The Iliofemoral Line

A Radiographic Sign of Acetabular Dysplasia in the Adult Hip

Matthew J. Kraeutler,* MD, Zachary R. Ashwell,† MD, Tigran Garabekyan,‡ MD, Jesse A. Goodrich,§ BA, K. Linnea Welton,* MD, Jonathan A. Flug,† MD, MBA, John N. O'Hara,‖ FRCS, and Omer Mei-Dan,*¶ MD

Investigation performed at the CU Sports Medicine and Performance Center, University of Colorado School of Medicine, Department of Orthopedics, Boulder, Colorado, USA

Background: Several radiographic parameters utilized for the diagnosis of acetabular dysplasia in adults suffer from poor reproducibility and reliability.

Purpose: To define and validate a novel radiographic parameter (the iliofemoral line [IFL]) for the detection of frank and borderline hip dysplasia and to compare the sensitivity and specificity of this radiographic marker to those of previously validated qualitative parameters.

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

Methods: A consecutive cohort of 222 adult patients (436 hips) undergoing hip preservation surgery was included. The IFL, which extends from the lateral femoral neck through the inner cortical lip of the iliac crest, intersects the femoral head in cases of dysplasia. Percent medialization of the IFL was defined as the horizontal distance of the exposed femoral head lateral to the IFL, relative to the horizontal femoral head width at the center of the femoral head.

Results: Percent medialization of the IFL was strongly correlated to the lateral center edge angle ($P < .0001$). Values of percent medialization ranging from 15% to 22% predicted the presence of borderline hip dysplasia with a sensitivity of 62% and specificity of 89%, while values exceeding 22% predicted the presence of frank acetabular dysplasia with a sensitivity of 77% and specificity of 94%. By comparison, abnormality of the Shenton line demonstrated a sensitivity of 3.7% and specificity of 97% for the detection of borderline dysplasia and a sensitivity of 16% and specificity of 99% for the detection of frank acetabular dysplasia. Compared with the Shenton line, percent medialization of the IFL was significantly more sensitive for the detection of both borderline and frank acetabular dysplasia (both $P < .0001$). The intraobserver and interobserver reproducibility of the horizontal difference outside the IFL were 0.99 and 0.96, respectively.

Conclusion: Percent medialization of the IFL is a reliable and accurate radiographic marker of frank acetabular dysplasia and, to a lesser extent, borderline dysplasia. The use of this radiographic parameter as an additional tool may enable the earlier detection of borderline and frank hip dysplasia in young adults presenting with hip pain.

Keywords: acetabular dysplasia; imaging; lateral center edge angle; Shenton line

Despite newborn screening programs and improvements in early diagnostic imaging, there is an estimated 0.1% prevalence of hip dysplasia that goes undetected until adulthood.[4,23] These patients eventually develop symptoms mainly because the hypertrophied labrum that has been responsible for maintaining mechanical stability in a pathological hip fails because of increased stress across a smaller surface area.[11,14,20,29] Although by definition patients with hip dysplasia have abnormal hip anatomy and biomechanics, symptoms often arise when this abnormal anatomy results in tears of the labrum. This in turn leads to increased joint reactive forces on exposed cartilage, resulting in articular surface damage.[1,10,14,16,24,29] Young adults can become symptomatic either from altered hip mechanics, labral tears, or cartilage damage, and it has been well documented that 20% to 50% of adult patients with hip dysplasia go on to develop early osteoarthritis (OA) by 50 years of

¶Address correspondence to Omer Mei-Dan, MD, Department of Orthopedics, University of Colorado School of Medicine, 12631 East 17th Avenue, Mail Stop B202, Room L15-4505, Aurora, CO 80045, USA (email: omer.meidan@ucdenver.edu).

*Department of Orthopedics, University of Colorado School of Medicine, Aurora, Colorado, USA.

†Department of Radiology, University of Colorado School of Medicine, Aurora, Colorado, USA.

‡Southern California Hip Institute, North Hollywood, California, USA.

§Department of Integrative Physiology, University of Colorado Boulder, Boulder, Colorado, USA.

‖Birmingham Hip Clinic, Birmingham, UK.

One or more of the authors has declared the following potential conflict of interest or source of funding: J.N.O. receives royalties from the Extra Fixation Cup, part of the ADEPT Hip Resurfacing System. O.M.-D. holds stock or stock options in MITA and is a paid consultant for and receives research support from Smith & Nephew.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546517708983

age.[1,8,13,31] All of these patients eventually develop symptomatic OA before the time they reach 60 years of age.[36]

Many patients with hip dysplasia, or inherent hip joint instability, have symptoms for years before the development of OA. The common clinical presentation of mild and borderline hip dysplasia does not differ considerably from that of other young adult hip disorders such as femoroacetabular impingement.[26] Thus, it is important to be able to diagnose and treat these patients appropriately, not only to improve their quality of life but also, importantly, to preserve their articular cartilage, prolonging, if not eliminating, their need for total hip replacement by altering the natural history of this disease.[35] The correct diagnosis begins with a clinical history, physical examination, and preliminary radiographic imaging.[9] Unfortunately, some radiographic parameters of developmental dysplasia in the adult hip are lacking in accuracy and reliability.[7,25] Clohisy et al[7] showed only good to moderate intraobserver reliability and poor interobserver reliability among experienced hip surgeons' interpretations of radiographic markers of dysplasia, including hip center, joint congruency, and acetabular inclination. While the Shenton line has more recently been shown to have both excellent intraobserver and interobserver reliability, it lacks sensitivity in detecting mild forms of dysplasia.[30] This is the most common form of dysplasia encountered by clinicians and also the type of dysplasia that requires the most work-up for a conclusive diagnosis. A study by Nunley et al[27] showed that skeletally mature patients with acetabular dysplasia have an average delay in diagnosis of over 3 years, with more than 3 health care professionals seen before a definitive diagnosis. Because the clinical presentation of acetabular dysplasia in adults is variable, but the consequences of this deformity can be life altering, the development of simple, accurate, and reliable radiographic parameters to aid in a timely diagnosis is paramount.

The purposes of this study were to define and validate a novel radiographic parameter (the iliofemoral line [IFL]) for the detection of frank and borderline hip dysplasia and to compare the sensitivity and specificity of this radiographic marker to the Shenton line, another radiographic marker of hip dysplasia.[30]

METHODS

After institutional review board approval was obtained, the authors performed a single-center prospective study on a cohort of 222 patients (436 hips) undergoing hip preservation surgery and who met inclusion criteria between January 2013 and October 2015. 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 modification, 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, and (4) no previous hip joint surgery. 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 test, the posterior impingement test, the Beighton hypermobility score, and subjective reports of hip instability.[17] Common indications for hip arthroscopic surgery were symptomatic femoroacetabular impingement, hip instability due to dysplasia (before periacetabular osteotomy), and/or excessive femoral torsion (before femoral derotational osteotomy). Patients undergoing surgical treatment for diagnoses of slipped capital femoral epiphysis, Legg-Calvé-Perthes disease, osteochondromatosis, or post-dislocation syndrome were excluded. Demographic variables including age, clinical diagnosis, sex, height, weight, and body mass index were recorded for all patients.

Imaging Protocol and Measurements

After a comprehensive clinical evaluation by the senior author (O.M.-D.), patients underwent a standardized series of anteroposterior (AP) pelvis radiographs, and once scheduled for surgery, all patients went on to undergo magnetic resonance imaging and whole-pelvis computed tomography (CT). Standard AP pelvis radiographs were obtained with the patient positioned supine with the lower extremities internally rotated 15° to maximize the femoral neck length. The X-ray beam was directed midway between the anterior superior iliac spine and the pubic symphysis, with a focus film distance of 120 cm.[15] Radiographs were determined to be adequate given symmetric obturator foramina and a distance of 1 to 3 cm between the coccyx and pubic symphysis.[6]

The IFL is a novel radiographic measurement that is defined as the smooth line extending from the apex of the concavity of the lateral femoral neck through the inner cortical lip of the ilium on an AP pelvis radiograph (Figure 1). In hips with acetabular overcoverage, the IFL is tangential to the femoral head or may even lie completely lateral to the head (Figure 2). As lateral coverage is reduced or the hip center is shifted superolaterally (as in varying degrees of dysplasia), the IFL increasingly intersects the femoral head, leaving a progressively greater percentage of the head lying lateral to the IFL (Figure 3). In these cases, medialization of the IFL is quantitatively measured as the horizontal distance between the femoral head line segment lying lateral to the IFL as a percentage of the entire horizontal femoral head width measured, at the center of the femoral head. In all cases, the IFL was drawn using a PACS workstation (McKesson). Although the IFL is a quantifiable measure, a high value of percent medialization of the IFL may be easily detected visually without necessitating an exact measurement (Figure 4).

The lateral center edge angle (LCEA) was determined on AP pelvis radiographs as described previously.[28] The degree of acetabular coverage was determined by the LCEA measurement: acetabular overcoverage ($\geq$40°), normal acetabular coverage (25°-39.9°), borderline dysplasia (20°-24.9°), and frank dysplasia (<20°). The Shenton line was determined to be broken if the inferior femoral neck projection was cephalad to the superior arch of the obturator foramen.[30]

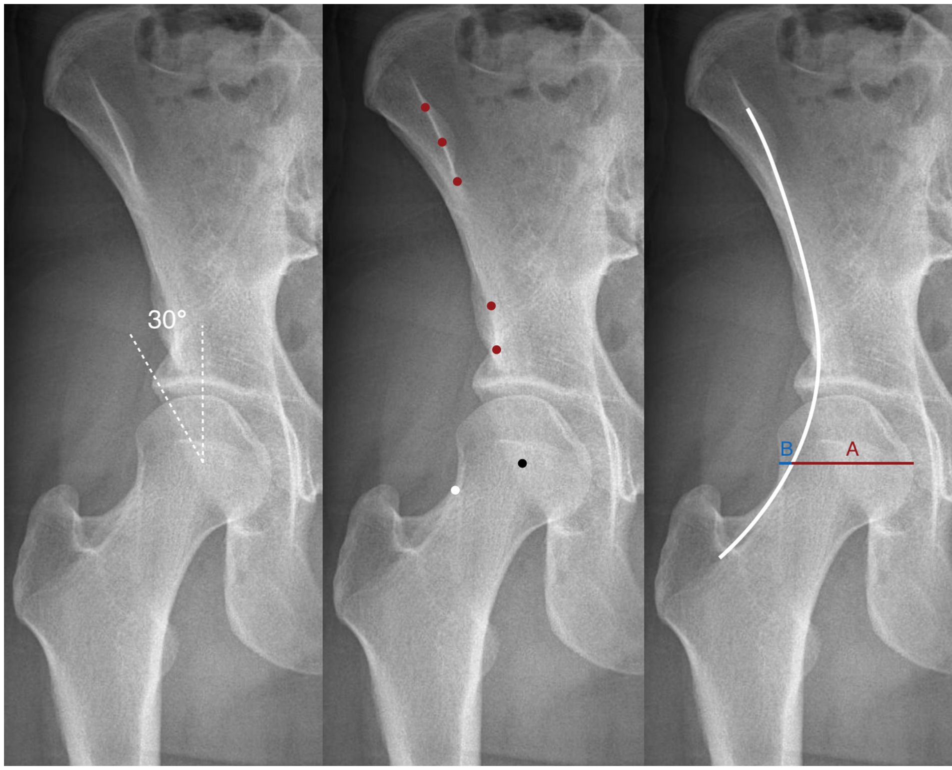

Figure 1. Anteroposterior pelvis radiograph of a hip with a lateral center edge angle of 30° (normal acetabular coverage), cropped down to the right hip (left image). Points along the inner cortical line of the ilium (red dots) and point of maximum concavity along the lateral femoral neck (white dot) used to construct the iliofemoral line (IFL) as well as a point (black dot) representing the center of the femoral head (middle image). Percent medialization of the IFL is calculated by measuring the horizontal distance from the IFL to the lateral femoral head (B) and dividing by the femoral head diameter (A, B) (right image).

Clinical examination and radiographic findings were determined initially by a senior hip preservation orthopaedic surgeon (O.M.-D.). All radiographic measurements were then repeated by a fellowship-trained musculoskeletal radiologist and a radiology resident, both of whom were specifically trained to perform these measurements. Intraobserver and interobserver reproducibility were validated as substantial to excellent.[18]

To validate this parameter for both supine and weightbearing standardized radiographs,[6] percent medialization of the IFL was measured on a cohort of 20 patients who had both sets of radiographs available for comparison (same distance from the coccyx to the pubis for both views; no rotation). There was no statistical difference seen between the measurements on supine versus weightbearing views, and the largest difference obtained was 0.6 mm (5% of the measured distance) with an average difference of 0.3 mm (2% of the measured distance).

Statistical Analysis

All variables were evaluated for distribution of normality using a combination of histograms, quantile-quantile plots, and Shapiro-Wilk tests. Descriptive statistics were summarized as means and SDs for quantitative variables and as counts and frequencies for categorical variables. A generalized linear mixed model with an unstructured covariance matrix and identity link function was used to evaluate the relationship between percent medialization of the IFL and LCEA. The predictive ability of the final regression model was evaluated using multiclass receiver operating characteristic (ROC) curve analysis, and optimal cut-off values were determined using the Youden Index.[22] 95% CIs for sensitivity and specificity of the optimal cut-off values were computed via nonparametric bootstrapping with 10,000 replicates. Sensitivity between the IFL and Shenton line parameters was compared using the McNemar test. Intraobserver and interobserver reproducibility of the IFL were evaluated using a 2-way, mixed, consistency, single-measure intraclass correlation coefficient. Statistical significance for all comparisons was set at $P < .05$ (2-tailed). All analyses were conducted using R Statistical Software version 3.3.1 (R Foundation for Statistical Computing).

RESULTS

Participants and Descriptive Data

The study cohort comprised 222 patients (436 hips; 60 male, 162 female) with a mean (±SD) age of 33.8 ± 11.4 years. The mean height was 168.6 ± 9.8 cm, the mean

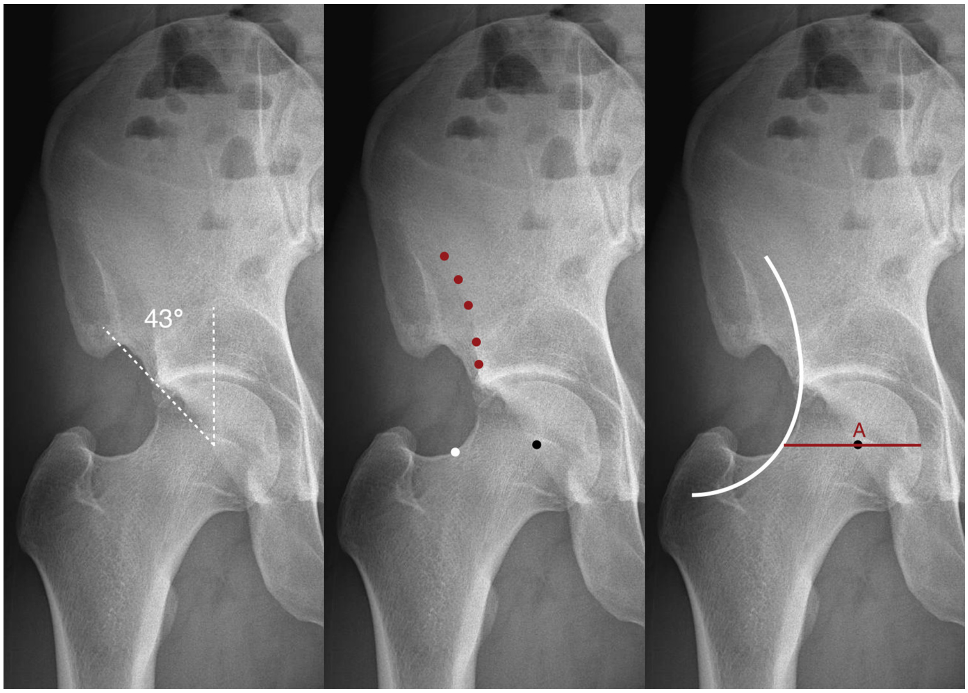

Figure 2. Anteroposterior pelvis radiograph of a hip with a lateral center edge angle of 43° (acetabular overcoverage), cropped down to the right hip (left image). Points along the inner cortical line of the ilium (red dots) and point of maximum concavity along the lateral femoral neck (white dot) used to construct the iliofemoral line (IFL) as well as a point (black dot) representing the center of the femoral head (middle image). Percent medialization of the IFL is calculated by measuring the horizontal distance from the IFL to the lateral femoral head (in this case, it is 0) and dividing by the femoral head diameter (in this case, designated entirely by line A) (right image).

weight was 69.3 ± 14.5 kg, and the mean body mass index was 24.3 ± 4.4 kg/m^2. One hundred ninety-three hips (44.3%) had normal acetabular coverage, 87 (20.0%) had acetabular overcoverage, 81 (18.6%) had borderline dysplasia, and 75 (17.2%) had frank dysplasia (Table 1).

Accuracy of the IFL in Predicting Acetabular Coverage

Percent medialization of the IFL was significantly associated with the LCEA (β = –0.94; 95% CI, –1.01 to –0.87; P < .0001) (Table 2 and Figure 5). The final predictive model was the following:

$$\text{LCEA} = 42.03 - (0.94 \times \text{Percent Medialization of Iliofemoral Line}).$$

Using ROC curve analysis, percent medialization of the IFL ranging between 15% and 22% predicted the presence of borderline hip dysplasia (based on the LCEA as a reference standard) with a sensitivity of 62% (95% CI, 51%-72%) and specificity of 89% (95% CI, 85%-92%) (Figure 6A), while values exceeding 22% predicted the presence of frank acetabular dysplasia with a sensitivity of 77% (95% CI, 65%-85%) and specificity of 94% (95% CI, 91%-96%) (Figure 6B). By comparison, abnormality of the Shenton line in our cohort demonstrated a sensitivity of 3.7% (95% CI, 0.01%-10.3%) and specificity of 97% (95% CI, 94%-98%) for the detection of borderline dysplasia and a sensitivity of 16% (95% CI, 8.9%-25%) and specificity of 99% (95% CI, 98%-100%) for the detection of frank acetabular dysplasia. Compared with the Shenton line, percent medialization of the IFL was significantly more sensitive for the detection of both borderline hip dysplasia ($\chi^2(1)$ = 80, P < .0001) and frank acetabular dysplasia ($\chi^2(1)$ = 64, P < .0001). The intraobserver and interobserver reproducibility of the horizontal length outside the IFL were 0.99 (95% CI, 0.98-1.00) and 0.96 (95% CI, 0.93-0.98), respectively. Furthermore, no significant effect was found with regard to percent medialization of the IFL in patients with increased/decreased femoral torsion compared with normal femoral torsion.

DISCUSSION

This study assesses the utility of a novel radiographic marker, the IFL, in measuring acetabular dysplasia. Percent medialization of the IFL was strongly correlated to the LCEA and was shown to detect the presence of borderline hip dysplasia and frank acetabular dysplasia with high specificities and moderate to high sensitivities. The advantage of this new parameter is that it detects subtle

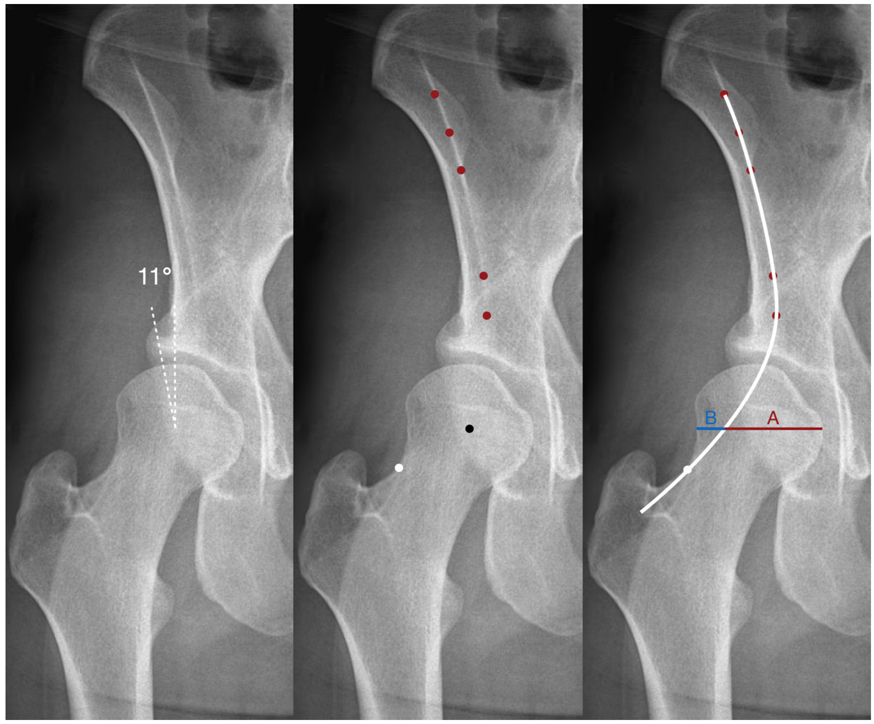

Figure 3. Anteroposterior pelvis radiograph of a hip with a lateral center edge angle of 11° (frank dysplasia), cropped down to the right hip (left image). Points along the inner cortical line of the ilium (red dots) and point of maximum concavity along the lateral femoral neck (white dot) used to construct the iliofemoral line (IFL) as well as a point (black dot) representing the center of the femoral head (middle image). Percent medialization of the IFL is calculated by measuring the horizontal distance from the IFL to the lateral femoral head (B) and dividing by the femoral head diameter (A, B) (right image).

Figure 4. Three-dimensional reconstruction of the pelvis and bilateral hip joints from a computed tomography (CT) scan used to illustrate the concept of the iliofemoral line (IFL) (solid white lines).

TABLE 1
Patient Demographics and Baseline Characteristics[a]

	Values
No. of patients	222
No. of hips	436
Age, mean ± SD, y	33.8 ± 11.4
Male sex, n (%)	60 (27.0)
Height, mean ± SD, cm	168.6 ± 9.8
Weight, mean ± SD, kg	69.3 ± 14.5
Body mass index, mean ± SD, kg/m^2	24.3 ± 4.4
Acetabular coverage of hips, n (%)	
Frank dysplasia (LCEA <20°)	75 (17.2)
Borderline dysplasia (LCEA 20°-24.9°)	81 (18.6)
Normal acetabular coverage (LCEA 25°-39.9°)	193 (44.3)
Acetabular overcoverage (LCEA ≥40°)	87 (20.0)

[a]LCEA, lateral center edge angle.

lateral undercoverage of the femoral head seen in instability patients and therefore may be used in diagnosing hip dysplasia in addition to other established parameters such as the LCEA or Shenton line. This becomes more important in cases in which other parameters are not consistent with the suspected diagnosis and additional parameters can aid the clinician in establishing the correct diagnosis. An example would be a young female patient with Ehlers-Danlos syndrome with a low normal LCEA and normal Tönnis angle but with subtle lateralization of the femoral head caused by increased laxity characteristics.

TABLE 2
Results of Generalized Linear Mixed Model Identifying Independent Predictors of the Lateral Center Edge Angle[a]

Outcome Variable	Explanatory Variables	Unstandardized Beta Coefficient	95% CI	*P* Value	Adjusted R^2 Value
Lateral center edge angle	Intercept	42.03	40.88 to 43.17	<.001	0.95
	Percent medialization of iliofemoral line	–0.94	–1.01 to –0.87	<.001	

[a] $F(1,419.75) = 791.84$, $P < .0001$.

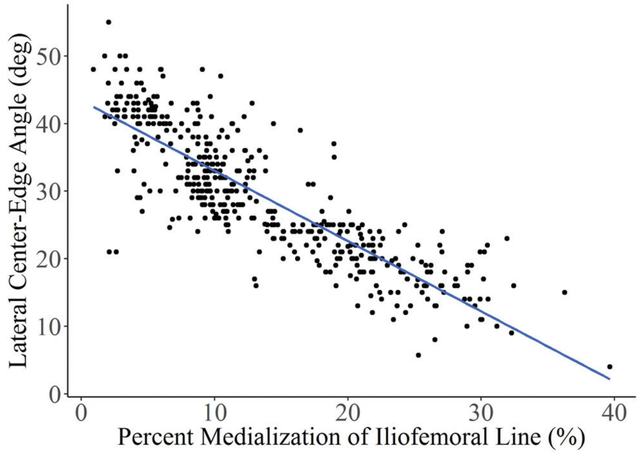

Figure 5. Percent medialization of the iliofemoral line is negatively correlated to the lateral center edge angle.

The Shenton line is a commonly used qualitative radiographic marker of acetabular dysplasia. A break in the Shenton line is indicative of more severe forms of acetabular dysplasia with a superolateral hip center, whereas a continuous line does not exclude an unstable hip. Rhee et al[30] performed a study in which 6 orthopaedic surgeons were asked to review a total of 128 AP pelvis radiographs, including 64 radiographs of patients with developmental dysplasia of the hip and 64 radiographs of normal (control) hips. Surgeons were given the definition of the Shenton line and were asked to diagnose each radiograph as normal or dysplastic based on this parameter. The use of the Shenton line resulted in only a 57.8% agreement of the dysplastic hips by all 6 orthopaedic surgeons. In contrast, the intraobserver (0.99) and interobserver (0.96) reproducibility of the horizontal length outside the IFL were excellent.

In the current study using LCEA values between 20° and 24.9° to indicate borderline hip dysplasia and LCEA <20° to indicate frank hip dysplasia,[12] the Shenton line demonstrated high specificities for diagnosing both borderline and frank hip dysplasia. However, the sensitivities of the Shenton line were only 3.7% and 16% in diagnosing borderline and frank hip dysplasia, respectively. This is in comparison to sensitivities of 62% and 77%, respectively, with use of the IFL. The reason for the difference between these parameters is likely attributed to the type and severity of hip dysplasia used to assess the Shenton line in the study by Rhee et al.[30] A broken Shenton line is not a common finding in early to mild hip dysplasia and represents a significant predictor of arthroscopic treatment failure in adults with hip dysplasia.[34] In our cohort, 16% of frank dysplastic hips had a broken Shenton line, in comparison to only 3.7% of borderline dysplastic hips, which represents a more common population presenting to the hip preservation surgeon.

While bony realignment procedures such as periacetabular osteotomy have resulted in successful outcomes in patients with frank hip dysplasia,[3,21,33] there exists some debate as to the appropriate treatment strategy in patients with mild or borderline hip dysplasia. Larson et al[19] demonstrated worse subjective outcomes and higher failure rates in patients with mild/borderline hip dysplasia undergoing arthroscopic-only management in comparison to a cohort of patients undergoing arthroscopic surgery for femoroacetabular impingement. Furthermore, it has recently been shown that patients with borderline dysplasia experience similar degrees and patterns of labral and cartilage hypertrophy as patients with frank dysplasia.[2,12] Thus, patients with borderline and frank acetabular dysplasia may experience similarly increased shear forces within the hip caused by a lack of sufficient bony coverage, thereby questioning the utility of a soft tissue–only approach in patients with borderline dysplasia. Therefore, the IFL may serve as an additional tool in the clinician's hands to establish instability and determine when periacetabular osteotomy would serve as a potentially better treatment option compared with a soft tissue–only approach in a patient with borderline dysplasia. We found that percent medialization of the IFL exceeding 15% predicted borderline or frank hip dysplasia with a high specificity. Therefore, for patients with a percent medialization value above this threshold, dynamic instability should be considered. However, although percent medialization of the IFL may be quantified, it may be most useful for surgeons to use this new parameter as a qualitative, visual, quick-screening marker for instability, similar to the Shenton line.

Because patients with borderline dysplasia have fallen into a gray area between arthroscopic and realignment procedures, other factors are necessary to determine which of these patients may benefit from an all-arthroscopic approach. Even if a surgeon and patient decide to proceed with arthroscopic soft tissue–only treatment for hip instability, it is important to state the outcomes of this procedure and to match the patient's expectations with an honest discussion regarding possible failure of this treatment. The current study demonstrates a significantly higher sensitivity of the IFL in detecting borderline hip

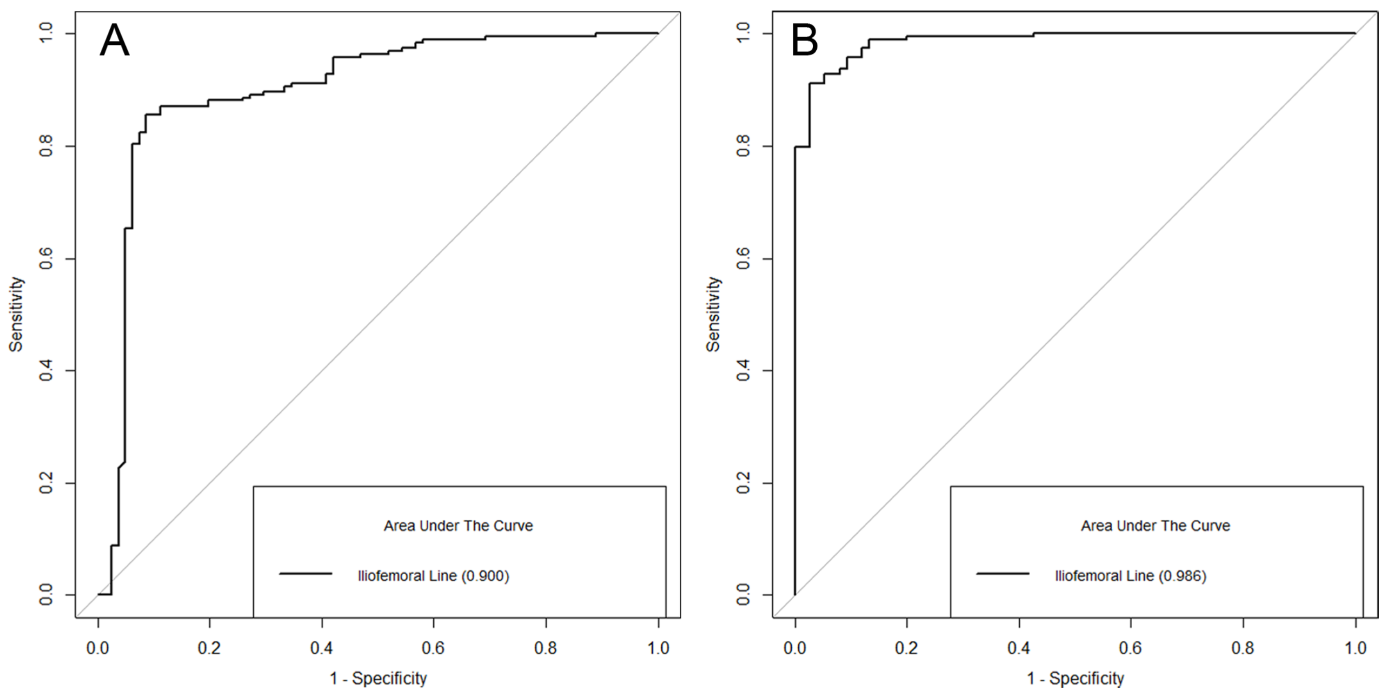

Figure 6. (A) Percent medialization of the iliofemoral line (IFL) accurately predicts borderline hip dysplasia. Ideal cut-off point = 15.13. (B) Percent medialization of the IFL accurately predicts frank hip dysplasia. Ideal cut-off point = 21.78.

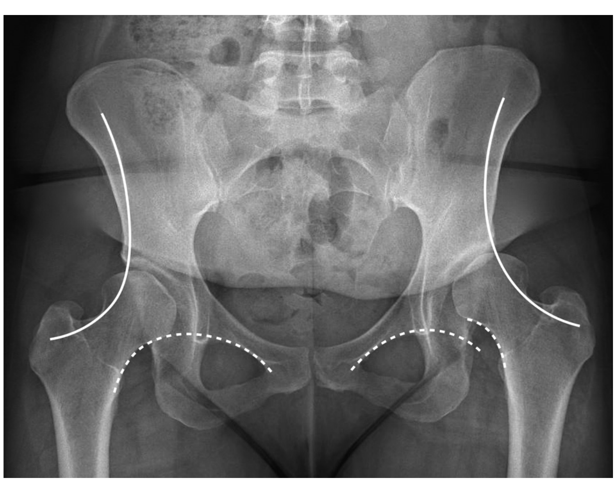

Figure 7. Anteroposterior pelvis radiograph of a patient with bilateral frank acetabular dysplasia. The Shenton line is continuous on the right and broken on the left (dashed white lines), indicating a superolateral left hip center. The iliofemoral line is drawn on both sides (solid white lines) and enables rapid, qualitative visual identification of dysplastic undercoverage of the right femoral head, despite having a continuous Shenton line.

dysplasia compared with the Shenton line (62% vs 3.7%, respectively) (Figure 7). Thus, the use of the IFL may detect mild cases of hip instability associated with acetabular dysplasia that otherwise may go undiagnosed, thereby resulting in earlier surgical treatment for these patients and possibly yielding better long-term outcomes.

Certain radiographic parameters may not be reliably assessed with the use of different imaging modalities.[5,32] In particular, in using the LCEA, Chadayammuri et al[5] found that many patients who were identified as frankly dysplastic on plain radiographs (LCEA <20°) were identified as normal or borderline dysplastic (LCEA >25° and 20°-25°, respectively) on CT. Therefore, in determining the dysplasia status of a patient, it is necessary to use the gold-standard imaging modality of the respective radiographic parameter during an assessment. As described in the current study, the IFL was measured on standardized AP pelvis radiographs, the current gold standard for this parameter.

The strengths of this study include the large sample size of a prospective, consecutive series of patients. The limitations of this study should also be noted. The sensitivities and specificities of the IFL and the Shenton line were calculated based on the LCEA as a standard radiographic parameter used to assess hip dysplasia. Hip dysplasia represents a complex 3-dimensional pathoanatomy that can be present in cases of normal LCEA, when acetabular version or femoral torsion is excessive, or when significant hyperlaxity is seen. Additionally, the IFL may be medialized in hips with severe coxa vara, coxa valga, or pelvic dysmorphism. In some hips, the inner cortical line of the ilium is less pronounced. In addition, it is sometimes difficult to draw the IFL with a curvilinear contour in the femoral neck as an extension of the proximal curvilinear line in the ilium. Thus, these 2 factors may sometimes introduce error in the estimation of the IFL, although a qualitative assessment of the IFL would still serve as a helpful tool. Despite these limitations, however, with experience and familiarity, the IFL can become a quick visual estimate with which the clinician can assess for underlying instability that then prompts further evaluation with advanced imaging.

CONCLUSION

The IFL is a simple radiographic marker that can be used as an additional tool to detect borderline and frank acetabular dysplasia on AP pelvis radiographs. When using the LCEA as a standard, the sensitivity of the IFL in detecting borderline dysplasia is significantly higher than that of the Shenton line.

REFERENCES

1. Aronson J. Osteoarthritis of the young adult hip: etiology and treatment. *Instr Course Lect*. 1986;35:119-128.
2. Ashwell ZR, Flug J, Chadayammuri V, Pascual-Garrido C, Garabekyan T, Mei-Dan O. Lateral acetabular coverage as a predictor of femoroacetabular cartilage thickness. *J Hip Preserv Surg*. 2016;3(4):262-269.
3. Bogunovic L, Hunt D, Prather H, Schoenecker PL, Clohisy JC. Activity tolerance after periacetabular osteotomy. *Am J Sports Med*. 2014;42(8):1791-1795.
4. Bracken J, Tran T, Ditchfield M. Developmental dysplasia of the hip: controversies and current concepts. *J Paediatr Child Health*. 2012;48(11):963-972.
5. Chadayammuri V, Garabekyan T, Jesse MK, et al. Measurement of lateral acetabular coverage: a comparison between CT and plain radiography. *J Hip Preserv Surg*. 2015;2(4):392-400.
6. Clohisy JC, Carlisle JC, Beaulé PE, et al. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am*. 2008;90 Suppl 4:47-66.
7. Clohisy JC, Carlisle JC, Trousdale R, et al. Radiographic evaluation of the hip has limited reliability. *Clin Orthop Relat Res*. 2009;467(3):666-675.
8. Clohisy JC, Dobson MA, Robison JF, et al. Radiographic structural abnormalities associated with premature, natural hip-joint failure. *J Bone Joint Surg Am*. 2011;93 Suppl 2:3-9.
9. Clohisy JC, Keeney JA, Schoenecker PL. Preliminary assessment and treatment guidelines for hip disorders in young adults. *Clin Orthop Relat Res*. 2005;441:168-179.
10. Cooperman D. What is the evidence to support acetabular dysplasia as a cause of osteoarthritis? *J Pediatr Orthop*. 2013;33 Suppl 1:S2-S7.
11. Fujii M, Nakashima Y, Jingushi S, et al. Intraarticular findings in symptomatic developmental dysplasia of the hip. *J Pediatr Orthop*. 2009;29(1):9-13.
12. Garabekyan T, Ashwell Z, Chadayammuri V, et al. Lateral acetabular coverage predicts the size of the hip labrum. *Am J Sports Med*. 2016;44(6):1582-1589.
13. Harris WH. Etiology of osteoarthritis of the hip. *Clin Orthop Relat Res*. 1986;213:20-33.
14. Henak CR, Abraham CL, Anderson AE, et al. Patient-specific analysis of cartilage and labrum mechanics in human hips with acetabular dysplasia. *Osteoarthritis Cartilage*. 2014;22(2):210-217.
15. Jesse MK, Petersen B, Strickland C, Mei-Dan O. Normal anatomy and imaging of the hip: emphasis on impingement assessment. *Semin Musculoskelet Radiol*. 2013;17(3):229-247.
16. Klaue K, Durnin CW, Ganz R. The acetabular rim syndrome: a clinical presentation of dysplasia of the hip. *J Bone Joint Surg Br*. 1991;73(3):423-429.
17. Kraeutler MJ, Garabekyan T, Pascual-Garrido C, Mei-Dan O. Hip instability: a review of hip dysplasia and other contributing factors. *Muscles Ligaments Tendons J*. 2016;6(3):343-353.
18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
19. 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.
20. Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. *Clin Orthop Relat Res*. 2004;418:74-80.
21. Lodhia P, Chadrasekaran 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.
22. Luo J, Xiong C. DiagTest3Grp: an R package for analyzing diagnostic tests with three ordinal groups. *J Stat Softw*. 2012;51(3):1-24.
23. Manaster BJ. From the RSNA Refresher Courses: Radiological Society of North America. Adult chronic hip pain: radiographic evaluation. *Radiographics*. 2000;20 Spec No:S3-S25.
24. Michaeli DA, Murphy SB, Hipp JA. Comparison of predicted and measured contact pressures in normal and dysplastic hips. *Med Eng Phys*. 1997;19(2):180-186.
25. Nelitz M, Guenther KP, Gunkel S, Puhl W. Reliability of radiological measurements in the assessment of hip dysplasia in adults. *Br J Radiol*. 1999;72(856):331-334.
26. Nepple JJ, Clohisy JC. The dysplastic and unstable hip: a responsible balance of arthroscopic and open approaches. *Sports Med Arthrosc*. 2015;23(4):180-186.
27. Nunley RM, Prather H, Hunt D, Schoenecker PL, Clohisy JC. Clinical presentation of symptomatic acetabular dysplasia in skeletally mature patients. *J Bone Joint Surg Am*. 2011;93 Suppl 2:17-21.
28. Ogata S, Moriya H, Tsuchiya K, Akita T, Kamegaya M, Someya M. Acetabular cover in congenital dislocation of the hip. *J Bone Joint Surg Br*. 1990;72(2):190-196.
29. Peelle MW, Della Rocca GJ, Maloney WJ, Curry MC, Clohisy JC. Acetabular and femoral radiographic abnormalities associated with labral tears. *Clin Orthop Relat Res*. 2005;441:327-333.
30. Rhee PC, Woodcock JA, Clohisy JC, et al. The Shenton line in the diagnosis of acetabular dysplasia in the skeletally mature patient. *J Bone Joint Surg Am*. 2011;93 Suppl 2:35-39.
31. Solomon L. Patterns of osteoarthritis of the hip. *J Bone Joint Surg Br*. 1976;58(2):176-183.
32. Stelzeneder D, Hingsammer A, Bixby SD, Kim YJ. Can radiographic morphometric parameters for the hip be assessed on MRI? *Clin Orthop Relat Res*. 2013;471(3):989-999.
33. Steppacher SD, Tannast M, Ganz R, Siebenrock KA. Mean 20-year followup of Bernese periacetabular osteotomy. *Clin Orthop Relat Res*. 2008;466(7):1633-1644.
34. Uchida S, Utsunomiya H, Mori T, et al. Clinical and radiographic predictors for worsened clinical outcomes after hip arthroscopic labral preservation and capsular closure in developmental dysplasia of the hip. *Am J Sports Med*. 2016;44(1):28-38.
35. Wedge JH, Wasylenko MJ. The natural history of congenital dislocation of the hip: a critical review. *Clin Orthop Relat Res*. 1978;137:154-162.
36. Wiberg G. Studies on dysplastic acetabula and congenital subluxation of the hip joint: with special reference to the complication of osteoarthritis. *Acta Chir Scand*. 1939;83(Suppl 58):28-38.