A Multicenter Study of Radiographic Measures Predicting Failure of Arthroscopy in Borderline Hip Dysplasia

Beware of the Tönnis Angle

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Background: Hip arthroscopy has been previously demonstrated to be an effective treatment for adult mild hip dysplasia. There are many radiographic parameters used to classify hip dysplasia, but to date few studies have demonstrated which parameters are of most importance for predicting surgical outcomes.

Purpose: To identify preoperative radiographic parameters that are associated with poor outcomes in the arthroscopic treatment of adult mild hip dysplasia.

Study Design: Case-control study; Level of evidence, 3.

Methods: Radiographic analysis was performed in patients with mild hip dysplasia who underwent arthroscopic surgery between 2009 and 2015. Preoperative radiographic measurements included lateral center edge angle, Tönnis angle, neck shaft angle, anterior center edge angle, alpha angle, femoral head extrusion index, and acetabular depth-to-width ratio. Failure was defined as failure to achieve the minimal clinically important difference (MCID) utilizing the modified Harris Hip Score or as the need for secondary operation. The equal variance *t* test was used to analyze radiographic parameters. Statistical significance was determined using a *P* value of .05.

Results: A total of 373 hips underwent analysis with an average follow-up of 41 months (range, 24-102 months). Of these, 46 hips (12%) required secondary operation, and 95 (25%) failed to meet the MCID. The overall failure rate was 32.4%. There was no single measurement or combination thereof associated with failure to reach the MCID. Higher preoperative Tönnis angles were associated with secondary operation, with a mean of 6.7° (95% CI, 5.3°-8.1°) in the secondary operation group versus 4.8° (95% CI, 4.4°-5.3°) in the nonsecondary operation group (P = .006). The odds ratio was 1.12 (95% CI, 1.0-1.2; P = .05) per degree increase in Tönnis angle for secondary operation. In patients with a Tönnis angle >10°, 84% required secondary operation.

Conclusion: Higher Tönnis angles portend a higher risk for revision surgery. The probability of secondary operation was increased by a magnitude of 1.12 with each degree increase in the Tönnis angle. In patients with a Tönnis angle >10°, 84% required a secondary operation.

Keywords: hip arthroscopy; hip dysplasia; lateral center edge angle; Tönnis angle

Hip dysplasia can be defined as a bony anatomic abnormality of the acetabulum that contributes to undercoverage of the femoral head.[23,49] This undercoverage ultimately leads to a decreased contact surface area through which forces on the hip can be distributed.[23,31,35,49] The increased forces through the hip lead to excessive wear of articular cartilage, tearing of the acetabular labrum, and elongation with possible tearing of the ligamentum teres.[11,14,40,55] The summation of these bony and soft tissue pathologic abnormalities may lead to pain and rapid degenerative joint changes and ultimately arthritis.

In cases of moderate to severe hip dysplasia, traditional treatment involves either reorienting the acetabulum to provide adequate femoral head coverage with appropriate periacetabular osteotomy (PAO) or reconstruction of the hip through total hip arthroplasty (THA).[48,49] Indications of exactly when and how to intervene in mild hip dysplasia are not as straightforward as with moderate to severe dysplasia. Although PAOs have a high success rate,[1,2,19] they are associated with significant morbidity and complication rates that may reach as high as 40%.[4,45] In mildly dysplastic hips, the risks of PAO often outweigh the benefits. With

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regard to THA, many patients with dysplastic hips are young (<40 years of age) and active and radiographically do not show signs of hip arthritis, thus rendering them poor candidates for THA. The question remains of what to do with the symptomatic, mildly dysplastic hip.

The recent advent of hip arthroscopy has afforded the opportunity to treat a wide range of hip pathologies that were once believed to require open surgery. Despite its successes with other pathological conditions,[6,27,28,39] the role of arthroscopy in the management of hip dysplasia remains controversial. Some studies have demonstrated that arthroscopy exacerbates mild dysplasia and speeds progression of joint degeneration, potentially leading to worse outcomes, although these studies are widely technique based.[23,55] When incorporating labral and capsular repair as part of the surgical technique, there have been significant increases in patient-reported outcome measures (PROMs) at 2 and 5 years, and incorporating this technique may have possibly delayed more invasive procedures, such as THA.[14,23,28,49]

Hip dysplasia is a multifaceted pathology that lies on a wide spectrum of severity. The 3-dimensional (3D) nature of this pathology makes it exceedingly difficult to classify with 2-dimensional (2D) radiographs. Several radiographic measurements have been developed to help aid in classifying the severity of this complex 3D deformity. To date, there have been more than 10 different parameters used to measure and classify hip dysplasia. They include Heyman and Herndon's[22] acetabular depth-to-width ratio (ADWR), femoral head extrusion index,[41] Eijer head-neck offset,[38] neck shaft angle, anterior center edge angle (ACEA) of Lequesne and de Seze,[29] lateral center edge angle (LCEA) of Wiberg,[56] Tönnis angle,[54] acetabular inclination angle,[42] disruption of the Shenton line,[47] and several others.[47] Although the degree of hip dysplasia is most commonly defined using the LCEA of Wiberg, this single unidimensional radiographic measurement is likely inadequate to effectively classify this complex 3D deformity.[6,23,32] As with every procedure, favorable outcomes occur when choosing proper surgical candidates. Given the plethora of radiographic parameters available to classify hip dysplasia, it is difficult to discern which parameters, or combination of parameters, are of the most importance for predicting surgical outcomes. To date, there have been few studies that have attempted to answer this question.[20,28] The purpose of this study was to identify preoperative radiographic parameters that are associated with poor outcomes in the arthroscopic treatment of adult hip dysplasia. Our null hypothesis was that there would be no statistically significant single or combination of preoperative radiographic measurements associated with poor outcomes.

METHODS

Retrospective radiographic analysis occurred in patients who underwent arthroscopic hip surgery between 2009 and 2015 at 3 centers with high-volume sports medicine–trained hip arthroscopists. Hips with an LCEA between 20° and 25° or a Tönnis angle of >10° were utilized to identify patients who were termed mildly dysplastic within this database. These parameters are regularly recorded, and this is why they were utilized as search criteria. The inclusion criteria for this study were the presence of radiographic features of mild dysplasia (Tönnis angle >10° or LCEA <25°), >2 years of follow-up, age <40 years, clinical signs of intra-articular hip pain, capsular and labral repair accomplished as part of arthroscopic surgery, and previous enrollment in the hip database. Patients were excluded from the study if they had a history of pediatric hip conditions (slipped capital femoral epiphysis, Legg-Calve-Perthes disease), avascular necrosis, concomitant peritrochanteric or deep gluteal space procedures, incomplete preoperative radiographs, previous hip surgery, labral debridements or reconstructions, Tönnis grade >1, any concomitant open procedures, or a break in the Shenton line seen on plain anterior-posterior radiograph of the hip. Although the present study represents a unique analysis, data on some patients in this study may have been reported in other studies. All data collection received institutional review board approval.

Radiographic Workup

Preoperative radiographs were obtained for each hip utilizing a standing anterior-posterior view of the pelvis, false profile view, and 45° Dunn view. The following angles were measured for each radiograph: LCEA,[56] Tönnis angle,[54] neck shaft angle, ACEA,[29] alpha angle,[47] femoral head extrusion index,[41] and ADWR.[22] Radiographic analysis was performed utilizing a picture archiving and communication system. Specific radiographic analyses of these angles were performed by the methodology outlined in Figure 1.

Surgical Technique

Patients were positioned in the modified supine position, and anterolateral, midanterior, and distal lateral accessory

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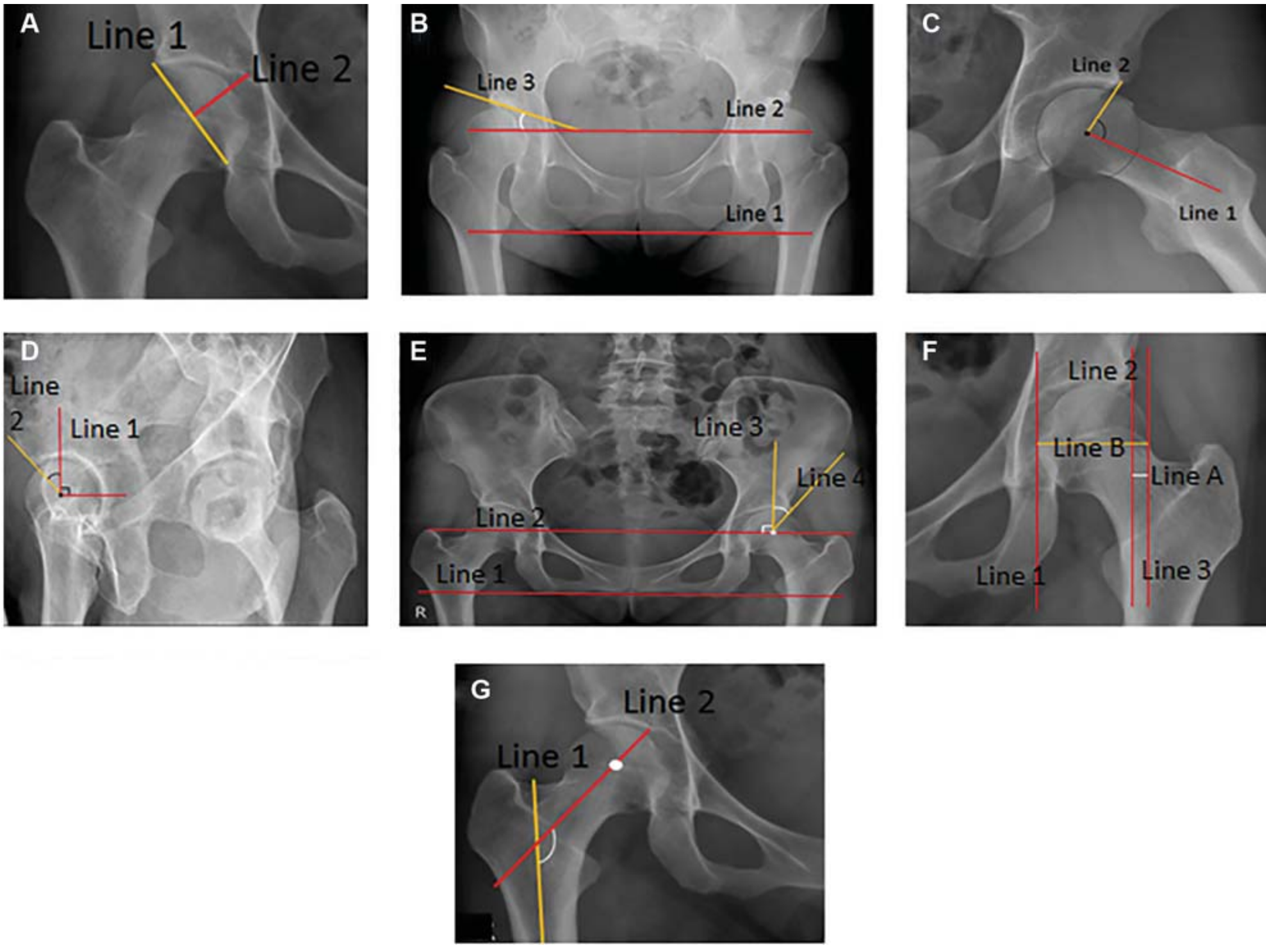

Figure 1. How to perform measurements. (A) Acetabular depth-to-width ratio: a line is drawn connecting the superolateral edge and the inferomedial edge of the acetabulum and measured (line 1). A second line is draw perpendicular to line 1 at the deepest aspect of the acetabulum and measured (line 2). To calculate the depth-to-width ratio, divide the length of line 2 by the length of line 1. Normal, >38%. (B) Tönnis angle: a horizontal reference is established using the ischium to correct for pelvic obliquity (line 1). A second line is drawn, parallel to line 1, that intersects the medial most aspect of the sourcil (line 2). A third line is drawn connecting the lateral-most aspect of the acetabular sourcil to the most medial aspect of the sourcil (line 3). The Tönnis angle is formed between lines 2 and 3. Normal, 0° to 10°. (C) Alpha angle: draw a circle around the femoral head. Place a dot in the center of the circle. From the center dot, draw a line down the midshaft of the femoral neck (line 1). Draw a second line from the center of the femoral head to the point where there is a disruption of the sphericity of the femoral head (line 2). The angle between these 2 lines is the alpha angle. Normal, <50°. (D) Anterior center edge angle: using a false profile view of the hip, place a dot at the center of the femoral head. Draw a vertical line from the center of the femoral head (line 1). Draw a second line from the center of the femoral head through the anterior-most aspect of the acetabulum. The angle between lines 1 and 2 is the anterior center edge angle. Normal, 25° to 50°. (E) Lateral center edge angle: a horizontal reference is established using the ischium to correct for pelvic obliquity (line 1). Place a dot in the center of the femoral head. A second line is made parallel to line 1 that passes through the center of the femoral head (line 2). A third line is drawn vertical from the center of the femoral head 90° to line 2 (line 3). A fourth line is drawn from the center of the femoral head to the lateral-most aspect of the acetabulum (line 4). The angle between lines 3 and 4 is the lateral center edge angle. Normal, 25° to 40°. (F) Femoral head extrusion index: a vertical line is drawn passing through the most medial aspect of the femoral head (line 1). A second line is drawn passing through the most lateral aspect of the acetabulum (line 2). A third line is drawn passing through the lateral-most aspect of the femoral head (line 3). The extrusion index is calculated by measuring the distance between lines 2 and 3 and dividing it by the distance between lines 1 and 3: (Length of A)/(Length of B). Normal, 25%. (G) Neck shaft angle: a line is drawn down the center of the femoral shaft (line 1). A second line is drawn down the center of the femoral neck (line 2). The neck shaft angle is the angle formed between lines 1 and 2. Normal, 125° to 135°.

portals were created. Patient positioning and operative approach have been described in detail previously.[5,21,25,37] Diagnostic arthroscopy was performed to evaluate labral and chondral status, and we corrected cam and pincer lesions when present.[8,9] All patients included in this study underwent labral repair.[10,18,25] Capsular repair was performed on all patients included in this study using previously described techniques.[33]

Outcomes

The modified Harris Hip Score (mHHS) was used to measure patient outcomes. The mHHS has been previously validated as a good clinimetric tool, supporting its use in this study.[34,52,53] Failure of arthroscopic treatment was analyzed 2 separate ways: first, as failure to meet the minimal clinically important difference (MCID) utilizing the mHHS, and second, as the need for further surgery. As statistical significance of PROMs does not always parallel clinical importance,[51] the MCID is a metric that has been shown to be effective in assessing the clinical relevance of improvements in PROM scores.[26] The need for further surgery was based on patients' subjective and objective results, as well as radiographic data utilized and the surgeon's discretion. Generally, surgery was indicated for patients reporting significant pain and disability after 6 to 12 months of physical therapy, nonsteroidal anti-inflammatory drugs, and activity modification.

Rehabilitation Protocol. Patients underwent a standard postoperative rehabilitation and analgesic protocol that was consistent among physicians within the same institution, similar among institutions, and outlined in detail in previous publications.[11,12] Patients used crutches with foot-flat partial weightbearing for 2 weeks, with passive motion started immediately postoperatively. Patients were instructed to avoid extension and external rotation for the first 4 weeks to minimize stress to the capsular repair. As crutches were discontinued, patients progressed through the institutional rehabilitation protocols, with jogging exercises beginning at 3 months, as tolerated, and return to sports and full function allowed at 5 to 6 months.

Statistics

Logistic regression was modeled on the need for further surgery, as well as achievement of MCID. The equal variance *t* test was used to analyze each radiographic parameter. Odds ratios were calculated for each radiographic parameter, and statistical significance was determined using a *P* value of .05. Statistical analysis was performed using SAS software version 9.4 of the SAS System for Unix.

RESULTS

A total of 373 hips from our database were identified as having mild hip dysplasia. All 373 hips underwent radiographic evaluation and were included in the final analysis. Follow-up ranged between 24 and 102 months, with a mean patient follow-up of 41 months. For the characteristics of patients included in the study, refer to Table 1.

TABLE 1
Patient Characteristics[a]

Age, y	
N	373
Mean (SD)	31.4 (12.5)
Range	13.2-40.0
BMI, kg/m^2	
N	373
Mean (SD)	24.8 (4.8)
Range	16.6-48.5
Sex (%)	
Female	300 (80.4)
Male	73 (19.6)
Hip laterality (%)	
Left	170 (45.6)
Right	203 (54.4)

[a]BMI, body mass index.

TABLE 2
Abnormal Measurements and Associated Failure Rates[a]

	Failure to Reach mHHS MCID (%)	Secondary Operation (%)
LCEA <20°	2.1	2.2
Tönnis angle >10°	10.5	21.7
Neck shaft angle >140°	10.5	8.7
ACEA <20°	2.1	2.2
Alpha angle <60°	46.3	41.3
Extrusion index >25%	1.1	0
ADWR <250	5.3	10.9

[a]ACEA, anterior center edge angle; ADWR, acetabular depth-to-width ratio; LCEA, lateral center edge angle; MCID, minimal clinically important difference; mHHS, modified Harris Hip Score.

The mean LCEA and Tönnis angle of the study cohort were 30° (SD, 7.3°) and 5.1° (SD, 4.4°), respectively. Of the 373 total hips treated with hip arthroscopy, 46 hips (12%) required further surgery, and 95 (25%) failed to meet the MCID. There was a total of 121 patients whose treatment failed by either or both definitions of failure, for an overall failure rate of 32.4%. Refer to Table 2 for a more comprehensive list of failure rates in patients with abnormal preoperative radiographic measurements.

Failure to Reach MCID

A total of 95 of 373 hips (25%) failed to reach the MCID using the mHHS. There was no single measurement or combination of preoperative radiographic measurements that were associated with the ability to achieve MCID within our cohort. The mean LCEA in the failure to reach MCID group was 30.1° (SD, 6.4°), compared with the mean

TABLE 3
Tönnis Angle and Probability of Secondary Operation[a]

Tönnis Angle (Deg)	Predicted Probability of Secondary Operation (%)
0	6.3
1	7.2
2	7.8
3	8.6
4	9.5
5	10.5
6	11.6
7	12.8
8	14.0
9	15.4
10	16.9
11	18.5
12	20.2
13	22.0
14	24.0
15	26.1

[a]Logistic regression modeling demonstrates when other measures are constant, with each degree increase in Tönnis angle reflecting an odds ratio of 1.12 for secondary operation probability.

LCEA of 30.1° (SD, 7.6°) in those who did achieve the MCID (*P* = .98). The mean Tönnis angle in the failure to reach MCID group was 4.9° (SD, 4.1°), compared with the Tönnis angle of 5.0° (SD, 4.5°; *P* = .76) in those who did reach MCID. We did not find any preoperative radiographic measurements to be reliable, statistically significant prognosticators of arthroscopic success or any preoperative measurements with significant odds ratios in patients whose hips failed to reach MCID.

Failure by Secondary Operation

A total of 46 of 373 hips (12%) required secondary operation. The most common indication for further surgery was significant hip pain despite maximizing nonoperative therapy. The mean preoperative LCEA was not a statistically significant radiographic indicator of arthroscopic success. Patients who required a secondary operation had a mean LCEA of 28.4° (SD, 7.2°) compared with those who did not, with a mean LCEA of 30.3° (SD, 7.2°; *P* = .10). We did not find any combination of radiographic parameters that increased the likelihood of secondary operation. The only statistically significant indicator of secondary operation in the treatment of hip dysplasia was the preoperative Tönnis angle. Higher preoperative Tönnis angles were associated with secondary operation; the secondary operation group had a mean preoperative Tönnis angle of 6.7° (95% CI, 5.3°-8.1°) versus 4.8° (95% CI, 4.4°-5.3°) in the nonsecondary operation group (*P* = .006). In total, 84% of patients with a Tönnis angle >10° required a secondary operation (Figure 2). Odds ratios were modeled on the presumption of the need for further surgery. The odds ratio was 1.12 (95% CI, 1.0-1.2; *P* = .05) per

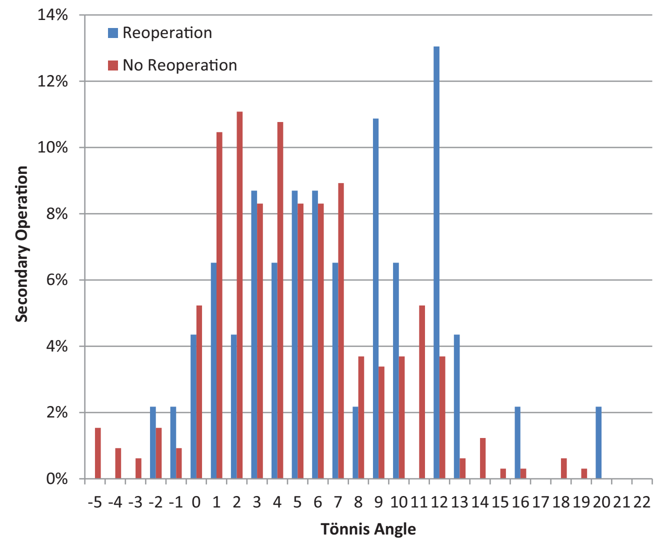

Figure 2. Tönnis angle and secondary operation rate.

degree increase in Tönnis angle for secondary operation (Table 3).

The odds ratios for the remaining preoperative radiographic measurements, including LCEA, neck shaft angle, alpha angle, femoral neck extrusion index, ACEA, and ADWR, failed to reach statistical significance. Smaller ACEAs neared statistical significance (*P* = .06) for secondary operation, with a mean preoperative ACEA in the secondary operation group of 30.2° (95% CI, 28.0°-32.5°) versus the nonsecondary operation group with a mean 32.7° (95% CI, 31.8°-33.5°).

DISCUSSION

Our analysis identified higher Tönnis angles as the single statistically significant radiographic measurement that was associated with the need for additional surgery (*P* = .006). Although not statistically significant, lower preoperative ACEA neared significance as an additional radiographic predictor of the need for further surgery (*P* = .06). Younger individuals with radiographic evidence of mild hip dysplasia represent a significant proportion of the patient population.[20] Despite the notable quantity of patients who have this condition, the guidelines for arthroscopic intervention in the young patient with a mildly dysplastic hip remain controversial. The causes of failure are likely more complex than simple radiographic measurements and likely include several technical and genetic factors and patient characteristics, in addition to other 3D radiographic variables.

Grammatopoulos et al[20] conducted a study to identify radiographic and intraoperative features that could predict the success of hip preservation with arthroscopic surgery. Using a mean follow-up of 4.5 years, they concluded that arthroscopic hip surgery can be associated with an excellent chance of hip preservation with a Tönnis angle <15° and an LCEA >25° in the absence of hip instability. In their study, the alpha angle and the extrusion index failed to reach statistical significance as radiographic indicators of arthroscopic treatment success. Using a Tönnis angle and an LCEA within the aforementioned ranges, they reported a total of 5 of 48 patients (10.4%) with failed arthroscopic management.[20] Additionally, a systematic review conducted by Lodhia et al[32] of 834 hips concluded that arthroscopy in mildly dysplastic hips resulted in improved patient-reported outcomes. Dysplastic hips were characterized solely on the LCEA. In their study, mild dysplasia was defined by an LCEA of between 18° and 25°. In another systematic review that analyzed 13 different studies, Jo et al[23] reported higher patient outcomes in those with mild hip dysplasia. They also defined mild dysplasia solely on LCEA and categorized mild dysplasia as an LCEA between 20° and 25°. It is no surprise that these systematic reviews categorized hip dysplasia based solely on a single measurement, as traditionally this is how hip dysplasia has been categorized.

Hip dysplasia is a complex 3D deformity that is extremely difficult to appropriately categorize by a single radiographic measure. On post hoc analysis of our cohort, an unintended and interesting finding was the extent of variance in radiographic measurement within the hips that were analyzed. For example, our inclusion criteria required either an LCEA <25° or a Tönnis angle >10°. Even though the inclusion criterion of LCEA was <25° or Tönnis angle was >10°, in our final cohort, the mean LCEA was 30° (range, 15°-27°) and the mean Tönnis angle was 5.1° (range, –10° to 20°). This demonstrates that when using only a single measurement to identify hip dysplasia, the observer could be overlooking a significant proportion of hips that would be classified as dysplastic according to other measurements. This was also the conclusion of Pereira et al,[44] who demonstrated that while only using the LCEA, 20% to 39% of hips categorized as normal were actually mildly dysplastic by other measurements (Tönnis angle, depth/width ratio, and acetabular head index). They concluded that measurement of a single anatomic variable (the LCEA) would lead to an incorrect diagnosis of mild hip dysplasia, and they recommended combining the LCEA together with the Tönnis angle for optimal diagnostic accuracy. We too emphasized the importance of the preoperative Tönnis angle in our study. We found higher Tönnis angles were significantly associated with a higher risk for revision surgery. The odds of requiring further surgery in our sample were increased by a magnitude of 1.12 per degree increase in Tönnis angle. With all other radiographic measurements kept constant, logistic regression modeling revealed a 12% increase in baseline probability of secondary operation with each degree increase in Tönnis angle greater than zero (Table 3). Also notable, only 16% of patients with a Tönnis angle >10° did not require a secondary operation (Figure 2). We recommend including the Tönnis angle as a part of the overall evaluation of patients with mild hip dysplasia.

Apart from radiographic measurements, there appear to be several other factors that contribute to a successful outcome in arthroscopy for hip dysplasia. Surgical technique plays a major role in the wide discrepancy of reported outcomes. The results from several studies suggest better outcomes with labral repair as opposed to labral debridement.[11,14,24,28,32] The labrum is likely to be a protective structure against microinstability in addition to helping restore the suction seal of the hip joint.[32] Better outcomes in several studies were also reported with capsular plication.[7,14] Capsular plication, with a focus on shifting the inferior medial capsule proximally and laterally, is theorized to aid in decreasing abnormal translation and microinstability of the hip. Our study included only patients with both capsular and labral repair to attempt to control for these surgical variables. In several different studies, patients with dysplastic hips who underwent capsular and labral repair had greater patient satisfaction, higher Harris Hip Scores, and lower failure rates compared with patients who did not.[13,14,17,28] In 1 study performed by Larson et al,[28] surgical outcomes were compared between mildly dysplastic hips treated arthroscopically with and without labral and capsular repair. Dysplastic hips that underwent capsular and labral repair had a higher percentage of "good/excellent results" at 73% versus the nonlabral/noncapsular repair cohort at 53% (P = .06). The mHHS scores were also higher in hips that underwent labral and capsular repair compared with those that did not (85 vs 77; P = .13). In this same study, failure rates were also statistically significant between the 2 groups (18% vs 40%; P = .03). Domb et al[12] showed that hip arthroscopic surgery with labral preservation and concurrent capsular repair in patients with mild hip dysplasia (LCEA, 18°-25°) have lasting, positive outcomes at a minimum 5-year follow-up with reported sustained improvements in both the visual analog score and mHHS score. In their 5-year follow-up, no patients required conversion to THA. The systematic reviews conducted by Lodhia et al[32] and Jo et al[23] also demonstrated strong evidence for labral and capsular repair during arthroscopy for hip dysplasia.

One study that has commonly been cited to argue against using hip arthroscopy for the treatment of mild hip dysplasia was conducted by Parvizi et al.[43] They followed 36 dysplastic hips with an LCEA <20° that underwent arthroscopic intervention for a mean period of 3.6 years. Twenty-four of the 36 hips (67%) had a decline in functional scores, and 14 of 36 hips (39%) had accelerated arthritis. Over half (55%) of the cohort required further surgical intervention. The poor results of arthroscopy in this study should be viewed as a caution against using labral debridement and capsular release, as 100% of the patients were treated in this fashion.

Apart from labral debridement, additional surgical techniques associated with poor outcomes in the arthroscopic treatment of the dysplastic hip include acetabular rim resection >3 mm, extensive capsulotomy, microfracture, and psoas tenotomy.[36,46,50]

Arguably, just as important as the surgical technique, patient selection has been shown to be a reliable forecaster for successful patient outcomes. Maldonado et al[33] conducted a study to evaluate which patient factors were associated with successful outcomes in the arthroscopic treatment of mild hip dysplasia. The study analyzed age, body mass index, sex, and several preoperative PROMs. It was concluded that age >28.5 years was the only statistically significant factor associated with arthroscopic failure. Worse preoperative visual analog scale, mHHS, and Nonarthritic Hip Score scores closely approached significance as indicators of failure. This analysis is consistent with several other studies that have suggested preoperative functional status may be predictive of postoperative outcomes.[3,16] In addition to age and worse preoperative PROMs, Larson et al[28] found that significant preoperative (grade 4) chondral defects were also associated with poor outcomes. Several others have concluded that significant preoperative femoral head cartilage wear and acetabular cartilage wear negatively affect patient outcomes.[15] Preoperative diagnosis of these chondral defects remains a challenge.

Arthroscopic treatment for mild hip dysplasia is not as predictable as arthroscopic interventions for other pathologies. This study noted a 25% failure to achieve MCID utilizing mHHS, which is markedly increased from the general population with femoroacetabular impingement, which in a separate study did not achieve MCID in only 3% of cases.[30] We also found a 32.4% overall failure rate. These data can be directly used by providers to better inform patients of the likely outcomes associated with the arthroscopic treatment of mild hip dysplasia, which will facilitate shared decision making with families and patients. This clearly suggests that surgery in the population with hip dysplasia is much less predictable and there may be subtle radiographic entities on 2D and 3D imaging that have yet to be appreciated, as well as patient characteristics and ligamentous, psychosocial, and genetic factors at play that are not accounted for with radiographic data.

The limitations of this study include its design as a retrospective analysis of prospectively collected data. In addition, there is no gold standard for failure after hip arthroscopy; consequently, the authors utilized MCID and revision surgery as surrogates for failure. Another limitation of this study was our patient selection process. Patients from our database were flagged as having mild dysplasia based solely on their preoperative Tönnis angle or LCEA, as these 2 measurements are commonly used to classify severity of hip dysplasia. The other measurements were only obtained if the patients were classified as having mild dysplasia according to the Tönnis angle or LCEA. It is likely that utilizing only these 2 variables to identify mildly dysplastic hips within the database could have caused researchers to overlook patients who would have been classified as having dysplasia according to other measurements (width/depth ratio, anterior center edge, etc).

CONCLUSION

Higher Tönnis angles portend a higher risk for revision surgery. The probability of secondary operation was increased by a magnitude of 1.12 with each degree increase in the Tönnis angle. In total, 84% of patients with a Tönnis angle >10° required a secondary operation. The causes of failure were likely more complex than simple radiographic measurements and likely included several technical and genetic factors and patient characteristics, in addition to other 3D radiographic variables.

REFERENCES

1. Armand M, Lepistö J, Tallroth K, Elias J, Chao E. Outcome of periacetabular osteotomy: joint contact pressure calculation using standing AP radiographs, 12 patients followed for average 2 years. *Acta Orthop*. 2005;76(3):303-313.
2. Armiger RS, Armand M, Tallroth K, Lepistö J, Mears SC. Three-dimensional mechanical evaluation of joint contact pressure in 12 periacetabular osteotomy patients with 10-year follow-up. *Acta Orthop*. 2009;80(2):155-161.
3. Bedi A, Galano G, Walsh C, Kelly BT. Capsular management during hip arthroscopy: from femoroacetabular impingement to instability. *Arthroscopy*. 2011;27(12):1720-1731.
4. Biedermann R, Donnan L, Gabriel A, Wachter R, Krismer M, Behensky H. Complications and patient satisfaction after periacetabular pelvic osteotomy. *Int Orthop*. 2008;32(5):611-617.
5. Byrd JW. Hip arthroscopy. The supine position. *Clin Sports Med*. 2001;20(4):703-731.
6. Byrd JWT, Jones KS. Arthroscopic management of femoroacetabular impingement: minimum 2-year follow-up. *Arthroscopy*. 2011;27(10):1379-1388.
7. Chandrasekaran S, Darwish N, Martin TJ, Suarez-Ahedo C, Lodhia P, Domb BG. Arthroscopic capsular plication and labral seal restoration in borderline hip dysplasia: 2-year clinical outcomes in 55 cases. *Arthroscopy*. 2017;33(7):1332-1340.
8. Chow RM, Krych AJ, Levy BA. Arthroscopic acetabular rim resection in the treatment of femoroacetabular impingement. *Arthrosc Tech*. 2013;2(4):e327-e331.
9. Chow RM, Kuzma SA, Krych AJ, Levy BA. Arthroscopic femoral neck osteoplasty in the treatment of femoroacetabular impingement. *Arthrosc Tech*. 2014;3(1):e21-e25.
10. Chow RM, Owens CJ, Krych AJ, Levy BA. Arthroscopic labral repair in the treatment of femoroacetabular impingement. *Arthrosc Tech*. 2013;2(4):e333-e336.
11. Crawford MJ, Dy CJ, Alexander JW, et al. The 2007 Frank Stinchfield Award. The biomechanics of the hip labrum and the stability of the hip. *Clin Orthop Relat Res*. 2007;465:16-22.
12. Domb BG, Chaharbakhshi EO, Perets I, Yuen LC, Walsh JP, Ashberg L. Hip arthroscopic surgery with labral preservation and capsular plication in patients with borderline hip dysplasia: minimum 5-year patient-reported outcomes. *Am J Sports Med*. 2018;46(2):305-313.
13. Domb BG, Philippon MJ, Giordano BD. Arthroscopic capsulotomy, capsular repair, and capsular plication of the hip: relation to atraumatic instability. *Arthroscopy*. 2013;29(1):162-173.
14. Domb BG, Stake CE, Lindner D, El-Bitar Y, Jackson TJ. Arthroscopic capsular plication and labral preservation in borderline hip dysplasia: two-year clinical outcomes of a surgical approach to a challenging problem. *Am J Sports Med*. 2013;41(11):2591-2598.
15. Dwyer MK, Lee J-A, McCarthy JC. Cartilage status at time of arthroscopy predicts failure in patients with hip dysplasia. *J Arthroplasty*. 2015;30(9)(suppl):121-124.
16. Evans PT, Redmond JM, Hammarstedt JE, Liu Y, Chaharbakhshi EO, Domb BG. Arthroscopic treatment of hip pain in adolescent patients with borderline dysplasia of the hip: minimum 2-year follow-up. *Arthroscopy*. 2017;33(8):1530-1536.

17. Frank RM, Lee S, Bush-Joseph CA, Kelly BT, Salata MJ, Nho SJ. Improved outcomes after hip arthroscopic surgery in patients undergoing T-capsulotomy with complete repair versus partial repair for femoroacetabular impingement: a comparative matched-pair analysis. *Am J Sports Med*. 2014;42(11):2634-2642.
18. Fry R, Domb B. Labral base refixation in the hip: rationale and technique for an anatomic approach to labral repair. *Arthroscopy*. 2010;26(9)(suppl):S81-S89.
19. Ganz R, Klaue K, Vinh TS, Mast JW. A new periacetabular osteotomy for the treatment of hip dysplasia. Technique and preliminary results. *Clin Orthop Relat Res*. 1988;232:26-36.
20. Grammatopoulos G, Davies OLI, El-Bakoury A, Gill HS, Pollard TCB, Andrade AJ. A traffic light grading system of hip dysplasia to predict the success of arthroscopic hip surgery. *Am J Sports Med*. 2017;45(12):2891-2900.
21. Hevesi M, Krych AJ, Johnson NR, et al. Multicenter analysis of midterm clinical outcomes of arthroscopic labral repair in the hip: minimum 5-year follow-up. *Am J Sports Med*. 2018;46(2):280-287.
22. Heyman CH, Herndon CH. Legg-Perthes disease; a method for the measurement of the roentgenographic result. *J Bone Joint Surg Am*. 1950;32(4):767-778.
23. Jo S, Lee SH, Wang SI, Smith B, O'Donnell J. The role of arthroscopy in the dysplastic hip—a systematic review of the intra-articular findings, and the outcomes utilizing hip arthroscopic surgery. *J Hip Preserv Surg*. 2016;3(3):171-180.
24. Kain MSH, Novais EN, Vallim C, Millis MB, Kim Y-J. Periacetabular osteotomy after failed hip arthroscopy for labral tears in patients with acetabular dysplasia. *J Bone Joint Surg Am*. 2011;93(suppl 2):57-61.
25. Kelly BT, Weiland DE, Schenker ML, Philippon MJ. Arthroscopic labral repair in the hip: surgical technique and review of the literature. *Arthroscopy*. 2005;21(12):1496-1504.
26. Kemp JL, Collins NJ, Roos EM, Crossley KM. Psychometric properties of patient-reported outcome measures for hip arthroscopic surgery. *Am J Sports Med*. 2013;41(9):2065-2073.
27. Larson CM, Giveans MR. Arthroscopic management of femoroacetabular impingement: early outcomes measures. *Arthroscopy*. 2008;24(5):540-546.
28. Larson CM, Ross JR, Stone RM, et al. Arthroscopic management of dysplastic hip deformities: predictors of success and failures with comparison to an arthroscopic FAI cohort. *Am J Sports Med*. 2016;44(2):447-453.
29. Lequesne M, de SEZE J. [False profile of the pelvis. A new radiographic incidence for the study of the hip. Its use in dysplasias and different coxopathies]. *Rev Rhum Mal Osteoartic*. 1961;28:643-652.
30. Levy DM, Kuhns BD, Chahal J, Philippon MJ, Kelly BT, Nho SJ. Hip arthroscopy outcomes with respect to patient acceptable symptomatic state and minimal clinically important difference. *Arthroscopy*. 2016;32(9):1877-1886.
31. Lloyd-Roberts GC, Harris NH, Chrispin AR. Anteversion of the acetabulum in congenital dislocation of the hip: a preliminary report. *Orthop Clin North Am*. 1978;9(1):89-95.
32. Lodhia P, Chandrasekaran S, Gui C, Darwish N, Suarez-Ahedo C, Domb BG. Open and arthroscopic treatment of adult hip dysplasia: a systematic review. *Arthroscopy*. 2016;32(2):374-383.
33. Maldonado DR, Perets I, Mu BH, et al. Arthroscopic capsular plication in patients with labral tears and borderline dysplasia of the hip: analysis of risk factors for failure. *Am J Sports Med*. 2018;46(14):3446-3453.
34. Martin RL, Philippon MJ. Evidence of validity for the Hip Outcome Score in hip arthroscopy. *Arthroscopy*. 2007;23(8):822-826.
35. Mast JW, Brunner RL, Zebrack J. Recognizing acetabular version in the radiographic presentation of hip dysplasia. *Clin Orthop Relat Res*. 2004;418:48-53.
36. Mei-Dan O, McConkey MO, Brick M. Catastrophic failure of hip arthroscopy due to iatrogenic instability: can partial division of the ligamentum teres and iliofemoral ligament cause subluxation? *Arthroscopy*. 2012;28(3):440-445.
37. Mohan R, Johnson NR, Hevesi M, Gibbs CM, Levy BA, Krych AJ. Return to sport and clinical outcomes after hip arthroscopic labral repair in young amateur athletes: minimum 2-year follow-up. *Arthroscopy*. 2017;33(9):1679-1684.
38. Myers SR, Eijer H, Ganz R. Anterior femoroacetabular impingement after periacetabular osteotomy. *Clin Orthop Relat Res*. 1999;363:93-99.
39. Nho SJ, Magennis EM, Singh CK, Kelly BT. Outcomes after the arthroscopic treatment of femoroacetabular impingement in a mixed group of high-level athletes. *Am J Sports Med*. 2011;39:14S-19S.
40. Nishii T, Sugano N, Tanaka H, Nakanishi K, Ohzono K, Yoshikawa H. Articular cartilage abnormalities in dysplastic hips without joint space narrowing. *Clin Orthop Relat Res*. 2001;383:183-190.
41. Nötzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br*. 2002;84(4):556-560.
42. Novais EN, Duncan S, Nepple J, Pashos G, Schoenecker PL, Clohisy JC. Do radiographic parameters of dysplasia improve to normal ranges after Bernese periacetabular osteotomy? *Clin Orthop Relat Res*. 2017;475(4):1120-1127.
43. Parvizi J, Bican O, Bender B, et al. Arthroscopy for labral tears in patients with developmental dysplasia of the hip: a cautionary note. *J Arthroplasty*. 2009;24(6)(suppl):110-113.
44. Pereira F, Giles A, Wood G, Board TN. Recognition of minor adult hip dysplasia: which anatomical indices are important? *Hip Int*. 2014;24(2):175-179.
45. Peters CL, Erickson JA, Hines JL. Early results of the Bernese periacetabular osteotomy: the learning curve at an academic medical center. *J Bone Joint Surg Am*. 2006;88(9):1920-1926.
46. Ranawat AS, McClincy M, Sekiya JK. Anterior dislocation of the hip after arthroscopy in a patient with capsular laxity of the hip. A case report. *J Bone Joint Surg Am*. 2009;91(1):192-197.
47. Reiman MP, Décary S, Mathew B, Reiman CK. Accuracy of clinical and imaging tests for the diagnosis of hip dysplasia and instability: a systematic review. *J Orthop Sports Phys Ther*. 2019;49(2):87-97.
48. Sanchez-Sotelo J, Berry DJ, Trousdale RT, Cabanela ME. Surgical treatment of developmental dysplasia of the hip in adults: II. Arthroplasty options. *J Am Acad Orthop Surg*. 2002;10(5):334-344.
49. Sanchez-Sotelo J, Trousdale RT, Berry DJ, Cabanela ME. Surgical treatment of developmental dysplasia of the hip in adults: I. Nonarthroplasty options. *J Am Acad Orthop Surg*. 2002;10(5):321-333.
50. Sansone M, Ahldén M, Jónasson P, Swärd L, Eriksson T, Karlsson J. Total dislocation of the hip joint after arthroscopy and ileopsoas tenotomy. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(2):420-423.
51. Tashjian RZ, Deloach J, Green A, Porucznik CA, Powell AP. Minimal clinically important differences in ASES and simple shoulder test scores after nonoperative treatment of rotator cuff disease. *J Bone Joint Surg Am*. 2010;92(2):296-303.
52. Thorborg K, Tijssen M, Habets B, et al. Patient-reported outcome (PRO) questionnaires for young to middle-aged adults with hip and groin disability: a systematic review of the clinimetric evidence. *Br J Sports Med*. 2015;49(12):812.
53. Tijssen M, van Cingel R, van Melick N, de Visser E. Patient-reported outcome questionnaires for hip arthroscopy: a systematic review of the psychometric evidence. *BMC Musculoskelet Disord*. 2011;12:117.
54. Tönnis D. *Congenital Dysplasia and Dislocation of the Hip in Children and Adults*. Berlin: Springer-Verlag; 1987.
55. Wenger DE, Kendell KR, Miner MR, Trousdale RT. Acetabular labral tears rarely occur in the absence of bony abnormalities. *Clin Orthop Relat Res*. 2004;426:145-150.
56. Wiberg G. Studies on dysplastic acetabula and congenital subluxation of the hip joint with special references to the complication of osteoarthritis. *Acta Chir Scand*. 1939;83:58.