoperatively. The Kendall Tau analysis of the data gave a rank correlation coefficient of 0.373 ($p < 0.001$). Higher alpha angles therefore correlated ($p < 0.001$) with more severe ALAD lesions, showing the potential to use CT measurements to predict intraoperative arthroscopic findings of cartilage damage.

All analyses were completed using SPSS (SPSS Inc, Chicago, IL, USA).

Results

The ICCs for the radiologists' assessment of the 12 CT-based measurements ranged from 0.159 to 0.940 (Table 3).

The subset of patients in whom a cam lesion was diagnosed by intraoperative assessment showed 97% agreement with the radiologists' gross assessment of the 3D-CT scans (ie, presence of cam lesion) but 89% agreement when the presence of a cam lesion was determined by an alpha angle

Table 4. Labral tear type and CAM-pincer presence

Labral tear type	Cam-pincer presence			
	Cam (–), pincer (–)	Cam (+), pincer (–)	Cam (–), pincer (+)	Cam (+), pincer (+)
Type 0 tear	6 (66.7%)	5 (26.3%)	1 (7.1%)	0 (0%)
Type 1 tear	3 (33.3%)	14 (73.7%)	0 (0%)	2 (2.6%)
Type 2 tear	0 (0%)	0 (0%)	6 (42.9%)	6 (7.9%)
Combined	0 (0%)	0 (0%)	7 (50.0%)	68 (89.5%)

Chi-square test to determine differences in proportions of femoro-acetabular impingement lesion and labral tear type ($p = < 0.0001$).

greater than 50° on the CT axial images. However, for patients in whom a cam lesion was determined by intraoperative assessment as being absent, there was only 33% agreement with the radiologists' gross assessment of the 3D CT scans (ie, absence of cam lesion) and 54% agreement when absence of a cam lesion was determined by an alpha angle of 50° or less on the CT axial images. The kappa values for CT and intraoperative assessments of cam lesions were 0.48 for gross assessment by 3D CT and 0.46 for alpha angle greater than 50° . The kappa value for CT and intraoperative assessments of pincer lesions was 0.16 for gross assessment with 3D CT and acetabular version less than 15° .

The presence of a cam lesion made the presence of an ALAD lesion 10 times more likely (odds ratio, 10.4; 95% CI, 3.6–30.3; $p = < 0.001$) on intraoperative assessment. Moreover, the alpha angle correlated (rank correlation coefficient of 0.37; $p = < 0.001$) with the severity of an ALAD lesion (Fig. 1).

FAI lesion pattern appears to be associated with each of the four labral tear types. No presence of a FAI lesion was more likely to have been Type 0 labral tears compared with all other tear types ($p < 0.001$). The highest proportion of isolated cam lesions was found in Type 1 tears compared with all other tear types, but that proportion was not statistically significant ($p = 0.251$). The highest proportion of isolated pincer lesions was highest in Type 2 tears compared with all other tears ($p < 0.001$). Combined FAI lesions were highest ($p < 0.001$) in Type 3 tears (Table 4).

Discussion

As appreciation of the complex interplay of underlying bony abnormalities and soft tissue lesions in hip disease affecting young people continues to expand, the importance of radiographic imaging modalities in assessing normal and abnormal bony morphologic features increases. Reliance on traditional plain radiographs in elucidating complex hip conditions, such as FAI, has limitations related to inconsistency in patient positioning, imaging

technique, imaging quality, and reliability of radiographic readings [8, 19, 32]. Conversely, CT provides improvements in detailing bony features of hip disorders, with the ability to accurately control for patient position when assessing femoral version and acetabular version [1, 10, 12]. As a result, CT is now used as part of standard diagnostic protocol by some surgeons who treat FAI. However, its true value as a primary or supportive diagnostic measure for FAI is not completely established, and concerns remain regarding the additional costs and long-term risk of radiation exposure inherent in CT use [6]. We therefore evaluated the reliability of CT-based measurements of bony geometry and pathologic features related to FAI, the agreement between CT findings and arthroscopic findings in patients with FAI, and the ability of CT-based features of cam lesions to predict features of acetabular cartilage and labral disorders.

There are several limitations of the current study that are important to consider when interpreting the results of this study. First, blinding of the intraoperative assessor was not performed, since the same individual performed the surgeries. Further, the dictated operative report and intraoperative findings forms were completed when the surgeon was not blinded to the findings of the CT scan. This introduced the potential for bias in study measurements. Second, although the sample size of more than 100 patients was considerable, it proved insufficient to conduct robust stratified analyses of the ability of CT to predict intraoperative findings among the various subgroups of hip disorders, such as those with only cam lesions, only pincer lesions, or those with no bony abnormalities. This limited the analyses that were able to be performed and the power of the analyses that were conducted. Third, comparative analyses of the CT with MRI and plain radiographic findings in the same patients were not conducted for this cohort, leaving the question of CT superiority for use in measuring FAI-related geometry and pathologic features and in predicting arthroscopic hip disease findings unanswered. Fourth, the articular cartilage grading systems used, such as the ALAD system, have not undergone reliability or validity studies for use in the hip, and these are needed for this expanding area of orthopaedic research. To our knowledge, other similar systems that are in use, such as that described by Beck et al. [4], have yet to be deemed reliable or valid. Finally, the study cohort was not compared with any control group such as a series of patients having CT scans who were not undergoing hip arthroscopy or who were without a bony hip disorder, which would have further validated the readings of the radiologists.

We found most of the basic, established anatomic hip measurements we studied that were rendered from CT were reliable when assessed independently by four radiologists

who were blinded to clinical information. Although Beaulé et al. [3] examined the ability of 3D CT to assess for cam impingement in 30 patients, only two radiologists were involved in their study with one having been “recently trained in the technique of 3D CT”. ICC values in the current study were superior to those reported by Beaulé et al. [3], who also did not study the effect of femoral anteversion. Although 21 of the 30 patients had undergone surgery in their series, the results of MR arthrography, rather than intraoperative assessment, were used to document the presence of labral or cartilage disorders, neither of which was subclassified or stratified by severity. Notably, the lowest agreement between radiologists’ readings in the current study was seen in the assessment of the presence of a pincer lesion, which may be consistent with other studies citing limitations in radiographic and surgical assessment of pincer lesions and their associated morphologic findings [8, 9, 43]. However, we are not aware of other CT-based studies specifically assessing pincer lesions, and this remains an area of controversy [17].

When assessing the agreement between the presence of bony lesions detected on CT with those detected by arthroscopic inspection, we found kappa values for CT and intraoperative assessments of cam lesions were 0.48 for gross assessment by 3D CT and 0.46 for alpha angle greater than 50°, whereas kappa values for CT and intraoperative assessments of pincer lesions were notably lower, at 0.16 for gross assessment with 3D CT and 0.16 when using acetabular version less than 15° as a proxy for the presence of pincer lesion. Again, these results speak to the difficulty in radiographic assessment of pincer lesions cited by others [9] and the need for a standardized method of diagnosis. One potential explanation for the moderate ability of CT findings to predict intraoperative findings relates to the fact that FAI is a dynamic process, and therefore it potentially would be inaccurate to examine the femur and acetabulum each in isolation. We believe FAI therefore is best assessed intraoperatively by direct fluoroscopic imaging of the impingement process, as the hip is taken through a ROM. However, dynamic modeling of this process preoperatively is now becoming possible using 3D modeling software [5], which may predict FAI patterns, labral tear type, and articular cartilage damage, better than static imaging alone.

We found several CT-based measurements predict the presence and severity of soft tissue lesions not appreciable on CT, such as labral tears and articular cartilage lesions. Specifically, the presence of a cam lesion predicted the presence and severity of cartilage lesions at the chondrolabral junction. These findings are consistent with those of Beck et al. [4], who reported that isolated cam-type FAI was associated with a type of acetabular cartilage damage, similar to that shown by our findings, that was unique from pincer-type FAI. However, our data further support the

pathophysiologic process proposed by Beck et al., in that greater severity of damage was seen with larger cam size.

Finally, we found specific FAI patterns correspond to specific labral tear patterns. Although Seldes et al. [38] provided an early framework by which to interpret two different types of labral tears, they did not specifically correlate features of FAI to their types of labral tears. Rather, they theorized acetabular osteophyte formation may actually be a byproduct of a detached labrum, as can be seen in acetabular dysplasia. Our modern understanding of FAI speaks instead to the potential role of cam lesions in generating a shearing force to the chondrolabral junction, leading to injury to the transitional zone of the cartilage and detachment of the labrum with relative sparing of the midsubstance of the labrum and the bony attachment, whereas the repetitive impingement phenomenon of pincer lesions may generate a crushing force on the labrum, which leads to fraying and intrasubstance degeneration previously seen in Type 2 tears [4]. The results of the current study support this theory in that isolated cam lesions and pincer lesions, although relatively rare, were associated with greater frequency with the presence of Type 1 and Type 2 tears, respectively. This paradigm was further substantiated with the finding that the more common combined cam-pincer FAI lesion corresponded well to the presence of labral tears in which separation and intrasubstance degeneration were seen arthroscopically, a finding we characterize as a Type 3 labral tear. These overall findings are similar to those of Dolan et al. [12], who retrospectively studied the CT scans of a group of patients with known labral tears, and found a high rate of underlying bony anomalies, most commonly cam and pincer lesions. In contrast, Nepple et al. [31] used multivariate regression analysis to identify radiographic hip features predicting labral lesions, and found that although high alpha angle was a predictor for a disorder, pincer lesions were not. However, their rate of pincer impingement (9%) was notably lower than those identified in other series of patients with acetabular labral tears [4, 14], and advanced imaging, such as CT, was not used. Additionally, when labrums without separation or intrasubstance degeneration were seen, there was high correspondence with the absence of bony abnormalities on the CT scan and the presence of a separate, newly appreciated soft tissue condition, previously called a “psoas impingement” [14]. In this pathophysiologic process, it is theorized that a tight psoas tendon contacts the anteroinferior labrum at the 3 o’clock position on the acetabulum, leading to an erythematous, contusion-type lesion as seen on arthroscopic investigation. Because this condition usually is seen before frank tearing of the labrum, we have termed this a Type 0 tear, which is treated with fractional release of the tendinous portion of the undersurface of the musculotendinous unit of the psoas

as it crosses over the anterior aspect of the joint. Future studies with second-look arthroscopy would be necessary to investigate the healing capacity of the labrum after such treatment and understand the natural history of this unique condition affecting the hip.

Our observations elucidate several critical features of CT scans and their use as part of the preoperative planning process for arthroscopic treatment of hip disorders. Most of the CT-based measures used in our analysis had moderate to high interrater reliability, although more standardization of accepted measurements and definitions across multiple institutions and among radiologists may be warranted. CT measurements may allow for prediction of labral tear patterns, but the data suggest better parameters for assessment of pincer lesions are needed. Increasingly larger cam lesions predict increasing severity of paralabral acetabular cartilage injury. Moreover, the consistency with which labral tear pattern predicted one of four patterns of underlying disorder may lend itself to a new arthroscopic-based classification system for acetabular labral tears.

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