

## Residual Deformity Is the Most Common Reason for Revision Hip Arthroscopy: A Three-dimensional CT Study

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### Abstract

**Background** Previous studies have reported residual deformity to be the most common reason for revision hip arthroscopy. An awareness of the most frequent locations of the residual deformities may be critical to minimize these failures. **Questions/purposes** The purposes of this study were to (1) define the three-dimensional (3-D) morphology of hips with residual symptoms before revision femoroacetabular impingement (FAI) surgery; (2) determine the limitation in

range of motion (ROM) in these patients using dynamic, computer-assisted, 3-D analysis; and (3) compare these measures with a cohort of patients who underwent successful arthroscopic surgery for FAI by a high-volume hip arthroscopist.

**Methods** Between 2008 and 2013, one senior surgeon (BTK) performed revision arthroscopic FAI procedures on patients with residual FAI deformity and symptoms after prior unsuccessful arthroscopic surgery; all of these 47 patients (50 hips) had preoperative CT scans. Mean patient age was  $29 \pm 9$  years (range, 16–52 years). Three-dimensional models of the hips were created to allow measurements of femoral and acetabular morphology and ROM to bony impingement using a validated, computer-based dynamic imaging software. During the same time period, 65 patients with successful primary arthroscopic treatment of FAI by the same surgeon underwent preoperative CT scans for the symptomatic contralateral hip; this group of 65 patients thus fortuitously provided postoperative evaluation of the originally operated hip and served as a control group. A comparison of the virtual correction with the actual correction in the primary successful FAI treatment cohort was performed. Correspondingly, a comparison of the recommended virtual correction with the correction evident at the time of presentation after failed primary surgery in the revision cohort was performed. Analysis was performed by

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two independent observers (JRR, OA) and a paired t-test was used for comparison of continuous variables, whereas chi-square testing was used for categorical variables with  $p < 0.05$  defined as significant.

**Results** Ninety percent (45 of 50) of patients undergoing revision surgery for symptomatic FAI had residual deformities; the mean maximal alpha angle in revision hips was  $68^\circ \pm 16^\circ$  and was most often located at 1:15, considering the acetabulum as a clockface and 1 to 5 o'clock as anterior independent of side. Twenty-six percent (13 of 50) of hips had signs of overcoverage with a lateral center-edge angle greater than or equal to  $40^\circ$ . Dynamic analysis revealed mean direct hip flexion of  $114^\circ \pm 11^\circ$  to osseous impingement. Internal rotation in  $90^\circ$  of hip flexion and flexion, adduction, internal rotation to osseous contact were  $28^\circ \pm 12^\circ$  and  $20^\circ \pm 10^\circ$ , respectively, which were less than those in hips that had underwent hip arthroscopy by a high-volume hip arthroscopist (all  $p < 0.001$ ).

**Conclusions** We found marked radiographic evidence of incomplete correction of deformity in patients with residual symptoms compared with patients with successful results with residual deformity present in the large majority of patients (45 of 50 [90%]) undergoing residual FAI surgery. We recommend careful attention to full 3-D resection of impinging structures.

**Level of Evidence** Level III, retrospective study, case series.

## Introduction

Surgical treatment of femoroacetabular impingement (FAI) has been shown to provide symptomatic improvement and result in good-to-excellent short-term outcome scores [5, 6, 8, 10, 17, 21]. Additionally, the number of hip arthroscopy procedures that have been performed by American Board of Orthopaedic Surgery candidates has increased 18-fold between 2003 and 2009 [9]. Despite the favorable clinical outcomes of hip arthroscopy for symptomatic FAI published in the literature, there is a subgroup of patients who present with continued or recurrent symptoms after surgical treatment. There has also been a corresponding increase in the number of revision hip arthroscopy and hip preservation surgeries [4, 7, 11, 13, 18].

Previous studies have reported residual deformity and incomplete correction of symptomatic hip FAI to be the most common reason for revision hip arthroscopy [4, 7, 11, 18]. However, no studies to date have compared the structural outcomes of clinically successful and failed arthroscopic FAI surgery compared with templated virtual corrections of idealized proximal femoral and acetabular morphology nor has the most common morphology and location of the missed residual deformity been defined.

The purposes of our study were to (1) define the three-dimensional (3-D) morphology of hips with residual pain and/or restricted ROM after corrective arthroscopic FAI surgery before revision surgery; (2) determine the residual limitation in ROM in these patients using dynamic, computer-assisted, 3-D analysis; and (3) compare the 3-D morphology of hips undergoing revision FAI surgery with postoperative 3-D morphology of hips that underwent successful primary surgical treatment.

## Patients and Methods

Our study was approved by the institutional review board. Between 2008 and 2013, one senior surgeon (BTK) performed revision arthroscopic FAI procedures on patients with residual FAI deformity and symptoms after prior unsuccessful arthroscopic surgery (FAI revision group); all of these 47 patients (50 hips) had preoperative CT scans. The diagnosis of FAI was made by history and physical examination and confirmed with radiographic pathomorphology on plain films and 3-D imaging. Dysplasia, posttraumatic deformity, Legg-Calvé-Perthes disease, postslipped capital femoral epiphysis, and any cases with greater than Tönnis I chondral changes were excluded. The mean age of patients in our series was  $29 \pm 9$  years (range, 16–52 years). Fifty-four percent (27 of 50) of the patients were women, and 62% (31 of 50) of the surgeries involved the right hip. In addition to a standardized plain radiographic series, the patients underwent high-resolution CT scans of the pelvis (and distal femur for assessment of femoral version) as part of their clinical care and preoperative surgical planning. A modified CT protocol, using decreased radiation exposure (2.85 mSv), was used to maximize patient safety as described in Milone et al. [16]. Positioning of the patient in the scanner was standardized with the legs in native abduction/adduction and the patellae pointing directly anterior.

Preoperative CT scans were uploaded into a CT-based, computer software program (DYONICS<sup>TM</sup> PLAN software; Smith & Nephew, Andover, MA, USA) to generate patient-specific 3-D models of the hip. The software program also allowed subsequent generation of virtual plain radiographs. The virtual radiographs, which simulated an AP pelvic radiograph, were analyzed for parameters of acetabular and pelvic orientation. The static, two-dimensional radiographic parameters were calculated, including the presence or absence of the crossover sign and the lateral center-edge angle (LCEA) [22]. Three-dimensional radiographic parameters measured included acetabular version measurements between the 1:00 (cranial) position and 4:00 (caudal) position in 15-minute increments as on a clockface [15] as well as percent femoral head coverage of the

acetabulum in the anterior, superior, and posterior quadrants. The clockface was standardized between hips so that 12:00 was lateral and 3:00 was always anterior in both right and left hips [3, 14, 19]. Femoral neck version was measured relative to the posterior condylar axis of the knees and the alpha angles of the various clockface positions at 15-minute increments circumferentially around the entire femoral head on radial sequences. The CT-based measurements of the proximal femur and the percent coverage of the femoral head were then compared with a series of both preoperative and postoperative high-resolution CT scans of 65 patients who underwent arthroscopic treatment of their affected hip by the same high-volume hip surgeon (> 400 hip arthroscopies per year) (BTK) during the same time period (FAI successful surgery group). Although postoperative CT scans are not routinely obtained in patients with successful outcomes, it was fortuitously captured in this population at the time of preoperative imaging for a symptomatic contralateral hip in patients with bilateral disease; this group represented < 5% of patients treated during time. The average age of patients in the FAI successful surgery group was  $25 \pm 9$  years (range, 15–45 years). Fifty-seven percent (37 of 65) of the patients were women, and 52% (34 of 65) of the surgeries involved the right hip.

Simulated hip ROM of the FAI revision group as well as the pre- and postoperative hips from the FAI successful surgery group was performed with the 3-D-generated model as previously described [1, 2]. The pelvis was fixed in the predefined position and the femur was free to move in all directions but constrained to rotate about the proscribed rotation axis against the congruous acetabular surface. A posteriorly and superiorly directed force was applied to the femur to maintain reduction of the femur during simulation [2]. The femur was positioned with the posterior femoral condylar axis parallel to the horizontal axis of the pelvis (native femoral version). During the simulated ROM maneuvers, the femur was moved in a specific motion until contact between the femur and acetabulum occurred (detected by the resultant translation of the femoral head). Capsulolabral or soft tissue impingement was not addressed by the described model. The point of osseous collision was defined as the occurrence of mechanical impingement, which was recorded in degrees of motion. Three ROM simulations were performed: (1) internal rotation in  $90^\circ$  of hip flexion (IRF); (2) internal rotation in  $90^\circ$  of hip flexion with  $15^\circ$  of adduction (FADIR); and (3) maximum hip flexion.

Virtual surgical correction through the computer software was performed on the preoperative CT scans of both the FAI revision and FAI successful surgery groups to simulate idealized surgical results (Fig. 1). The femoral head-neck junction was surgically contoured by correcting

the alpha angle to less than  $50^\circ$  from 11:00 to 4:30 positions on all radial reformats in the clockface zone. Once the surgical correction was performed, the ROM simulations were repeated as previously described for maximum flexion, IRF, and FADIR positions. Additionally, among the FAI successful surgery group, the pre- and postoperative CT scans were compared in the same manner as described previously. The virtual correction that was advised based on the preoperative CT scan was compared with the actual correction on the postoperative CT scan using the software-based morphology and dynamic ROM analysis described previously.

## Statistics

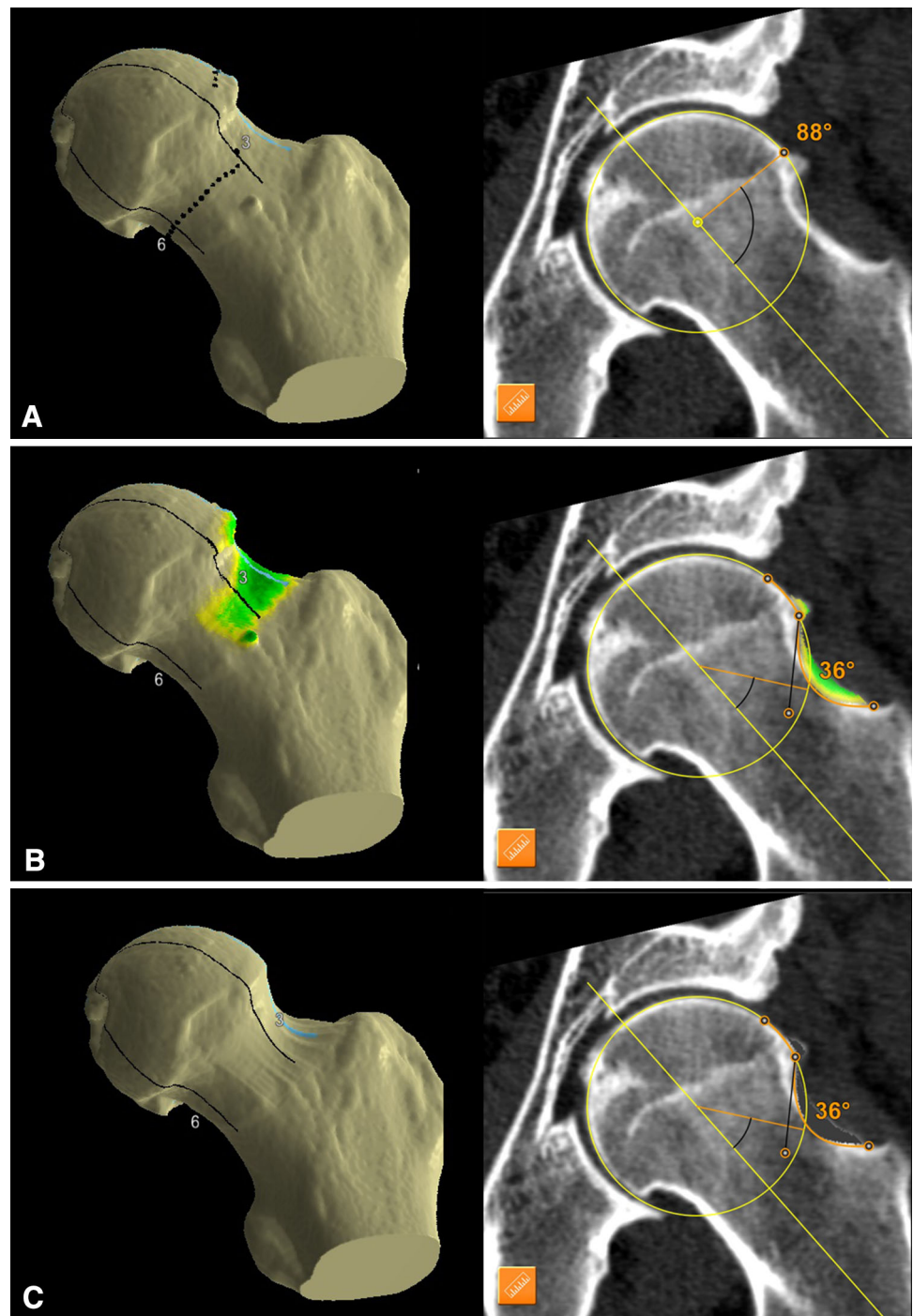
Statistical analysis was performed with Microsoft Excel (Redmond, WA, USA) software to compare changes in radiographic parameters and ROM with impingement between the different pelvic tilt conditions. A paired Student's t-test was used for comparison of continuous variables, whereas chi square testing was used for categorical variables. A p value < 0.05 was considered significant.

## Results

### Morphology

Ninety percent (45 of 50) of the patients in the FAI revision Group were noted to have residual radiographic pathomorphology consistent with residual FAI (18 hips [36%] with isolated cam, two hips [4%] with isolated pincer, and 25 hips [50%] with combined). The remaining five patients underwent revision hip arthroscopy for anteroinferior iliac spine decompression (three patients [6%]), psoas lengthening (one patient [2%]), and capsular adhesions (one patient [2%]). The mean femoral version was  $15^\circ \pm 10^\circ$  (range,  $-5^\circ$  to  $38^\circ$ ) among the patients who underwent revision surgery (n = 50). Fourteen percent of patients (seven of 50) had relative femoral retroversion (<  $5^\circ$ ), whereas 28% of patients (14 of 50) had increased femoral version (>  $20^\circ$ ). The mean maximum alpha angle for all revision hips was  $68^\circ \pm 16^\circ$  (range,  $44^\circ$ – $99^\circ$ ) and was located, on average, at the 1:15 clockface position (range, 11:30–2:30; Fig. 2). Eighty-six percent (43 of 50) of the revision hips had a maximum alpha angle measurement greater than  $50^\circ$  and were thus diagnosed with residual cam pathomorphology. The mean alpha angles at 12:00, 1:30, and 3:00 positions were  $53^\circ$ ,  $62^\circ$ , and  $47^\circ$ , respectively. The mean alpha angles among this population were elevated (>  $50^\circ$ ) between the 12:00 and 2:30 positions. The

**Fig. 1A–C** This figure is an example of a patient who underwent revision hip arthroscopy. (A) CT analysis demonstrated a maximum alpha angle of  $88^\circ$  at the 1:00 position. (B) Virtual correction demonstrates the areas of template resection along the femoral head-neck junction. (C) Virtual postoperative correction demonstrates restoration of the head-neck offset with an alpha angle of  $36^\circ$ .

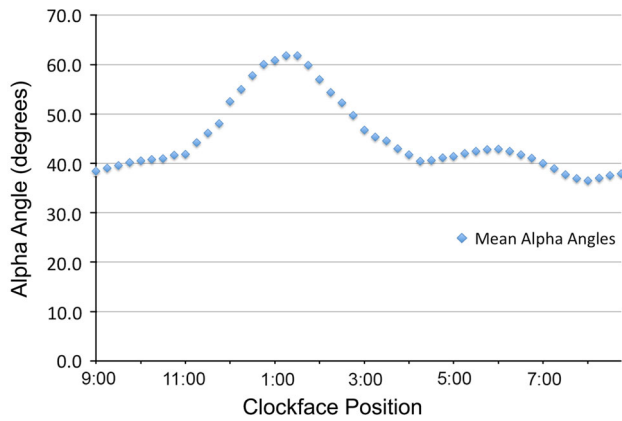


mean cranial acetabular version (1:30 position) was  $4^\circ \pm 8^\circ$  (range,  $-10^\circ$  to  $22^\circ$ ), whereas central acetabular version (3:00 position) was  $12^\circ \pm 7^\circ$  (range,  $-5^\circ$  to  $26^\circ$ ). Thirty-six percent (18 of 50) of the patients had a positive crossover sign. The mean LCEA was  $35^\circ \pm 7^\circ$  (range,  $22^\circ$ – $50^\circ$ ), and 26% (13 of 50) of hips had signs of overcoverage with LCEA  $> 40^\circ$ . The mean percent coverage of the femoral head in the anterior, superior, and posterior

quadrants was 36%, 63%, and 49%, respectively. The overall 3-D femoral coverage was 42%.

#### Range of Motion

Dynamic analysis in the FAI revision group revealed mean direct hip flexion of  $114^\circ \pm 14^\circ$  (range,  $78^\circ$ – $145^\circ$ ) to



**Fig. 2** The mean CT-derived alpha angles in patients undergoing revision hip arthroscopy demonstrate areas with residual deformity.

**Table 1.** Comparison of dynamic analysis of failed hip arthroscopy (FAI revision group) before and after virtual corrective surgery

Parameter	FAI revision group (preoperative analysis)		FAI revision group (postvirtual correction)		p value
	Mean ± SD	Range	Mean ± SD	Range	
Dynamic motion analysis (°)					
Flexion	114 ± 14	78–145	121 ± 11	97–145	< 0.001
IRF	28 ± 15	0–60	34 ± 13	8–60	< 0.001
FADIR	20 ± 14	0–52	25 ± 13	0–52	< 0.001

FAI = femoroacetabular impingement; IRF = internal rotation in 90° of hip flexion; FADIR = flexion, adduction, internal rotation.

osseous impingement; IRF and FADIR to osseous contact were 28° ± 15° (range, 0°–60°) and 20° ± 14° (range, 0°–52°), respectively. Virtual correction of the residual cam deformity in the revision hips resulted in improvement in flexion (114° versus 121°; *p* < 0.001), IRF (28° versus 34°; *p* < 0.001), and FADIR (20° versus 25°; *p* < 0.001; Table 1).

**Comparison**

The mean maximum preoperative alpha angle was 62° ± 12° (range, 41°–93°) among patients in the FAI successful surgery group. After the virtual osteoplasty, the mean alpha angle was 37° ± 3° (range, 28°–45°), and analysis of the actual postoperative scans revealed a slightly greater mean alpha angle of 39° ± 4° (range, 31°–49°, *p* = 0.003). The actual postoperative values were all less than those for patients with failed primary hip arthroscopy surgery and residual symptoms (FAI revision group) (Table 2). The analysis of acetabular coverage by radial center-edge angles revealed less than a 3° difference

**Table 2.** Femoral and acetabular measures/dynamic analysis of failed (FAI revision group) versus prior successful hip arthroscopy (FAI successful surgery group)

Parameter	FAI revision group		FAI successful surgery group		p value
	Mean ± SD	Range	Mean ± SD	Range	
Maximum alpha angle (°)	68 ± 16	44–99	39 ± 4	31–49	< 0.001
Acetabular coverage (%)					
Anterior	36 ± 5	27–45	31 ± 3	23–41	< 0.001
Superior	63 ± 6	35–77	59 ± 4	50–71	< 0.001
Posterior	49 ± 6	40–64	48 ± 5	37–57	0.35
3-D	42 ± 4	35–52	39 ± 3	33–47	< 0.001
Dynamic motion analysis (°)					
Flexion	114 ± 14	78–145	129 ± 10	105–155	< 0.001
IRF	28 ± 15	0–60	49 ± 11	25–90	< 0.001
FADIR	20 ± 14	0–52	40 ± 11	16–83	< 0.001

FAI = femoroacetabular impingement; 3-D = three-dimensional; IRF = internal rotation in 90° of hip flexion; FADIR = flexion, adduction, internal rotation.

and less than a 1% coverage difference of the femoral head between the virtual and actual rim osteoplasty, respectively. Simulated mean preoperative hip flexion was 121° ± 11°, mean IRF 35° ± 13°, and mean FADIR 26° ± 13° in the FAI successful surgery group. After the virtual osteoplasty, there was improvement in ROM with hip flexion was 128° ± 9°, IRF of 50° ± 10°, and FADIR of 40° ± 12°, respectively (Table 3). Dynamic ROM of the postoperative hips showed no difference when compared with the virtual osteoplasty group (Table 3). In contrast, all dynamic measurements were significantly higher in the FAI successful surgery group than those hips that had underwent failed hip arthroscopy (FAI revision group) (Table 2).

**Discussion**

Treatment of symptomatic patients with FAI has become more common over the past decade [9]. However, some patients present with continued or recurrent symptoms after treatment with hip arthroscopy. Previous studies have reported residual deformity and incomplete correction of symptomatic hip FAI to be the most common reason for revision hip arthroscopy [4, 7, 11, 13, 18]. However these residual deformities have not been systematically characterized. Therefore, the purposes of our study were to (1) define the 3-D morphology of hips with residual pain and/or restricted ROM after corrective arthroscopic FAI surgery that undergo revision surgery; (2) determine the

**Table 3.** Preoperative and postoperative CT analysis of patients that underwent surgery by a high-volume surgeon (FAI successful surgery group)

Parameter	Preoperative	Virtual corrected	p value	Actual correction	p value (pre-versus actual)	p value (virtual versus actual)
Maximum alpha angle	62° ± 12°	37° ± 3°	< 0.001	39° ± 4°	< 0.001	< 0.001
Acetabular coverage						
Anterior	34% ± 4%	31% ± 3%	< 0.001	31% ± 3%	< 0.001	0.27
Superior	61% ± 4%	59% ± 4%	< 0.001	59% ± 4%	0.002	0.48
Posterior	47% ± 4%	46% ± 4%	0.84	48% ± 5%	0.07	0.03
3-D	40% ± 3%	39% ± 3%	0.01	39% ± 3%	0.12	0.37
Dynamic motion analysis						
Flexion	121° ± 11°	128° ± 9°	< 0.001	129° ± 10°	< 0.001	0.56
IRF	35° ± 13°	50° ± 10°	< 0.001	49° ± 11°	< 0.001	0.57
FADIR	26° ± 13°	40° ± 12°	< 0.001	40° ± 11°	< 0.001	0.95

Values are mean ± SD; FAI = femoroacetabular impingement; 3-D = three-dimensional; IRF = internal rotation in 90° of hip flexion; FADIR = flexion, adduction, internal rotation.

residual limitation in ROM in these patients using dynamic, computer-assisted, 3-D analysis; and (3) compare the 3-D morphology of hips undergoing revision FAI surgery with postoperative 3-D morphology of hips that underwent successful primary surgery.

Our study has several limitations. ROM simulations in the study include only bony morphology, ignoring contributions of labrum, cartilage, capsule, and periarticular soft tissue structures. Current technology does not allow for the inclusion of soft tissue structures. Continued pain after failed hip arthroscopy can also be related to adhesions, capsular incompetence, laxity, labral deficiency, or other soft tissue pathology that are not detected with CT evaluation. However, we feel that the comparison of preoperative CT scans of patients undergoing revision hip arthroscopy with postoperative CT scans of patients who underwent appropriate corrective surgery is appropriate and adequate given that this study and others have demonstrated that residual FAI is the most prevalent diagnosis for continued pain. Although CT provides excellent visualization of the osseous pathomorphology, limitations of its use include additional radiation exposure. However, at our institutions, we use an advanced CT protocol that decreases radiation exposure by a factor of 2 to 3. We also recognize that the alpha angle is simply one measure of cam morphology/deformity and that achieving an impingement-free hip requires direct intraoperative visualization and dynamic assessment in addition to correction of the alpha angle. Our study also is limited in that no clinical outcome scores are reported, because the review was primarily a radiographic study by nature to examine for the completeness of morphologic correction of deformity. Additionally, our study is not applicable to all patients who fail hip arthroscopy, because the majority of patients within our study had

residual bony impingement morphology. Finally, it should be noted that both the control and revision groups may present some selection bias. The revision group includes only those who returned for evaluation of residual symptoms; it is possible that patients with similar residual radiographic deformity may be asymptomatic and not captured in this group. Correspondingly, the control group had a postoperative CT scan obtained fortuitously at the time of preoperative workup for the contralateral hip in patients with bilateral disease; in this regard, there is selection bias for patients with a favorable outcome who have decided to proceed with contralateral hip surgery. It is possible that patients with a similar correction without bilateral disease may not have been captured because they did not choose to pursue additional surgery. Finally, this study is not applicable to all patients who fail hip arthroscopy as previous studies have also documented other causes of failure such as advanced osteoarthritis, acetabular dysplasia, or recurrent labral tear.

In our study, 90% (45 of 50) of patients undergoing secondary hip arthroscopy surgery were noted to have residual femoral and/or acetabular deformity, most often in the form of cam-type (36%) or combined cam- and pincer-type (50%) pathomorphology. Residual cam-type deformity in our series was most often encountered at the superolateral head-neck junction, on average at the 1:15 o'clock location. Additionally, the mean alpha angles among this population were elevated (> 50°) between 12:00 and 2:30, which likely reflects the difficulty in exposing and accessing this region on the femoral head-neck junction and the proximity to the perfusing retinacular vessels. Although hip arthroscopy allows visualization of the anteroinferior-to-lateral femoral head-neck junction, full visualization can be difficult to obtain through a single

viewing portal and usually requires regional viewing through multiple portals. Regional evaluation can therefore make comprehensive resection of the cam deformity difficult and may present the underlying reason for the lack of complete bony correction. Many hip arthroscopists therefore use intraoperative fluoroscopy to avoid inadequate resection with residual impingement [20]. These findings are similar to previous studies that have documented bony FAI pathomorphology as the reason for revision FAI surgery [4, 11, 13, 18]. Heyworth et al. [11] reported 19 of 24 revision hip arthroscopies had radiographic findings of residual FAI pathomorphology. In their series, 20% were cam-type, 46% pincer-type, and 13% cam-type lesions; the remaining five patients had soft tissue pathology. In another investigation of revision hip arthroscopy, Philippon et al. [18] noted that 36 of 37 hips had evidence of radiographic impingement lesions that were not addressed or inadequately addressed at the index procedure. Although Philippon et al. did not comment on the classification of the bony pathomorphology, osteoplasty of cam impingement was performed in 76% of hips, whereas rim trimming of pincer impingement was performed in 46% of hips.

In addition to the characterization of the residual osseous impingement anatomy, we also demonstrated that patients who underwent revision hip arthroscopy had reduced dynamic motion to osseous contact. Specifically, when compared with the primary surgical cohort with a favorable clinical outcome, patients who underwent revision hip arthroscopy had approximately 15° less flexion, 20° less internal rotation in 90° of flexion, and 20° less internal rotation in the FADIR position. Successful removal of the mechanical block to motion should be expected to restore ROM and thus explains the difference in motion between those undergoing revision FAI surgery and those patients who were surgically treated with adequate decompression of the cam deformity. This agrees with an investigation by Kelly et al. [12], which demonstrated improvement in functional ROM after restoration of the femoral head-neck junction to an alpha angle less than 50°. Kelly et al. specifically noted a mean clinical increase of 18° in IRF at 3 months, which is similar to the dynamic results of our study when comparing preoperative CT scans of revision patients with postoperative CT scans of patients who underwent successful primary surgery by a high-volume hip arthroscopist.

Interestingly, the virtual osteoplasty of the preoperative CT scans for the primary cohort was very similar when compared with the actual postoperative resection by an experienced arthroscopist. Not only was the mean maximum alpha angle within the patient population lower than the revision cohort, but all alpha angles along the clockface (radial sequences) in the successfully treated group were corrected to less than 50°, indicating a more thorough and

complete correction in all planes. Although the virtual osteoplasty maximum alpha angle (37°) was lower than the actual postoperative osteoplasty maximum alpha angle (39°), the difference of 2° is not clinically relevant as demonstrated when comparing the dynamic ROM. This demonstrates the potential use of dynamic imaging as a preoperative templating tool with the goals of comprehensive correction and avoidance of residual deformity [4]. However, in those patients who present with recurrent hip symptoms after hip arthroscopy and have residual bony impingement pathomorphology, arthroscopic treatment with meticulous attention to assure exposure and complete correction of the deformity from the superior (12 o'clock) to inferior (6 o'clock) retinacular vessels and occasionally beyond the vessels may be critical to minimize the risk of residual impingement and need for revision surgery in patients with symptomatic FAI.

Despite the favorable clinical outcomes of hip arthroscopy for symptomatic FAI, there has also been an increase in the number of revision hip arthroscopy and hip preservation surgeries. We found radiographic evidence of incomplete correction of deformity in 90% of patients with residual symptoms compared to patients with successful results. We recommend careful attention to full 3-D resection of impinging structures to eliminate the need for revision surgery and thus ensure a successful clinical outcome. Preoperative 3-D imaging may be beneficial to assist with planning for appropriate surgical correction.

## References

1. Bedi A, Dolan M, Hetsroni I, Magennis E, Lipman J, Buly R, Kelly BT. Surgical treatment of femoroacetabular impingement improves hip kinematics: a computer-assisted model. *Am J Sports Med.* 2011;39(Suppl):43S–49S.
2. Bedi A, Dolan M, Magennis E, Lipman J, Buly R, Kelly BT. Computer-assisted modeling of osseous impingement and resection in femoroacetabular impingement. *Arthroscopy.* 2012;28:204–210.
3. Blankenbaker DG, De Smet AA, Keene JS, Fine JP. Classification and localization of acetabular labral tears. *Skeletal Radiol.* 2007;36:391–397.
4. Bogunovic L, Gottlieb M, Pashos G, Baca G, Clohisy JC. Why do hip arthroscopy procedures fail? *Clin Orthop Relat Res.* 2013;471:2523–2529.
5. Byrd JW. Hip arthroscopy utilizing the supine position. *Arthroscopy.* 1994;10:275–280.
6. Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 2-year follow-up. *Arthroscopy.* 2000;16:578–587.
7. Clohisy JC, Nepple JJ, Larson CM, Zaltz I, Millis M; ANCHOR Members. Persistent structural disease is the most common cause of repeat hip preservation surgery. *Clin Orthop Relat Res.* 2013;471:3788–3794.
8. Clohisy JC, St John LC, Schutz AL. Surgical treatment of femoroacetabular impingement: a systematic review of the literature. *Clin Orthop Relat Res.* 2010;468:555–564.
9. Colvin AC, Harrast J, Harner C. Trends in hip arthroscopy. *J Bone Joint Surg Am.* 2012;94:e23.

10. Farjo LA, Glick JM, Sampson TG. Hip arthroscopy for acetabular labral tears. *Arthroscopy*. 1999;15:132–137.
11. Heyworth BE, Shindle MK, Voos JE, Rudzki JR, Kelly BT. Radiologic and intraoperative findings in revision hip arthroscopy. *Arthroscopy*. 2007;23:1295–1302.
12. Kelly BT, Bedi A, Robertson CM, Dela Torre K, Giveans MR, Larson CM. Alterations in internal rotation and alpha angles are associated with arthroscopic cam decompression in the hip. *Am J Sports Med*. 2012;40:1107–1112.
13. Larson CM, Giveans MR, Samuelson KM, Stone RM, Bedi A. Outcomes after revision arthroscopy for hip impingement. *Am J Sports Med*. 2014;42:1785–1790.
14. Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. *Clin Orthop Relat Res*. 2004;418:74–80.
15. Mast JW, Brunner RL, Zebrack J. Recognizing acetabular version in the radiographic presentation of hip dysplasia. *Clin Orthop Relat Res*. 2004;418:48–53.
16. Milone MT, Bedi A, Poultides L, Magennis E, Byrd JW, Larson CM, Kelly BT. Novel CT-based three-dimensional software improves the characterization of cam morphology. *Clin Orthop Relat Res*. 2013;471:2484–2491.
17. O’Leary JA, Berend K, Vail TP. The relationship between diagnosis and outcome in arthroscopy of the hip. *Arthroscopy*. 2001;17:181–188.
18. Philippon MJ, Schenker ML, Briggs KK, Kuppersmith DA, Maxwell RB, Stubbs AJ. Revision hip arthroscopy. *Am J Sports Med*. 2007;35:1918–1921.
19. Philippon MJ, Stubbs AJ, Schenker ML, Maxwell RB, Ganz R, Leunig M. Arthroscopic management of femoroacetabular impingement: osteoplasty technique and literature review. *Am J Sports Med*. 2007;35:1571–1580.
20. Ross JR, Bedi A, Stone RM, Sibilsky Enselman E, Leunig M, Kelly BT, Larson CM. Intraoperative fluoroscopic imaging to treat cam deformities: correlation with 3-dimensional computed tomography. *Am J Sports Med*. 15 Apr 2014 [Epub ahead of print].
21. Santori N, Villar RN. Acetabular labral tears: result of arthroscopic partial limbectomy. *Arthroscopy*. 2000;16:11–15.
22. Wiberg G. Studies on dysplastic acetabula and congenital subluxation of the hip: with special reference to the complication of osteoarthritis. *Acta Chir Scand*. 1939;58:7–38.