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What is This?
Intraoperative Fluoroscopic Imaging to Treat Cam Deformities

Correlation With 3-Dimensional Computed Tomography

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Investigation performed at the University of Michigan, Ann Arbor, Michigan, USA

Background: In the diagnosis and surgical treatment of cam-type femoroacetabular impingement (FAI), 3-dimensional (3D) imaging is the gold standard for detecting femoral head-neck junction malformations preoperatively. Intraoperative fluoroscopy is used by many surgeons to evaluate and verify adequate correction of the deformity.

Purpose: (1) To compare radial reformatted computed tomography (CT) scans with 6 defined intraoperative fluoroscopic views before surgical correction to determine whether fluoroscopy could adequately depict cam deformity, and (2) to define the influence of femoral version on the clock-face location of the maximum cam deformity on these views.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: A consecutive series of 50 hips (48 patients) that underwent arthroscopic treatment for symptomatic FAI by a single surgeon were analyzed. Each patient underwent a CT scan and 6 consistent intraoperative fluoroscopy views: 3 views in hip extension and 3 views in hip flexion of 50°. The alpha angles of each of the fluoroscopic images were compared with the radial reformatted CT using a 3D software program. Femoral version was also defined on CT studies. Statistical analysis was performed using the Student t test, with P < .05 defined as significant.

Results: Fifty-two percent of patients were male, average age 28 years (range, 15-56 years). The maximum mean alpha angle on fluoroscopy was 65° (range, 37°-93°) and was located on the anteroposterior (AP) 30° external rotation (ER) fluoroscopy view. In comparison, the mean CT-derived maximum alpha angle was 67° and was located at 1:15 (P = .57). The mean clock-face positions of each of the fluoroscopic views (standardized to the right hip) were AP 30° internal rotation, 11:45; AP 0° (neutral) rotation, 12:30; AP 30° ER, 1:00; flexion/0° (neutral) rotation, 1:45; flexion/40° ER, 2:15; and flexion/60° ER, 2:45. Increased femoral anteversion (>20°) was associated with a significant change in the location of the maximum alpha angle (1:45 vs 1:15; P = .002).

Conclusion: The described 6 fluoroscopic views are very helpful in localization and visualization of the typical cam deformity from 11:45 to 2:45 and can be used to reliably confirm a complete intraoperative resection of cam-type deformity in most patients. These views correlate with preoperative 3D imaging and may be of even greater importance in the absence of preoperative 3D imaging.

Keywords: femoroacetabular impingement; cam lesion; hip arthroscopy; fluoroscopy; computer modeling

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The diagnosis and treatment of cam-type femoroacetabular impingement (FAI) relies on the radiographic identification of deformity and correction of the 3-dimensional (3D) asphericity and loss of offset at the femoral head-neck junction, respectively. Femoroacetabular impingement may be treated by surgical hip dislocation, limited open anterior approach, and/or hip arthroscopy.3,7,9,17,19 Hip arthroscopy has advanced since first being performed and, with proper technique, allows visualization of the anteroinferior/medial to posterosuperior/lateral femoral head-neck junction. Full visualization can be difficult to obtain through a single viewing portal and most commonly requires regional viewing through multiple portals. This regional evaluation can make comprehensive resection of the cam deformity...
difficult. To avoid inadequate resection with resultant residual impingement, clinicians may find that it is critical to use multiple fluoroscopic images—that is, take 2-dimensional images and then conceptualize a 3D structure—to accurately localize the deformity.

Regardless of surgical technique, successful clinical outcomes and improvement in range of motion after FAI surgery are predicated upon complete restoration of head-neck offset and elimination of the offending focal impingement lesions. Intraoperative fluoroscopy images are invaluable for an arthroscopic approach to better define and understand the 3D structure of the proximal femur (anterior, posterior, medial, and lateral head-neck junctions). Larson and Wulf previously described a reproducible and systematic intraoperative fluoroscopic evaluation of the hip for the management of cam and pincer deformities during arthroscopic treatment of FAI. However, the location on the clock face of the femur that each of these specific views demonstrates has not been clearly elucidated in the literature.

High-resolution computed tomography (CT) allows for precise definition of the osseous structure of the hip and may allow for patient-specific preoperative planning to assist with intraoperative localization and treatment of the impingement lesions. However, CT scans carry considerable risk of exposure to ionizing radiation and have not been universally used in preoperative planning for hip preservation surgery. In this regard, treating surgeons may incompletely characterize the preoperative femoral and acetabular deformity, which can lead to inadequate resections. Furthermore, even in the setting of a preoperative CT study, comparison of the images with intraoperative fluoroscopy has not been described and may significantly help surgeons confirm the completeness of the deformity correction.

The purpose of this study was to compare a set of 6 intraoperative, preresection fluoroscopic images to the corresponding radial reformatted CT scans to assist with localization and potential treatment of the maximum cam deformity, which typically occurs at the anterior and lateral portions of the femoral head-neck junction. We set out to determine the influence of femoral version on the clock-face location of the maximum cam deformity on these 6 defined fluoroscopy views.

MATERIALS AND METHODS

This study was performed under an institutional review board–approved protocol obtained at all participating sites. We performed a review of prospectively collected images on a consecutive series of 50 hips in 48 patients who were seen in the senior author’s (C.M.L.’s) clinic with symptomatic hip pain and who subsequently underwent hip arthroscopy between June and August 2012. All patients were diagnosed with FAI (24 hips [48%] with isolated cam, 1 hip [2%] with isolated pincer, and 25 hips [50%] with combined). No other hip abnormalities were noted (slipped capital femoral epiphysis, Perthes, etc.). In addition to having standard plain radiographs, the patients underwent high-resolution CT scans of the involved hip and lower extremity. A modified CT protocol using a decreased radiation exposure of 2.85 mSv was used to maximize patient safety. Positioning of the patient in the scanner was standardized, with the legs in neutral abduction/adduction and the patellae pointing directly anterior. Additional slices were obtained through the distal femoral condyles to determine femoral version.

Preoperative Fluoroscopic Evaluation

The patient was placed supine on the fracture table with generous padding of bony prominences and bilateral feet, in addition to a custom well-padded perineal post. The nonoperative leg was positioned in approximately 45° of abduction, while the operative leg was placed in neutral abduction, 0° to 10° of hip flexion, and maximum internal rotation. The anterior superior iliac spines (ASIS) were palpated and the bed was tilted until they were parallel to the floor. This allowed the pelvis to be placed in the neutral position to allow for standardization and comparison with well-centered (vertical center of the sacrum in line with the pubic symphysis), preoperative anteroposterior (AP) pelvic radiographs that are typically used for structural analysis and treatment planning (Figure 1). The fluoroscopy x-ray generator with image intensifier (C-arm) portion of the fluoroscopy unit was positioned between the legs at a 45° angle, and the monitor was positioned on the contralateral side of the patient for optimal viewing. An AP view of the operative hip was obtained, and the operative table was further positioned with Trendelenburg or reverse Trendelenburg to replicate the preoperative AP pelvis view of the patient, including the relationship between the anterior and posterior acetabular rims and the relationship between the ilioischial line and the acetabular teardrop.

Once the fluoroscopic image replicated the preoperative AP pelvis, the femoral head-neck junction was assessed with fluoroscopy with the leg in 6 different positions (Figure 2). Anteroposterior images of the hip were first obtained with the knee and hip in full extension and the leg in (1) 30° of internal rotation, (2) neutral rotation, and (3) 30° of external rotation. These positions were performed by rotating the foot of the operative leg and ensuring that the knee remained in full extension, especially when maximally externally rotated. These 3 views were obtained to evaluate the superolateral aspect of the femoral head-neck junction. Next, the hip and knee were positioned in approximately 50° of flexion, and images were obtained with the hip in (4) neutral (0°) rotation, (5) 40° of external rotation, and (6) 60° of external rotation (Figure 2). These latter 3 views were obtained to evaluate more anterior positions. At the conclusion of the hip arthroscopy, postoperative fluoroscopic views were obtained with the same 6 leg positions. Measurements of the alpha angle were performed by a single reader (J.R.R.) on each exported fluoroscopic view for every patient with the use of Adobe Photosh (Adobe Systems Inc, San Jose, California, USA). To assess the intra- and interrater reliability of the alpha angle measurements, 10 radiographs were remeasured.

The preoperative CT scans were uploaded into DYONICS Plan software (Smith & Nephew, Andover, Massachusetts, USA) to generate patient-specific, 3D models of
the hip joint. This software system was used to measure the femoral neck/shaft angle and femoral neck version relative to the posterior condylar axis of the knees. In addition, the alpha angles of the various clock-face positions at 15-minute increments were measured circumferentially around the entire femoral head. The clock face was standardized between hips so that 3:00 was always anterior. The alpha angles from the 6 preoperative fluoroscopy views were then correlated with the radial reformatted CT with assistance of the computer software. A patient profile of the CT-derived alpha angles of each clock-face position was plotted on a graph in addition to the 6 alpha angles that were calculated from the fluoroscopy views (Figure 3). The intersection points of each fluoroscopic view were determined and a clock-face position was assigned for the specific fluoroscopy views for each individual patient (Figure 2).

Figure 1. Patient example of visualization and correction of the cam deformity with fluoroscopic views. (A, B) Preoperative anteroposterior (AP) pelvis and Dunn lateral radiographs demonstrating the anterior to lateral extent of the cam lesion. Preoperative fluoroscopic images: (C) AP internal rotation, (D) AP neutral, (E) flexion 40° of external rotation, and (F) flexion 60° of external rotation. Postresection fluoroscopic images: (G) AP internal rotation, (H) AP neutral, (I) flexion 40° of external rotation, and (J) flexion 60° of external rotation.

Statistics

Statistical analysis was performed with Microsoft Excel software (Redmond, Washington, USA). A paired Student t test was used for comparison of continuous variables, while chi-square testing was used for categorical variables. A P value <.05 was considered significant. Because the primary outcome was descriptive, a power analysis was not applicable.

RESULTS

The average age of the 48 patients (50 hips) within this series was 28 years (range, 15-56 years). Fifty-two percent of the patients (n = 26) were male, and 56% (n = 28) of the surgeries involved the right hip. The mean total surgical fluoroscopy time was 72 seconds (range, 34-172 seconds). The mean fluoroscopy-derived maximum alpha angle for the entire cohort was 65° (range, 37°-93°) and was located on the AP external rotation fluoroscopy view (Table 1). The maximum alpha angle for each individual patient was also most commonly seen on the AP external rotation view (48% of cases) and the flexion neutral rotation view (26% of cases). There was significant improvement in the alpha angle on 5 of the 6 fluoroscopic views (Table 1). Intra- and interrater reliability of the alpha angle measurements demonstrated intraclass correlation coefficients of 0.92 and 0.99, respectively.
The mean CT-derived maximum alpha angle was 67° (range, 50°-94°) and was located at 1:15, which is slightly higher than the mean maximal alpha angle on fluoroscopic views (65°; P = .57) (Figure 4). The mean CT-derived alpha angle was elevated (>50°) between 12:00 and 3:00 among this patient population. The corresponding mean clock-face positions of each of the fluoroscopy views were as follows: AP internal rotation, 11:45; AP neutral, 12:30; AP external rotation, 1:00; flexion neutral, 1:45; flexion 40° external rotation, 2:15; and flexion 60° external rotation, 2:45 (Table 1). The maximum CT-derived alpha angle was located between 11:45 and 2:45 in all 50 hips (100%) and was thus detected by the standard 6 fluoroscopic images.

The mean femoral version was 17° (range, −3° to 37°). Increased femoral version (>20°) was associated with a significant anterior shift in the location of the maximum alpha angle (1:45 vs 1:15; P = .002) (Table 2). Increased femoral version (>20°) was also associated with an anterior shift of the respective clock-face positions on all of the 6 fluoroscopic views but was significant only on the AP neutral (P = .03), flexion 40° external rotation (P = .04), and flexion 60° external rotation (P = .02) views (Table 3). Relative femoral retroversion (<5°), in contrast, was associated with a superolateral shift in the clock-face position on all views; however, it was significant only on the AP external rotation (P = .01) and flexion neutral views (P = .01) (Table 3). Assessment of correlation between the femoral version value and maximum alpha angle, however, revealed no clear linear relationship (R² = 0.23). Some believe that increased femoral anteversion is protective from cam-type FAI and that relative femoral retroversion may enhance cam pathologic abnormalities. However, it is perhaps the version of the proximal femur that influences the location of contact between the proximal femur and acetabular rim and that could “induce” cam deformity during development, which may explain the varying locations of the cam lesions that are seen in individual patients.

**DISCUSSION**

The 6 specific views used in the current study allow for evaluation of the medial and lateral femoral head-neck junction (extension views) and anterior and posterior head-neck junction (flexion views). Because the maximal cam deformity was located anteriorly and laterally in all hips, the current study focused on this portion of the head-neck junction with regard to CT analysis. In this regard, a comparison of preoperative 3D imaging with intraoperative fluoroscopic positions may be invaluable to accurately localize and comprehensively verify correction of the deformity. Appropriate resections based on intraoperative dynamic assessment and fluoroscopic imaging can help to avoid inadequate or overzealous resection, which might result in residual impingement or iatrogenic fracture and/or loss of the labral seal, respectively.

The results of the current study demonstrate that the use of these 6 fluoroscopic radiographs can reproducibly characterize the topography of the cam deformity from the 11:45 to the 2:45 position, which covers the areas of the maximum alpha angles that are most commonly seen. In the current study, the maximal cam...
deformity was located between 11:45 and 2:45 in every case and was therefore identified with our 6 fluoroscopic views in every case. We also demonstrate that femoral version affects the interpretation of the radiographic visualization of the cam deformity and should thus be taken into account when these fluoroscopic images are obtained intraoperatively and correlated with the preoperative 3D imaging. Anecdotally, we also observed a trend for posterior and anterior shifts of the greater trochanter position relative to the femoral neck in patients with relative femoral neck anteversion and retroversion, respectively; however, the details of this relationship are a focus of a future investigation.

Visualization and treatment of the entire cam lesion are important to minimize the potential for inadequate resection with resultant residual cam deformity. Residual impingement remains the most common reason for subsequent revision hip preservation surgery.5,13,25 In a recent review of a prospective database, Bogunovic et al22 noted that 79% (30/38 hips) of revision hip preservation surgeries

<table>
<thead>
<tr>
<th>Fluoroscopy View</th>
<th>Mean Preoperative α Angle (range), deg</th>
<th>CT-Derived Clock-face Position, mean ± SD</th>
<th>Mean Postoperative α Angle, deg</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP internal rotation</td>
<td>47.7 (36.9-90.2)</td>
<td>11:45 ± 0.15</td>
<td>45.1</td>
<td>.13</td>
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<tr>
<td>AP neutral</td>
<td>60.4 (40.0-89.3)</td>
<td>12:30 ± 0.15</td>
<td>46.7</td>
<td>&lt;.0001</td>
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<tr>
<td>AP external rotation</td>
<td>65.3 (41.2-92.8)</td>
<td>1:00 ± 0.15</td>
<td>46.1</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Flexion neutral</td>
<td>63.7 (40.0-87.1)</td>
<td>1:45 ± 0.30</td>
<td>40.7</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Flexion 40° external rotation</td>
<td>60.3 (37.8-82.1)</td>
<td>2:15 ± 0.15</td>
<td>38.8</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Flexion 60° external rotation</td>
<td>56.2 (35.7-77.9)</td>
<td>2:45 ± 0.15</td>
<td>37.5</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

αAP, anteroposterior; CT, computed tomography; SD, standard deviation.

<table>
<thead>
<tr>
<th>No.</th>
<th>Mean Maximum α Angle (Range), deg</th>
<th>Mean CT-Derived Clock-face Position</th>
<th>P</th>
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<tbody>
<tr>
<td>&lt;5°</td>
<td>3</td>
<td>77.3 (66-87)</td>
<td>12:45</td>
</tr>
<tr>
<td>5°-20°</td>
<td>30</td>
<td>73.3 (50-94)</td>
<td>1:15</td>
</tr>
<tr>
<td>&gt;20°</td>
<td>17</td>
<td>68.7 (55-84)</td>
<td>1:45</td>
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</table>

αAP, anteroposterior.

<table>
<thead>
<tr>
<th>No.</th>
<th>AP Internal Rotation</th>
<th>AP Neutral</th>
<th>AP External Rotation</th>
<th>Flexion Neutral</th>
<th>Flexion 40° External Rotation</th>
<th>Flexion 60° External Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5°</td>
<td>3</td>
<td>11:30</td>
<td>12:15</td>
<td>12:45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1:15&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>5°-20°</td>
<td>30</td>
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<td>12:30</td>
<td>1:00</td>
<td>1:45</td>
<td>2:15</td>
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<tr>
<td>&gt;20°</td>
<td>17</td>
<td>12:00</td>
<td>12:45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1:15</td>
<td>1:45</td>
<td>2:30&lt;sup&gt;b&lt;/sup&gt;</td>
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<sup>b</sup>P < .05.

**TABLE 1**

Alpha Angle Calculation From the 6 Fluoroscopic Radiographs and the Corresponding Mean Clock-face Position for Each of the 6 Views

**TABLE 2**

Computed Tomography (CT)–Derived Alpha Angle Measurements According to Femoral Version

**TABLE 3**

Influence of Femoral Version on the Fluoroscopic View Correlation With the Computed Tomography (CT)–Derived Clock-face Position

*Figure 4.* The mean computed tomography–derived alpha angles for the individual clock-face positions circumferentially around the femoral head.
underwent femoral head/neck osteoplasty for residual cam deformity. Three-dimensional imaging allows the surgeon to localize the extent of the impingement preoperatively, but it is not universally used given the significant risk of ionizing radiation to young patients. Furthermore, 3D preoperative imaging does not necessarily facilitate intraoperative localization in the absence of navigated instrumentation. Further confirmation of the precise location of the cam deformity with reproducible fluoroscopic views as described in the current study might result in a more precise and comprehensive resection.

A previous investigation by Nepple et al. compared the alpha angles on the AP pelvis, 45° Dunn, frog-leg lateral, and cross-table lateral radiographs and CT reformats at 12:00, 1:00, 2:00, and 3:00. The investigators noted substantial correlation between the radiographs and corresponding radial locations on CT (AP pelvis, 12:00-1:00; 45° Dunn, 1:00-2:00; frog-leg lateral and cross-table lateral, 3:00). Our results echo these findings; however, we believe that obtaining the 6 fluoroscopic views described in the current study can further localize desired clock-face positions at the head-neck junction. The AP internal rotation view is also able to localize cam deformities that are posterior to the 12:00 position. In our study, the flexion 40° external rotation fluoroscopy position, on average, profiled the 2:15 position, which is similar to the 45° Dunn view in the aforementioned study. The flexion 60° external rotation view best profiles the 2:45 position, and thus if the surgeon wishes to correct deformities that are further anterior, one can position the hip intraoperatively in the frog-leg lateral position in concordance with the previous study.

Fluoroscopic guidance of any other interventional procedure results in the transmission of ionizing irradiation to the patient and the surgeon. Although recent studies have demonstrated that fluoroscopy-assisted hip arthroscopy entails safe levels of radiation, some may argue that our fluoroscopic views generate extra doses of radiation that could be avoided. We argue, however, that a systematic approach, with knowledge of the deformity location and the respective fluoroscopic views that require attention, would lead to less total fluoroscopy time and thus less cumulative dosage than use of fluoroscopy to search for the cam deformity or assess dynamically on cine, continuous images. The mean total surgical fluoroscopy time in our study was 72 seconds and fluoroscopy was performed with the low-dose setting, similar to the previous reported study by Budd et al. Manipulating the leg as we describe also prevents multiple repositionings of the C-arm, which often requires spot fluoroscopy views to confirm the location, potentially leading to an overall greater dosage of radiation. Furthermore, use of the reproducible preoperative and postoperative fluoroscopic views described in the current study may even obviate the need for preoperative CT imaging by experienced surgeons, thereby reducing the patient’s overall radiation exposure. For surgeons who do not routinely obtain 3D imaging, the intraoperative fluoroscopy views can help to define the cam deformity more accurately than traditional preoperative AP and lateral plain radiographs.

Our study is not without limitations. First, although the fluoroscopic views were obtained by the senior author alone using a standard protocol, there is inherent variability with each patient as a result of the technique. We used a single reader to measure the alpha angles on the fluoroscopic views as well as to confirm the alpha angle measurement on the radial reformatted CT as determined by the software program. While some studies have documented low interobserver reliability of the alpha angle measurement, other investigations have documented high intraobserver and interobserver reliability, and thus we believe that this is currently the best measurement for classifying the cam deformity. We also recognize that the alpha angle is simply one measure of cam deformity and that achieving an impingement-free hip requires direct intraoperative visualization and dynamic assessment.

CONCLUSION

Hip arthroscopy has a steep learning curve, and because of the limitations of arthroscopic visualization, we believe that our fluoroscopic technique can guide the surgeon and assist with localization and correction of the femoral cam-type deformity. These 6 fluoroscopic views also allow the surgeon to further confirm appropriate bony resection and thus help avoid inadequate resections with resultant residual impingement. Use of these reproducible fluoroscopic views may be particularly critical in the absence of preoperative 3D CT imaging to ensure that the femoral deformity has been fully characterized and corrected. Increased femoral anteversion does affect the perceived clock-face location of maximal cam deformity on fluoroscopic images and should be considered by surgeons when performing corrective femoral osteoplasty.

REFERENCES


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