Abstract

The "Outside-In" Lesion of Hip Impingement and the "Inside-Out" Lesion of Hip Dysplasia

Two Distinct Patterns of Acetabular Chondral Injury

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Background: Femoroacetabular impingement (FAI) and acetabular dysplasia lead to acetabular cartilage damage that commonly results in the chondral flaps seen during hip arthroscopy.

Purpose: To compare the acetabular chondral flap morphology seen during hip arthroscopy ("outside-in" vs "inside-out") with clinical and radiographic parameters underlying FAI and hip dysplasia.

Study Design: Cohort study; Level of evidence, 3.

Methods: Patients who underwent hip arthroscopy by the senior author between 2013 and 2017 with a finding of Outerbridge grade IV acetabular chondral flap were included. Each procedure was retrospectively reviewed on video and chondral flaps were categorized as inside-out or outside-in. An inside-out designation was made for flaps exhibiting an intact chondrolabral junction with a detached sleeve of chondrolabral tissue from the central acetabulum, and an outside-in designation was made for centrally anchored flaps exhibiting a break in the chondrolabral junction. Radiographic markers of hip impingement/dysplasia were noted for each patient during assignment into 1 of 2 radiographic groups: group 1, lateral center edge angle (LCEA) >20 with FAI, and group 2, LCEA ≤ 20 with or without cam FAI. Associations between chondral flap morphology and clinical diagnosis were tested using a chi-square test.

Results: Overall, 95 patients (103 hips) were included (group 1, 78 hips; group 2, 25 hips). Among hips in group 2, 24 had concurrent cam FAI. There was a significant relationship between chondral flap type and radiographic diagnosis ($P < .001$). Among group 1 hips, 78% exhibited outside-in type chondral flaps, 12% exhibited combined outside-in and inside-out flaps, and 10% exhibited inside-out flaps. Group 2 hips showed 72% inside-out type chondral flaps, 16% combined, and 12% outside-in. Hips exhibiting outside-in type flaps were significantly more likely to be in group 1 (positive predictive value [PPV], 91%; negative predictive value [NPV], 69%). Similarly, hips exhibiting inside-out type flaps were significantly more likely to be in group 2 (PPV, 56%; NPV, 95%). Altogether, 90% of group 1 hips exhibited an outside-in lesion and 88% of group 2 hips exhibited an inside-out lesion.

Conclusion: Acetabular chondral flap type visualized during hip arthroscopy correlates with radiographic markers of hip impingement and hip instability. Outside-in flaps are highly predictive of FAI, whereas inside-out flaps are highly predictive of acetabular dysplasia.

Keywords: cartilage; chondral flap; femoroacetabular impingement; hip arthroscopy; hip dysplasia

Femoroacetabular impingement (FAI) and acetabular dysplasia represent the 2 most common causes of secondary osteoarthritis of the hip joint.[3,25] These conditions are known to produce acetabular chondral flaps that can be seen during hip arthroscopy.[10,28,38] However, the pathomechanics by which each diagnosis brings about articular cartilage damage differ significantly. In all subtypes of FAI, there is a conflict between the acetabular rim and femoral head-neck junction, thereby resulting in chondral and labral injury starting in the periphery of the joint and progressing centrally ("outside-in" mechanism).[3,6,7,21,32] In contrast, acetabular dysplasia is marked by abnormal shear forces due to anterolateral femoral head subluxation, which results in a central tear in the articular cartilage

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and a contiguous chondrolabral sleeve that extends peripherally ("inside-out" mechanism).[14,18,29,30]

Although it is well established that acetabular chondral flaps may occur in patients with FAI,[10,24,28,31,38] the literature on chondral flaps in patients with hip dysplasia is sparse.[30] Furthermore, no prior studies have systematically characterized the morphology of these chondral flaps as outside-in versus inside-out based on the underlying radiographic diagnosis. This can be of great significance when performing hip arthroscopy on patients with radiographic findings of both impingement and instability. For these challenging cases, the pattern of acetabular chondral injury may aid in revealing the dominant pathomechanics and guiding treatment. The purpose of this study was to compare the acetabular chondral flap morphology seen during hip arthroscopy (outside-in vs inside-out) with clinical and radiographic parameters underlying FAI and hip dysplasia.

METHODS

After institutional review board approval was obtained, the authors performed a single-center prospective study on a cohort of patients undergoing hip arthroscopy and who met inclusion criteria between 2013 and 2017. Inclusion criteria for patients selected for this study were as follows: (1) persistent hip pain and mechanical symptoms refractory to nonoperative management (physical therapy, nonsteroidal anti-inflammatory drugs, activity modifications, corticosteroid injections) lasting at least 3 months, (2) reproducible clinical examination findings suggestive of impingement and/or instability, (3) joint-space width exceeding 3 mm on all views of plain radiography and cross-sectional imaging, (4) no previous hip joint surgery, and (5) presence of Outerbridge grade IV acetabular chondral flap noted during hip arthroscopy and documented by the senior author (O.M.-D.) in the operative report. Some of the physical examination tests used included passive hip range of motion (supine, lateral, prone), the FADIR (flexion, adduction, internal rotation) test, the FABER (flexion, abduction, external rotation) test, the ligamentum teres (LT) test, the Beighton hypermobility score to assist in the diagnosis of instability, the posterior impingement test, and subjective reports of hip instability such as a sensation of the hip "popping out" during loading.[18]

Common indications for hip arthroscopy were symptomatic FAI, hip instability due to dysplasia (before periacetabular osteotomy [PAO]), and/or excessive femoral torsion (before derotational femoral osteotomy [DFO]). Patients undergoing surgical treatment for diagnoses of slipped capital femoral epiphysis, Legg-Calves-Perthe disease, osteochondromatosis, or postdislocation syndrome were excluded.

Patient characteristics including age, clinical diagnosis, sex, height, weight, and body mass index (BMI) were recorded for all patients.

Imaging Protocol and Measurements

After a comprehensive clinical evaluation by the senior author, patients underwent a standardized series of anteroposterior (AP) pelvis radiographs,[36] and once scheduled for surgery all patients went on to have magnetic resonance imaging (MRI) and whole-pelvis computed tomography (CT) scans.

The presence of a cam lesion was determined by an alpha angle exceeding 50° on CT radial sequences of the head-neck junction and a femoral head-neck offset ratio of less than 0.18 on both radiographs and CT. Clinical diagnosis of osseous impingement was determined according to accepted pathomorphologic signs and measurements.[12,35] Physical examination findings suggestive of FAI included reduced hip flexion range of motion, reduced hip internal rotation range of motion, and/or positive provocative tests.[4] The diagnosis was confirmed by imaging findings of focal acetabular overcoverage as indicated by a lateral center edge angle (LCEA) $>40°$ and/or a Tönnis angle $<0°$ for pincer-type FAI and the presence of an anterior or lateral cam lesion for cam-type FAI. LCEA was determined on AP pelvis radiographs as described previously.[26] Patients with an LCEA between 20° and 24.9° were diagnosed with borderline hip dysplasia, and those with values $<20°$ were diagnosed with frank hip dysplasia. Hips were grouped according to radiographic markers of impingement and instability as follows: group 1, normal LCEA ($>20°$) with cam-, mixed-, or pincer-type FAI, and group 2, LCEA $\leq 20°$ with or without cam FAI. Patients with hip pain related to frank hip dysplasia were scheduled to undergo a PAO, although all patients underwent hip arthroscopy 3 to 10 days before the PAO to address concomitant intra-articular pathology.[23]

Surgical Technique

Hip arthroscopy was performed with the patient in the supine position without a perineal post, as previously described.[22] General anesthesia was used in all cases. The patient was placed in a supine position on a traction

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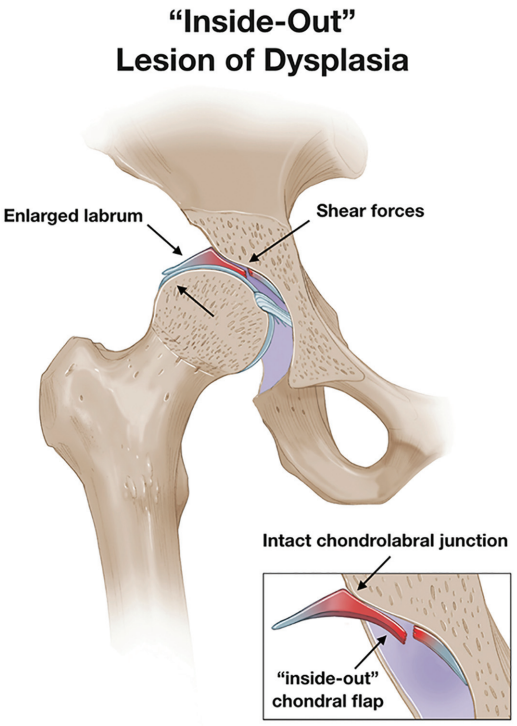

Figure 1. Schematic drawing of a dysplastic right hip and pelvis demonstrating the pathomechanics underlying the development of an inside-out acetabular chondral flap (inset). The inside-out flap is characterized by an intact chondrolabral junction with a detached sleeve of chondrolabral tissue from the central acetabulum.

table. Bony prominences of the foot and ankle were padded, and traction was achieved with the use of a limb positioner affixed to custom-machined table attachment arms enabling unrestricted limb positioning. The operative table was placed at an approximately 5° to 15° incline in the Trendelenburg position. With the aid of fluoroscopy, traction was applied and the hip was cannulated using the standard anterolateral and midanterior portals. An interportal capsulotomy was performed.[20,33] The joint was accessed and the central compartment pathology was addressed. Traction was then released, the table was brought back to a horizontal position, and the peripheral compartment intervention was undertaken.

Chondral damage was evaluated by probing to determine the thickness (Outerbridge grades I-IV), length (along the acetabular clock face), and depth (percentage rim to fovea) of involvement. For Outerbridge grade IV lesions, an inside-out designation was made for flaps exhibiting an intact chondrolabral junction with a detached sleeve of chondrolabral tissue from the central acetabulum (Figures 1 and 2) and an outside-in designation was made for centrally anchored flaps exhibiting a break in the chondrolabral junction (Figures 3 and 4). Occasionally, both outside-in and inside-out injury patterns were seen in the same hip, affecting different portions of the acetabulum, which we termed "combined" type. Assessment of chondral flap type was performed twice in

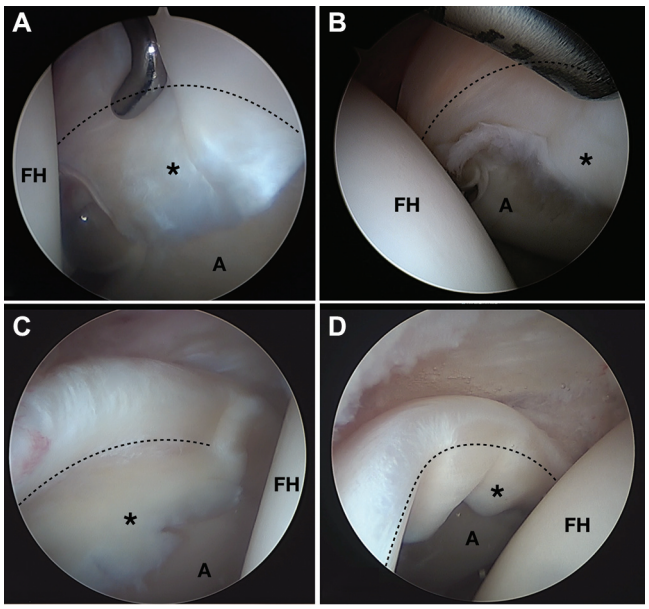

Figure 2. Arthroscopic views of (A, B) 2 left and (C, D) 2 right dysplastic hips demonstrating different cases of the inside-out chondral flap with intact chondrolabral junction. The asterisk indicates the inside-out flap, and the dashed line indicates the chondrolabral junction. A, acetabulum; FH, femoral head.

each case: initially during surgery with immediate documentation in the operative report by the senior author, and again during a retrospective review of surgical videos of each case by 2 reviewers (M.J.F., O.M.-D.) simultaneously, who agreed on the type of flap, while being blinded to the underlying radiographic measurements.

Statistical Analysis

Data were tabulated and associations between hip pathology and chondral flap type were tested using a chi-square test. Where significant differences were found, post hoc analysis was performed by comparing specific groups using chi-square test odds ratios, and positive and negative predictive ratios and CIs were calculated using the exact binomial. Data analysis was performed in R version 3.5.1 (R Core Team).

RESULTS

Overall, 95 patients (103 hips) were included in this study. Group 1 contained 78 hips including 60 hips with cam FAI, 18 hips with mixed FAI, and 0 hips with pincer FAI. Group 2 contained 25 hips including 24 hips with concurrent cam FAI and 1 hip without cam FAI (Table 1).

There was a significant relationship ($P < .001$) between chondral flap type and radiographic findings (Figure 5, Table 2). Among group 1 hips, 78% exhibited outside-in chondral flaps, 12% exhibited combined outside-in and

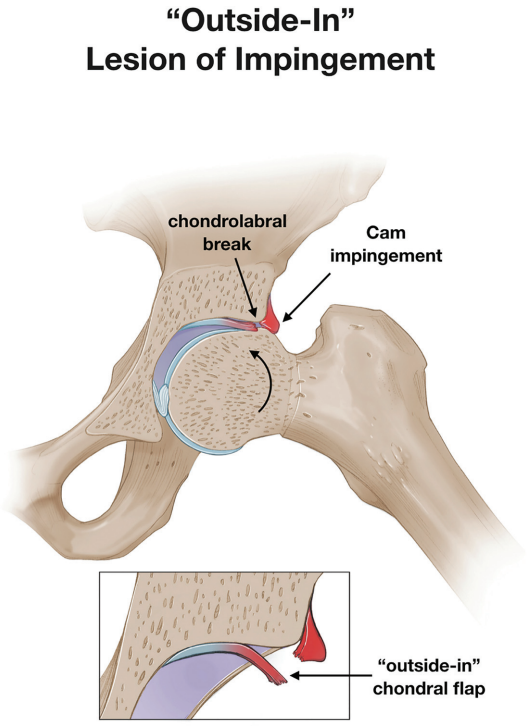

Figure 3. Schematic drawing of a left hip and pelvis demonstrating cam impingement and the pathomechanics underlying the development of an outside-in acetabular chondral flap (inset). The outside-in designation is made for centrally anchored flaps exhibiting a break in the chondrolabral junction.

inside-out, and 10% exhibited inside-out. Group 2 hips, on the other hand, showed 72% inside-out type flaps, 16% combined, and 12% outside-in. Altogether, 90% of group 1 hips exhibited an outside-in lesion and 88% of group 2 hips exhibited an inside-out lesion.

Hips exhibiting outside-in flaps (either alone or in combination with inside-out) were significantly more likely to have a clinical diagnosis of FAI, with a positive predictive value of 84% (95% CI, 74%-92%) and a negative predictive value of 81% (95% CI, 61%-93%). Hips exhibiting inside-out flaps (either alone or in combination with outside-in) were significantly more likely to have a clinical diagnosis of dysplasia, with a positive predictive value of 69% (95% CI, 52%-83%) and a negative predictive value of 91% (95% CI, 81%-96%).

Thirty hips in this study went on to an osteotomy procedure after hip arthroscopy (24 PAO, 1 DFO, 5 PAO + DFO). Of these, 21 were found to have an inside-out chondral flap intraoperatively, 4 had an outside-in flap (all were males with femoral retrotorsion), and 5 hips had combined flaps.

Post hoc analysis revealed that there was no significant difference in the prevalence of combined chondral flap type (both outside-in and inside out) between groups 1 and 2 ($P > .05$). Overall, 12.6% of hips had combined chondral flaps (95% CI, 6.9%-20.6%).

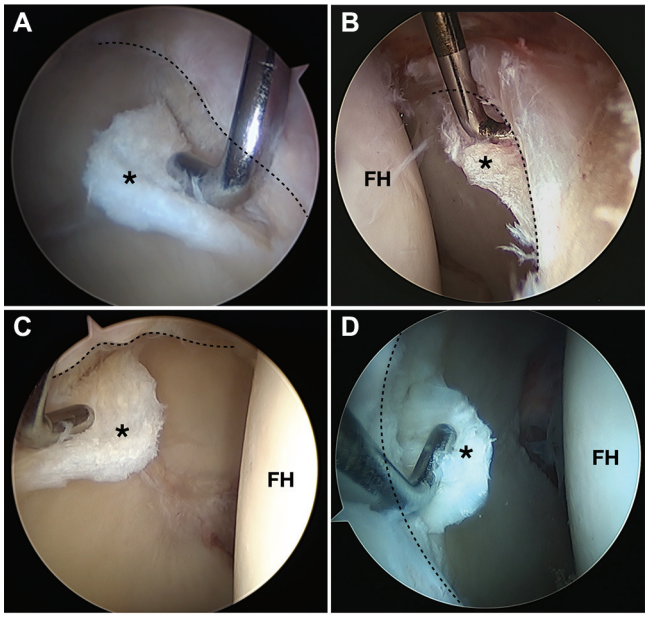

Figure 4. Arthroscopic views of (A, B) 2 right and (C, D) 2 left hips with cam impingement demonstrating different cases of the outside-in chondral flap with a break in the chondrolabral junction. The asterisk indicates the outside-in flap, and the dashed line indicates the chondrolabral junction. FH, femoral head.

Group 1 hips had a significantly higher likelihood of exhibiting outside-in chondral flaps compared with group 2 hips (odds ratio, 21.1; 95% CI, 7.1-71.7; $P < .001$). Conversely, group 2 hips had a significantly higher likelihood of exhibiting inside-out chondral flaps compared with group 1 hips (odds ratio, 24.3; 95% CI, 7.3-116.9; $P < .001$).

Seventeen of 78 hips (22%) in group 1 (LCEA, >20) paradoxically demonstrated an inside-out lesion (occurring alone or in combination with outside-in). Similarly, 3 of 25 hips (12%) in group 2 (LCEA, ≤20) lacked an inside-out lesion.

DISCUSSION

The most important finding from this study is that there is a significant association between acetabular chondral flap type visualized during hip arthroscopy and radiographic markers of hip impingement and hip instability. Specifically, patients with FAI are more likely to exhibit outside-in cartilage flaps, whereas those with hip dysplasia (LCEA, ≤20) frequently demonstrate inside-out flaps. Additionally, outside-in flaps were found to be highly predictive of type of impingement, whereas inside-out flaps were found to be predictive of dysplasia. These findings provide important diagnostic information, particularly for those patients with mixed radiographic findings, such as dysplasia with a cam lesion. Furthermore, this study suggests that we should not view all cartilage flaps equally, as they are the result of different pathomechanics that

TABLE 1
Patient Characteristics (N = 95)[a]

	Value
Age, y	34.2 ± 8.6
Male sex, n (%)	50 (52.6)
Height, cm	173.3 ± 10.7
Weight, kg	76.0 ± 16.7
Body mass index, kg/m^2	25.2 ± 4.5
Lateral acetabular coverage of hips, n (%)	
Frank dysplasia (LCEA, <20.0°)	24 (23.3)
Borderline dysplasia (LCEA, 20.0°-24.9°)	6 (5.8)
Normal (LCEA, 25.0°-39.9°)	54 (52.4)
Overcoverage (LCEA, >40.0°)	9 (8.7)

[a]Data are reported as mean ± SD unless otherwise indicated. LCEA, lateral center edge angle.

TABLE 2
Percentage of Hips Within Each Group Exhibiting Specified Chondral Flap Morphology

Pathology (n)	Inside-Out	Outside-In	Combined
Group 1 (78)	10[a]	78	12
Group 2 (25)	72	12[b]	16

[a]Significantly lower prevalence compared with group 2.
[b]Significantly lower prevalence compared with group 1.

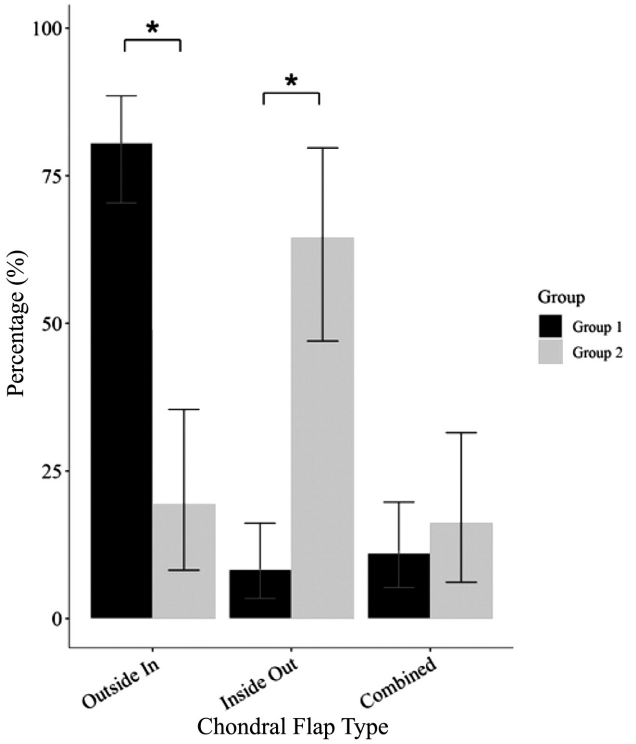

Figure 5. Distribution of type of cartilage flap type based on group. Error bars indicate 95% CIs for the prevalence of each chondral flap type for each hip pathology. The asterisk indicates a significant difference at $P < .001$ between groups for the prevalence of specific chondral flap type.

may provide crucial information to guide treatment for cases with mixed radiographic findings.

Patients with radiographic findings of both impingement (cam lesion, femoral retroversion, acetabular retroversion) and instability (reduced LCEA and increased Tönnis angle, posterior wall deficiency, femoral anteversion, acetabular anteversion, anterior horn hypoplasia) are among the most difficult to accurately diagnose and treat. In these cases, the surgeon is tasked with discriminating between treatment options ranging from isolated arthroscopic management to address cam pathology to PAO or DFO to address hip instability. Although much work has been done to characterize injury patterns in cases of impingement, the literature on the effect of instability alone is limited due to inclusion of patients with both instability and impingement. Clohisy et al[5] reported on the coincidence of femoral asphericity (72%) and insufficient femoral head-neck offset (75%) in a series of 108 dysplastic hips treated with PAO. Another study found that 40% of patients with dysplastic hips had radiographic cam lesions, increased pelvic tilt, and reduced femoral anteversion, all of which were thought to contribute to symptomatic impingement.[11] These findings are in keeping with our results, which showed that 24 of 25 hips categorized in group 2 (LCEA, ≤20) also exhibited a cam lesion. The correlation of femoral asphericity and hip dysplasia makes it difficult to study the effects of hip instability alone on cartilage flap type without also including the effects of potential cam FAI. This added complexity is further discussed below when we consider the paradoxical findings of our study.

The differences in acetabular chondral flap type between patients with FAI and hip dysplasia can be understood by considering their correspondingly distinct anatomic features. In patients with cam-type FAI, the nonspherical femoral head impinges on the acetabular rim as it forces itself into the acetabulum, thereby resulting in an outside-in chondral flap with disruption of the anterosuperior chondrolabral junction and cleavage along the corresponding portion of the articular cartilage.[1,3,6,24,34] The depth of cartilage injury is often quite extensive and may reach more than one-third the total depth in the area of impingement.[3,13,34] Pincer-type FAI, however, is marked by diffuse labral pathology including hypoplasia and osseous metaplasia.[3,6] Full-thickness cartilage flap tears are not a hallmark finding of pincer-type FAI, which was in keeping with the present study in which no patients with isolated pincer FAI were included due to the absence of grade IV chondral lesions.

In patients with hip dysplasia, hypertrophy of the acetabular labrum and cartilage is a common finding.[2,8,9,17,19,27] This is thought to occur as a result of hip instability and anterolateral migration of the femoral head, thereby leading to a chronic shear stress between the femoral head and acetabular roof and compensational labral hypertrophy to maintain the femoral head within the joint.[8,30] However, persistent shear stress may lead to a labral tear, a phenomenon that Klaue et al[15] coined

the "acetabular rim syndrome." In addition, the chronic shear stress may also result in an inside-out chondral flap with an intact chondrolabral junction.[30] This is a distinctly different mechanism from the outside-in lesion of impingement discussed above (see Figures 1 and 3).

This study is merely a first step in correlating markers of impingement and instability to the resultant distinct patterns of articular cartilage injury. Importantly, the design of the present study utilizes a simplified grouping of patients with the aim of generating statistically significant, yet clinically meaningful comparisons. Our method of grouping, based on accepted current literature, utilizes LCEA $\leq$20 as a marker for instability and LCEA $>$20 to indicate the absence of instability. However, the true assessment of hip instability goes far beyond the measured LCEA and includes acetabular version, femoral torsion, congruency of articulation, percentage medialization of the iliofemoral line,[16] presence of an upsloping lateral sourcil,[37] Beighton ligamentous laxity score, and clinical range of motion. In actual surgical practice, the senior author implements all of these important parameters in arriving at a treatment plan that is tailored to each patient. As a result, some patients with an LCEA $>$20 may still exhibit symptomatic instability, whereas others with an LCEA $\leq$20 may not, depending on the aforementioned parameters. Correspondingly, we believe it is the simplified grouping scheme in the present study that gives rise to the "paradoxical" results, including the 17 of 78 hips (22%) in group 1 (LCEA $>$20) with inside-out lesions (occurring alone or in combination with outside-in). Upon closer inspection, however, nearly every one of these group 1 paradoxical hips exhibited at least 1 other abnormality suggestive of instability, underscoring the inadequacy of utilizing LCEA as the sole marker of hip instability. Similarly, the 3 of 25 hips (12%) in group 2 that paradoxically lacked an inside-out lesion indicate that an LCEA $\leq$20 alone is not pathognomonic for hip instability, as many of these hips occurred in males with restricted range of motion, femoral retrotorsion, and no evidence of ligamentous laxity. At present, some patients who are "on the fence" with their measurements and therefore either were not offered or decided to opt out of major bony realignment (PAO or DFO) learn that the arthroscopic approach fails in 12 to 16 months. Others are unnecessarily treated with PAO or DFO when an arthroscopic surgery would have adequately addressed their problem. Since the start of this study, the senior author is now more likely to offer a PAO/DFO to patients for whom the underlying issue is unclear preoperatively but who are found to have an inside-out chondral flap during hip arthroscopy. By broadening our conception of hip pathology to include other important contributors, rather than oversimplifying the problem to femoral asphericity and LCEA, we may solve the difficult problem of how to best treat the patient with mixed findings of impingement and instability.

The strengths of this study include the evaluation of a large sample size of patients with acetabular chondral flaps identified during hip arthroscopy. The limitations of this study should also be noted. As discussed above, in an effort to simplify the analysis, this study focuses predominantly on radiographic markers of FAI (cam, pincer) and dysplasia (LCEA) without special consideration for other factors that are known important markers of hip pathology. We suspect that in future studies with a larger sample size of patients to enable these independent variables to be incorporated into analysis, we will be able to categorize patients into more inclusive groups: hip impingement and hip instability (rather than hip dysplasia), where hip impingement also includes those patients with femoral retrotorsion without a cam lesion, and hip instability also includes those patients with a normal LCEA but excessive femoral torsion and ligamentous laxity, to name a few examples. It is the senior author's practice to include all of these important variables in arriving at a treatment plan for each patient; however, the sample size in this study did not permit us to include these additional variables in our analysis. Additionally, the results of this study have not been correlated with clinical outcome. Finally, patients were not included in this study if they lacked grade IV chondral flaps, and as a result, our cohort contains only a few patients with borderline dysplasia and altogether lacks patients with isolated pincer FAI. However, we contend that the results are still applicable to those patients who demonstrate partial-thickness lesions or wave delamination, which can often be categorized as "early outside-in" or "early inside-out."

CONCLUSION

Acetabular chondral flap type visualized during hip arthroscopy correlates with radiographic markers of hip impingement and hip instability. Outside-in flaps are highly predictive of FAI, whereas inside-out flaps are highly predictive of acetabular dysplasia (LCEA $\leq$20).

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