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Characterization of version in the dysplastic hip and the need for subsequent femoral derotational osteotomy after periacetabular osteotomy

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ABSTRACT

Hip dysplasia is a three-dimensional pathomechanical condition that is often more complex than the standard method of measuring lateral center edge angle (CEA) can quantify. Yet there is a paucity of literature examining the differences in version seen between dysplastic and non-dysplastic femoroacetabular impingement (FAI) hips, the relationship of acetabular and femoral version (FV) within dysplastic hips and the contribution of each of these factors to symptoms and outcomes of dysplasia treatment. We sought to describe the acetabular version (AcetV) and FV in dysplastic hips and quantify how these measurements compared with non-dysplastic FAI hips. We also sought to analyze the association of these factors with patient-reported outcomes (PROs) after periacetabular osteotomy (PAO) and determine the need for subsequent femoral derotational osteotomy after PAO. A total of 113 dysplastic patients who underwent PAO (92% female, mean age 24) were compared with 1332 (45% female, mean age 25) non-dysplastic FAI (CEA $> 25^\circ$) patients. We found that dysplastic hips had a statistically higher AcetV and FV than non-dysplastic FAI hips. There was a very weak correlation between AcetV and FV in dysplastic hips, suggesting that patients with higher AcetV did not necessarily have higher FV. There was no association with AcetV or FV and patient outcomes in our very limited analysis of PROs after PAO, and only 5% of patients with excessive FV ($>20^\circ$) required subsequent femoral derotational osteotomy, suggesting that in a majority of patients with hip dysplasia, FV may not impact the post-operative clinical course.

INTRODUCTION

Hip dysplasia is a complex, three-dimensional (3D) pathomechanical condition that can result in hip pain and eventual osteoarthritis. While the classic diagnosis of hip dysplasia is based on an anterior-posterior pelvis radiograph by measuring the lateral center edge angle (CEA), we now appreciate that undercoverage of the acetabulum may not only be lateral but also anterior and/or posterior, or any combination of these [1–4]. Despite the fact that most PAO surgeons cite radiographic findings the highest importance in indicating patients for PAO surgery [5], there is a paucity of literature examining the differences in acetabular version (AcetV) and femoral version (FV) in the dysplastic hip compared with the non-dysplastic hip, and the contribution of FV to symptoms and outcomes of dysplasia treatment. As such, we do not have a clear understanding of all the nuances of how a dysplastic hip differs from a non-dysplastic hip, and how FV abnormalities contribute to the post-operative course after periacetabular osteotomy (PAO). The increasing utilization of 3D computed tomography (CT) has allowed us to visualize and measure the AcetV and FV in the dysplastic hip to identify the exact orientation and individual anatomy of the hip joint [6]. A better understanding of how dysplastic hips differ from non-dysplastic hips in both AcetV and FV, and whether FV contributes to the post-surgical recovery can help us approach diagnosis and the ideal correction of symptomatic acetabular dysplasia, as well as indicate whether or not we should be addressing FV abnormalities at the same time as acetabular reorientation.

The characterization of dysplastic hips has previously included analysis of pelvis and acetabular-sided anatomy [2, 3, 7–10], as well as observations of femoral morphology in this patient population [11, 12]. McKibbin first described the combined AcetV and FV in dysplasia of the newborn in 1970 [13]. Murphy *et al.* [3] further described the global acetabular undercoverage seen in dysplasia along with a wide variability in dysplastic hips, emphasizing the importance of critically analyzing each patient's anatomy in order to perform the appropriate correction. However, the specific description of AcetV and the relationship between AcetV and FV in the adult dysplastic hip is not fully understood. Additionally, little is published on the comparison of version (both AcetV and FV) in dysplastic and non-dysplastic hips, so we lack a complete understanding of how dysplastic hips differ from non-dysplastic hips outside of having less acetabular coverage. A high incidence of FV abnormalities has been described in hip preservation patients, but there does not appear to be a relationship between FV and severity of radiographic hip dysplasia or presenting symptoms [14, 15]. Additionally, the effect of FV on the patient-reported outcomes (PROs) after PAO surgery for acetabular dysplasia has, to our knowledge, not yet been investigated, nor has the incidence of subsequent femoral derotational osteotomies after primary PAOs. By investigating these unknowns, we may be able to answer the question of whether FV needs to be addressed at the time of PAO.

We sought to (i) compare AcetV and FV between non-dysplastic FAI hips (preoperative CT coronal CEA $> 25^\circ$) and hips that underwent a primary PAO for acetabular dysplasia, (ii) quantify the relationship between preoperative AcetV and FV in dysplastic hips and (iii) estimate the association of AcetV and FV with PROs at least 12 months post-operatively in patients who underwent a primary, unilateral PAO for acetabular dysplasia and quantify the incidence of subsequent femoral derotational osteotomy after PAO.

MATERIALS AND METHODS

We retrospectively identified all patients in our institutional review board approved prospectively collected hip preservation registry who underwent PAO for acetabular dysplasia at our institution from 1 March 2010 to 1 June 2016 with a minimum 1-year follow-up. We additionally analyzed a non-dysplastic comparison group (CEA $> 25^\circ$) of femoroacetabular impingement (FAI) hips, as these were the only non-dysplastic patients for whom data had been collected as part of our hip preservation registry. Based on preoperative 3D CT scans of the operative hip (Fig. 1) with standardized measurements performed by the radiology department (Fig. 2) as is standard of care for all hip preservation patients, we evaluated AcetV and FV, and we calculated the association between AcetV and FV, and between preoperative AcetV, FV, age, sex and preoperative and minimum 1-year post-operative modified Harris Hip Score (mHHS), Hip Outcome Score-Activities of Daily Living (HOS-ADL), Hip Outcome Score-Sport Specific (HOS-SS) and International Hip Outcome Tool 33 (iHOT-33) scores.

Power analysis was performed assuming a conservative within-group version standard deviation of 11° [16]. Power analysis revealed 75 PAO dysplastic hips and 1500 non-dysplastic FAI hips would provide 80% power at a two-sided alpha of 0.0125 (0.05/4 tests) to detect a minimum 4.6° difference in mean version between groups.

Our inclusion criteria were as follows: patients age $<$40 years with Tönnis grade 0 or 1, who underwent primary PAO, hip arthroscopy plus PAO or hip arthroscopy with coronal CEA $> 25^\circ$ between 1 March 2010 and 1 June 2016. Patients underwent hip arthroscopy with labral repair in addition to the PAO if a symptomatic labral tear was identified during the workup. If a cam lesion was identified on pre-operative CT scan, an open cam resection was performed after completion of the PAO. Exclusion criteria was as follows: missing preoperative CT data or 'revision PAOs' (PAO after a prior hip procedure or arthroscopy which may have altered acetabular or femoral bony morphology).

We analyzed patient demographics (age, sex), preoperative CT measurements via standardized method (AcetV at 1, 2 and 3 o'clock and FV) (Fig. 2) and PROs (mHHS, HOS-ADL, HOS-SS and iHOT-33). AcetV was measured in the axial plane as the angle between an orthogonal line to the posterior pelvic margin and a line drawn from this line to the superior acetabular margin; FV was measured in the axial plane as the angle been the femoral neck axis and a line across the posterior femoral condyles [17] (Fig. 2).

To compare AcetV and FV between dysplastic hips that underwent a primary PAO versus non-dysplastic FAI hips in our registry, analysis included multivariable linear regression based on a generalized estimating equations approach [covariates: age, sex, mean AcetV (for FV comparison), FV (for AcetV comparisons)]. Regression adjustment analysis accounted for sex imbalance between the dysplastic and non-dysplastic groups.

To estimate the association of AcetV and FV with PROs, we utilized multivariable linear regression [covariates: AcetV, FV, age, sex, preoperative PRO score]. We

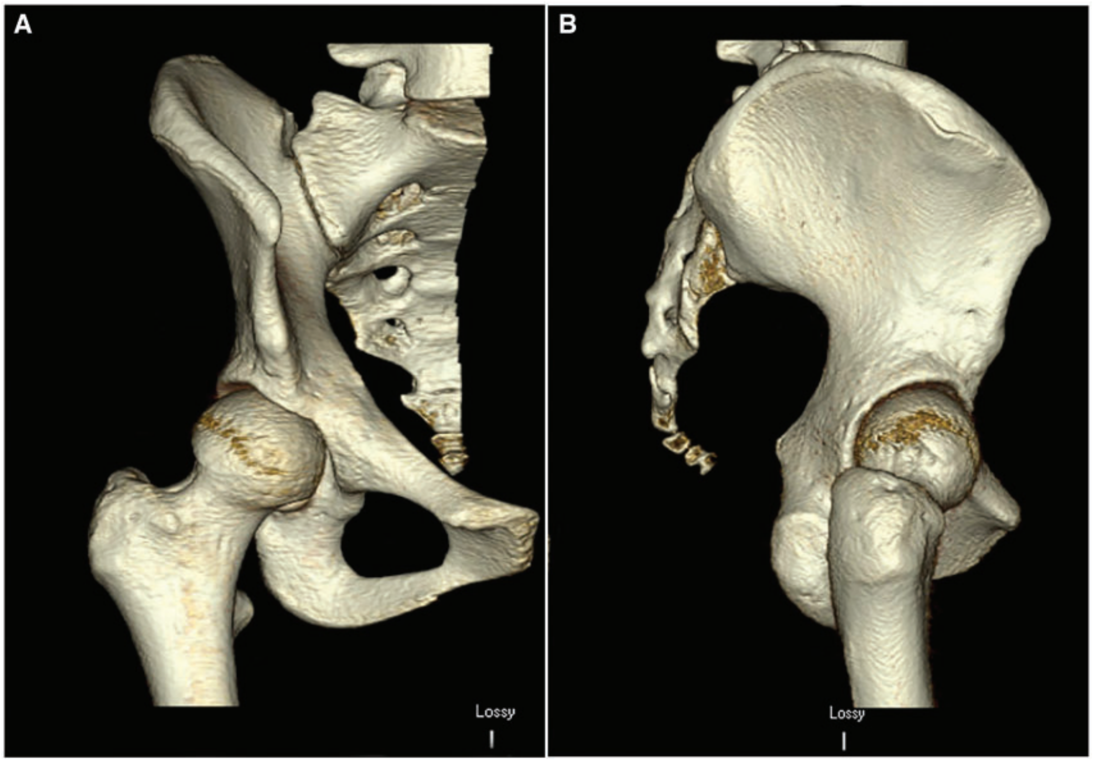

Fig. 1. (**A**) Coronal 3D CT scan and (**B**) Sagittal 3D CT images of a 28-year-old female patient with right hip dysplasia—showing combined anteversion of the acetabulum and femur, resulting in an area of anterior undercoverage.

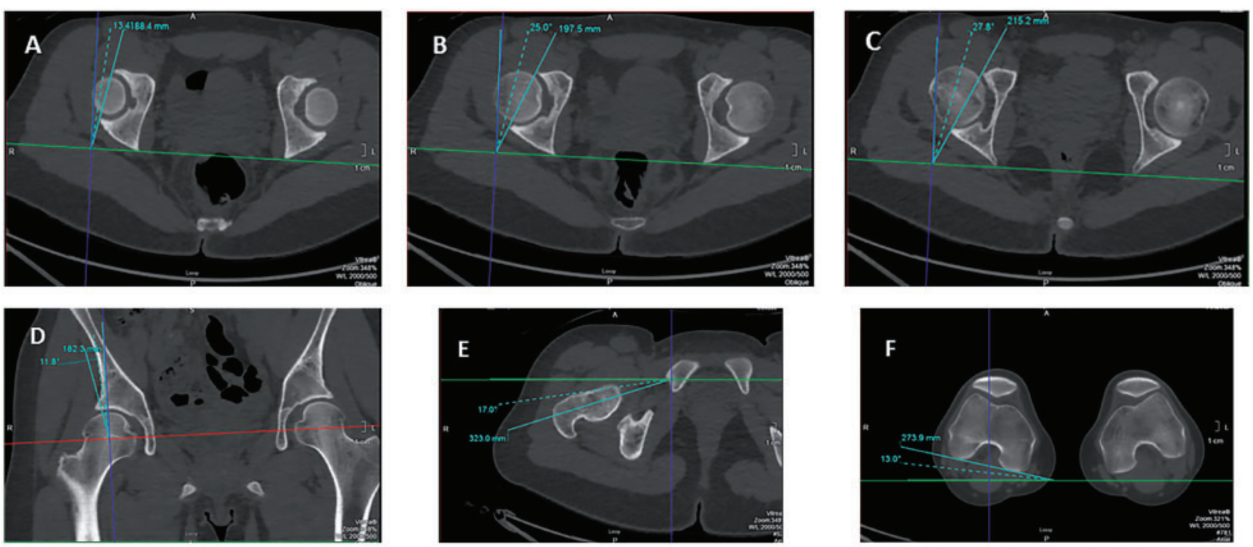

Fig. 2. Individual CT cuts of a 28-year-old woman demonstrating how measurements are obtained. Axial cut of right hip measuring acetabular version at the (**A**) 1 o'clock position, (**B**) 2 o'clock position, (**C**) 3 o'clock position. (**D**) Coronal cut of right hip measuring CEA, (**E**) axial cut of femoral neck and (**F**) distal femur—by combining the measurements from E and F, femoral version is determined.

additionally analyzed patients who had proximal femoral derotational osteotomies to change FV after the PAO to determine factors associated with need for subsequent femoral derotational osteotomies.

RESULTS

We identified 159 patients who underwent at least one primary PAO for hip dysplasia. Preoperative CT scans were available on 113 patients (130 hips), and of these, 75 had primary, unilateral PAOs with PROs available. We identified a group of 2222 matched non-dysplastic FAI patients from the registry with CT measured CEA > 25° (Fig. 2). All patients in the group with CEA >25° were those who underwent surgery (hip arthroscopy) for FAI, as the CT is only obtained in surgical patients as part of surgical planning. Of these, 1332 patients had preoperative CT scans available.

Ninety-two percent of dysplastic PAO patients were female, with mean age 24 years. In the matched cohort, 45% of patients were female with mean age 25 years (Table I).

AcetV at the 1, 2 and 3 o'clock positions on CT scan were compared between our dysplastic and matched non-dysplastic FAI cohort (95% confidence interval [CI]). At the 1 o'clock position, the dysplastic group had a mean AcetV of 8° (±9) and the non-dysplastic FAI group 1° (±9) ($P < 0.001$). At the 2 o'clock position, the mean version in the dysplastic group was 15° (±9), and in the non-dysplastic FAI group 10° (±9) ($P < 0.001$). At the 3 o'clock position, mean version in the dysplastic group was 21° (±7), and in the non-dysplastic FAI group 16° (±7) ($P < 0.001$). FV in the dysplastic group was 21° (±14) and in the non-dysplastic FAI group 14° (±11) ($P < 0.001$). The FV was relatively or frankly retroverted (FV < 5°) in 10% of the dysplastic patients and in 16.3% of the non-dysplastic FAI patients. FV was between 5° and 20° in 43.1% of the PAO patients and 58.9% of the non-dysplastic FAI patients. Excessive femoral anteversion (FV > 20°) was seen in 46.9% of the dysplastic hips but only 24.9% of the non-dysplastic FAI hips (Table II).

We calculated a very weak correlation between FV and AcetV at 1, 2 and 3 o'clock. There was, however, a very strong or strong correlation of AcetV at the 1, 2 and 3 o'clock positions (Table III). Correlation coefficients range from −1 to 1, where −1 indicates a perfect negative correlation and 1 indicates a perfect positive correlation. Correlation strength can be interpreted as follows: 0.00 to (−)0.19 = very weak, (−)0.20 to (−)0.39 = weak, (−)0.40 to (−)0.59 = moderate, (−)0.60 to (−)0.79 = strong, (−)0.80 to (−)1.0 = very strong [18].

We also found that there was no correlation between mHHS, HOS-ADL, HOS-SS or iHOT-33 scores and preoperative AcetV, FV, age or sex for the small percentage of patients with greater than 1-year PROs (48/75 patients, or 64%) (Table IV).

We noted a 3.5% overall complication rate and six patients who had subsequent surgeries. In the PAO group, three patients had femoral derotational osteotomy performed after the PAO for continued hip pain which was thought to be due to excessive FV abnormalities. All three patients subsequently had relief of their pre-derotational osteotomy hip pain. They had femoral anteversion of 34°, 36° and 49°. This represented 3/61 or 5% of patients with a FV >20° (Table V).

Table I. Patient demographics

	PAO hips (n = 113 patients)	*Non-dysplastic FAI hips (n = 1332 patients)*
Age (years), mean ± SD	24 ± 8	25 ± 7
Female, n (%)	104 (92.0)	599 (45.0)

DISCUSSION

Hip instability can be very challenging to diagnose, and using radiographic CEA alone may not adequately define acetabular coverage. Utilization of preoperative 3D CT has given us the ability to comprehensively analyze both acetabular and femoral-sided anatomy of hip dysplasia [6], which has resulted in a better understanding of each patient's anatomy for diagnostic purposes and for pre-surgical planning of acetabular reorientation. Prior literature has not clearly elucidated the differences in AcetV and FV seen in dysplastic hips when compared with non-dysplastic hips, and the relationship between AcetV and FV within a dysplastic hip has not been defined. Another unknown at the beginning of this study was the association between version and PROs after PAO as well as the incidence of subsequent femoral derotational osteotomy. We found that AcetV and FV were significantly higher (increased anteversion) in dysplastic patients than in our non-dysplastic FAI comparison group. Additionally, while there were strong correlations among AcetV measurements within the dysplastic hips, suggesting that if acetabular anteversion existed in one area of the acetabulum it most likely continued in other areas of the acetabulum, there is a very weak correlation between AcetV and FV in hip dysplasia, meaning that if anteversion existed in either the acetabulum or the femur, it did not necessarily exist in the other. We found no association between AcetV and FV and a very limited evaluation of PROs at 11–23 months,

Table II. Results aim 1: acetabular and femoral version in dysplasia versus controls (non-dysplastic FAI)

	PAO hips (n = 130 hips)	*'Control' hips (non-dysplastic FAI) (n = 1585 hips)*	*Adjusted difference in means (95% CI)*	P-*value*
Acetabular version at 1 o'clock (°), mean ± SD	8 ± 9	1 ± 9	6 (4, 8)	<0.001
Acetabular version at 2 o'clock (°), mean ± SD	15 ± 9	10 ± 9	4 (2, 5)	<0.001
Acetabular version at 3 o'clock (°), mean ± SD	21 ± 7	16 ± 7	3 (2, 5)	<0.001
Femoral version (°), mean ± SD	21 ± 14	14 ± 11	7 (4, 9)	<0.001
Femoral version category, n (%)				
<5°	13 (10.0%)	258 (16.3%)	—	—
≥5° and ≤20°	56 (43.1%)	933 (58.9%)	—	—
>20°	61 (46.9%)	395 (24.9%)	—	—

Table III. Results aim 2: correlations among acetabular and femoral version in dysplastic hips undergoing PAO (113 patients, 130 hips)

	PAO hips (number)	*Pearson correlation coefficient (95% CI)*
Acetabular version at 1 o'clock versus 2 o'clock	130	0.83 (0.76 to 0.88)
Acetabular version at 1 o'clock versus 3 o'clock	130	0.60 (0.48 to 0.70)
Acetabular version at 2 o'clock versus 3 o'clock	130	0.79 (0.72 to 0.85)
Femoral version versus acetabular version at 1 o'clock	130	−0.06 (−0.23 to 0.11)
Femoral version versus acetabular version at 2 o'clock	130	0 (−0.17 to 0.18)
Femoral version versus acetabular version at 3 o'clock	130	0.03 (−0.14 to 0.2)

Table IV. Results aim 3: association between version and PRO scores on unilateral PAO hips at 11–23 months

	mHHS (n = *47)*		*HOS-ADL* (n = *47)*		*HOS-SS* (n = *46)*		*iHOT-33 (n = 45)*	
Parameter	*(95% CI)*	P-*value*	b *(95% CI)*	P-*value*	b *(95% CI)*	P-*value*	b *(95% CI)*	P-*value*
Pre-op femoral version (°)	0.2 (−0.2 to 0.6)	0.316	0.1 (−0.2 to 0.4)	0.596	0.4 (−0.1 to 1)	0.094	0 (−0.5 to 0.6)	0.903
Pre-op mean acetabular version (°)	0.2 (−0.4 to 0.7)	0.508	−0.1 (−0.6 to 0.4)	0.622	−0.2 (−1 to 0.6)	0.628	−0.3 (−1.2 to 0.6)	0.568

Of our cohort of 113 patients, 130 hips, with primary, unilateral PAO, only 75 patients had patient reported outcomes available. Of those 75, only 48 patients (64%) had PRO follow-up >1 year.

although there were 3 out of 61 (5%) hips with >20° of femoral anteversion who subsequently went on to have a femoral derotational osteotomy to correct excessive FV. These patients were indicated for subsequent derotational osteotomy due to continued pain which was attributed to excessive femoral anteversion.

Table V. Complications and reoperations

	Primary PAO ($n = 113$ *patients*)
Complication, *n* (%)	4 (3.5%)
Loss of ASIS fixation	1 (0.9%)
Heterotopic ossification	3 (2.7%)
Reoperation, *n* (%)	6 (5%)

Limitations of the current investigation include a relatively small sample size of dysplastic hips which met our strict inclusion and exclusion criteria ($n = 113$ for CT data, $n = 75$ for PRO data, with only $n = 48$ for >1-year PRO data follow-up). The greatest limitation we encountered was our limited PRO follow-up. Only 75 patients had PRO data available and only 48 had >1-year follow-up (64%). We have implemented strategies to obtain better PRO follow-up, including hiring a dedicated research assistant, and we anticipate better PRO follow-up for future investigations. We were able to obtain a large comparison group of patients from our hip registry who were non-dysplastic FAI hips (CT measured CEA > 25°). This non-dysplastic comparison group consisted of patients who underwent hip arthroscopy for labral tears and FAI. We acknowledge that FAI is a different hip pathology than dysplasia; however, as our registry only contains surgical patients, these were the closest group to controls from which we could obtain a matching cohort of non-dysplastic (CEA > 25°) patients. Another limitation is the difference in sex distribution between the two groups (PAO patients were 92% female, while only 45% of the non-dysplastic group was female). The high percentage of females in the PAO group may introduce confounding version measurements, as females have been described to have more AcetV and FV than males [19, 20]. However, females more often have hip dysplasia than males [21], so it is difficult to separate this strong association of sex with the diagnosis of hip dysplasia. To address this limitation, we utilized regression adjustment analysis to account for this imbalance in sexes between the two groups. We also acknowledge that there can be a difference between radiographic CEA and CEA as measured on CT. CT CEA measurements have been shown to measure on average 2.1° higher than corresponding radiographic CEA measurements [22]. We chose to use CT CEA measurements for standardization, as the CT was the source of the other measurements we utilized, including AcetV and FV, and CT CEA measurements have been shown to consistently correspond to the bone-edge CEA on radiographs. [23] Chadayammuri *et al.* [22] found that the greatest differences in CT CEA compared with radiographic CEA measurements were in dysplastic patients, where CT measured the CEA as approximately 5° higher than the radiographic measurement. We did not use a CT CEA cutoff for our dysplastic cohort, but did use the CT CEA cutoff of >25° for our non-dysplastic FAI cohort. Fortunately, in FAI hips, the difference between plain radiograph and CT CEA measurements does not vary significantly as it does in dysplastic hips, so the use of CT CEA in the non-dysplastic FAI cohort should have reflected the radiographic CEA in this group [22]. Another limitation was the retrospective nature of our study. While the data in our hip registry were collected prospectively, our retrospective analysis could introduce selection bias. We minimized this by means of rigorous inclusion and exclusion criteria.

Our first objective was to compare AcetV and FV between patients with dysplasia (and undergoing PAO) versus those without dysplasia. We found that AcetV and FV were greater, on average, in dysplastic patients undergoing primary PAO than in non-dysplastic FAI patients. Nearly half of the hips in the dysplasia group had increased FV (>20°) compared with 25% in the non-dysplastic FAI group (Table II). These findings are similar to prior investigations of acetabular-sided anatomy [2, 3, 7, 8, 10] as well as femoral anatomy in dysplastic hips [11, 12, 16, 24]. Greater combined anteversion has been shown to correlate with an earlier onset of pain in dysplastic patients [25], and when compared with non-dysplastic patients, can perhaps explain debilitating symptoms of dysplasia even in the setting of relatively mild dysplasia based on plain radiographic CEA measurements. Decreased FV has been implicated as a potential source of FAI regardless of cam- or pincer-type impingement, so using a non-dysplastic FAI group to compare with our dysplastic group may represent more femoral retroversion than a non-FAI control group [26]. Unfortunately, we did not have 3D CT data available on non-FAI, asymptomatic controls. Acetabular anteversion, identifiable on CT scan but not plain radiographs, can manifest as deficient focal anterior hip coverage, especially in the setting of combined increased AcetV and FV. This emphasizes the importance of considering AcetV and FV in borderline dysplastic hips (CEA 18°–25°) when determining appropriate surgical management. In the authors' practice, we find the ability to measure acetabular anteversion with our low-dose 3D CT protocol to be very helpful in identifying focal anterior acetabular undercoverage/excessive anteversion.

Our second objective was to estimate the correlation between preoperative AcetV and FV in dysplastic hips to answer the question of whether version was paralleled on both the acetabular and femoral side of the ipsilateral dysplastic hip. There were strong correlations among AcetV measurements (at the 1, 2 and 3 o'clock positions) in dysplastic hips, but no significant correlation between AcetV and FV. This contradicted the findings of Akiyama *et al.* [16] in which they found that there was a correlation between AcetV and FV in a small group of Asian women with hip dysplasia. They did not find this correlation in normal hips, while Buller *et al.* [20] did find a proportionate correlation between AcetV and FV in normal hips. A separate recent study found that FV did not correlate with severity of hip dysplasia [15]. Based on our findings, it does not appear that in the dysplastic hip version abnormalities of the acetabulum are related to version abnormalities in the femur; the AcetV and FV appear to be independent of one another.

Finally, we wanted to estimate the association of AcetV and FV with PRO measures post-operatively after primary, unilateral PAO, and to determine the incidence of femoral derotational osteotomy after PAO. We hoped to answer the question of whether specific FVs corresponded with varying degrees of improvement after PAO and whether subsequent surgery to address FV was needed (as PAO corrected AcetV abnormalities but did not address FV abnormalities). It has been reported that 52% of all hip preservation patients have FV malrotation and 17% have severe FV abnormalities (significantly anteverted or retroverted) [14]. In the authors' own experience, we are often faced with the decision of whether to perform acetabular-sided surgery alone (PAO) or in conjunction with femoral derotational osteotomy to address FV abnormalities. There are no guidelines in the literature of when to perform a concurrent femoral osteotomy based on outcomes of PAO surgery alone. The association of FV in hip arthroscopy has been investigated, with some studies demonstrating no association [27], and others identifying a FV $< 5^\circ$ associated with a lower magnitude of improvement in post hip-arthroscopy PROs [28]. AcetV does not appear to make a difference in PROs after hip arthroscopy [28]. Unfortunately, in our current study, only 75 of our 113 patients had PRO data available, and only 48 had >1-year follow-up. While based on this 64% follow-up at 1 year, it seems there was no association of pre-operative FV and PROs, we acknowledge the flaws in making this assumption due to lack of patient follow up. However, we found that only 5% of our patients with a FV $> 20^\circ$ at clinical follow-up required a subsequent femoral derotational osteotomy. Based on this small incidence of subsequent femoral derotational osteotomy, we believe that in the majority of patients, addressing the acetabular-sided deformity alone is the only surgical intervention required. There are rare cases (5% of those with excessive anteversion in this cohort) where femoral derotational osteotomy may be indicated, such as patients with extreme femoral anteversion ($>35^\circ$). In our experience, these patients demonstrate symptoms of extreme femoral anteversion with functional limitations that include poor external rotation of the leg or severe leg and knee discomfort from a compensatory internal rotation gait.

In summary, our current investigation confirmed a statistically higher AcetV and FV in dysplastic hips than non-dysplastic FAI hips. However, while AcetV measurements at the 1, 2 and 3 o'clock positions correlated strongly with one another, there was no strong correlation between AcetV and FV in dysplastic hips. Only three patients subsequently went on to have a femoral derotational osteotomy, and all of these patients had excessive anteversion ($\geq 34^\circ$), suggesting that in the vast majority of cases, FV may not need to be addressed at the time of PAO surgery. The authors acknowledge that there is certainly a role for addressing FV abnormalities, but based on author experience and these current findings, there may be a role for staging FV correction, as most patients do not require additional surgery for FV abnormalities which are not addressed the time of PAO. Further study in this area is indicated to clarify these findings.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, A.M.S., upon reasonable request.

FUNDING

No sources of funding were utilized in this investigation.

CONFLICT OF INTEREST STATEMENT

A.M.S. is a paid consultant for Stryker. E.L.S. is an AAOS committee member. K.G.F. is a paid consultant for Horizon, Ironwood and Takeda. J.T.N. and A.C.W. have no disclosures.

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