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Research Article

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Validation of neck axis distance as a radiographic measure for acetabular anteversion

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ABSTRACT

Excessive acetabular anteversion is an important treatment consideration in hip preservation surgery. There is currently no reliable quantitative method for determining acetabular anteversion utilizing radiographs alone. The three main purposes of this study were to: (i) define and validate the neck axis distance (NAD) as a new visual and reproducible semi-quantitative radiographic parameter used to measure acetabular anteversion; (ii) determine the degree of correlation between NAD and computed tomography (CT)-measured acetabular anteversion; (iii) establish a sensitive and specific threshold value for NAD to identify excessive acetabular anteversion. This retrospective cohort study included all patients presenting to a single institution over a 14-month period who had undergone a dedicated musculoskeletal CT pelvis along with a standardized anteroposterior (AP) pelvis radiograph. Trained observers measured the NAD on the AP pelvis radiograph and equatorial acetabular anteversion on CT for all hips. Mixed model analysis was used to find prediction equations, and ROC analysis was used to evaluate the diagnostic accuracy of NAD. NAD is a valid semi-quantitative predictor of acetabular anteversion and strongly correlates with CT-measured equatorial acetabular anteversion ($P < 0.0001$). A NAD measurement of greater than 14 mm predicts excessive acetabular anteversion with 76% sensitivity and 78% specificity. NAD is an accurate radiographic predictor of acetabular anteversion, which may be readily used as an effective screening tool during the evaluation of patients with hip pain.

INTRODUCTION

Abnormal acetabular version has been correlated with various pathologic hip conditions. The association between acetabular retroversion and femoroacetabular impingement (FAI) has been well established in recent years as a source of hip pain contributing to early hip osteoarthrosis and labral tears [1–6]. Acetabular anteversion has classically been associated with developmental dysplasia of the hip (DDH), also a well-known cause of early osteoarthrosis and labral tears [7–9]. Recognition and appropriate treatment of abnormal acetabular version is crucial to preventing irreversible hip damage.

Acetabular version is commonly measured on computed tomography (CT), as there is no well-established measurement for radiography. However, because CT is higher in radiation dose and cost, it is usually reserved for patients undergoing preoperative planning, after diagnosis has been fully established. The routine use of previously proposed radiographic tools to quantify acetabular version has been limited, perhaps because these approaches are somewhat complex and time-consuming [10–12]. Establishing a simple, efficient radiographic measure of CT acetabular version for the initial evaluation of patients with hip pain is needed. Additionally, a radiographic cutoff for excessive acetabular anteversion or retroversion could help determine when further evaluation with CT or other advanced imaging modalities is appropriate.

The three main purposes of this study were to: (i) define a new radiographic measure of acetabular version, the neck axis distance (NAD). The NAD (measured in millimeters) is based on the relationship between the anterior and posterior walls of the acetabulum; (ii) produce a predictive equation, so that clinicians could calculate CT acetabular version based on NAD measurements; (iii) define a diagnostic threshold for acetabular anteversion using NAD. We hypothesized that the NAD will accurately predict the true acetabular version as measured by CT.

METHODS

Our institutional review board approved this retrospective cohort study. We searched PACS for CTs of the pelvis performed according to a dedicated musculoskeletal (MSK) protocol over a 14-month period. One hundred fifty one studies (302 hips) were initially identified. Patients were included if triradiate cartilage was fused and they had an adequately standardized anteroposterior (AP) pelvis radiograph. Fifty-two hips were excluded for having no radiograph. Ten hips were excluded for having prior surgical alteration or deformities of the acetabulum including periacetabular osteotomy (4), acetabular rim shaving (2), slipped capital femoral epiphysis (1) and total hip arthroplasty (3).

The musculoskeletal CT pelvis protocol is obtained at our orthopaedic center of hip preservation to determine acetabular version and other measurements for preoperative planning in symptomatic patients with suspected FAI or DDH [13]. The patient is imaged in supine position, with the pelvis squared and feet secured in a neutral toes-up position. Whole pelvis 1 mm acquisitions with 2-mm reconstructions in axial, sagittal and coronal planes are obtained.

AP pelvis radiographs are obtained at our institute according to standard protocol with the patient in supine position, lower extremities internally rotated 15° and X-ray tube-to-film distance of 120 cm. Radiographs were considered technically adequate if the horizontal distance between the vertical axis of the sacrum and the pubic symphysis (representing pelvic rotation) was 0–1 cm, and the vertical distance between the coccyx and pubic symphysis (representing pelvic tilt) was 1–3 cm [14]. Radiographs not meeting these criteria were excluded.

One hundred sixteen hips were excluded for excessive pelvic tilt with coccygeal to pubic symphysis distance less than 1 cm or greater than 3 cm. Fourteen hips were excluded for pelvic rotation greater than 1 cm. This left 110 hips included in the final analysis (Fig. 1). Seventy-two hips were female. Thirty-eight hips were male. The average age was 32 years with a range of 14–55 (Table I).

Measurements were made on PACS workstations by two trained observers. CT equatorial acetabular version was measured at the level of the mid femoral head on axial CT images, correlating to the center of a best-fit circle drawn around the femoral head on the central coronally reconstructed cut [3]. The version angle was measured in degrees between a line drawn tangent to the anterior and posterior walls of the acetabulum and the true sagittal plane (Fig. 2). NAD was measured in millimeters on the AP pelvic radiograph by drawing a line (N) along the long

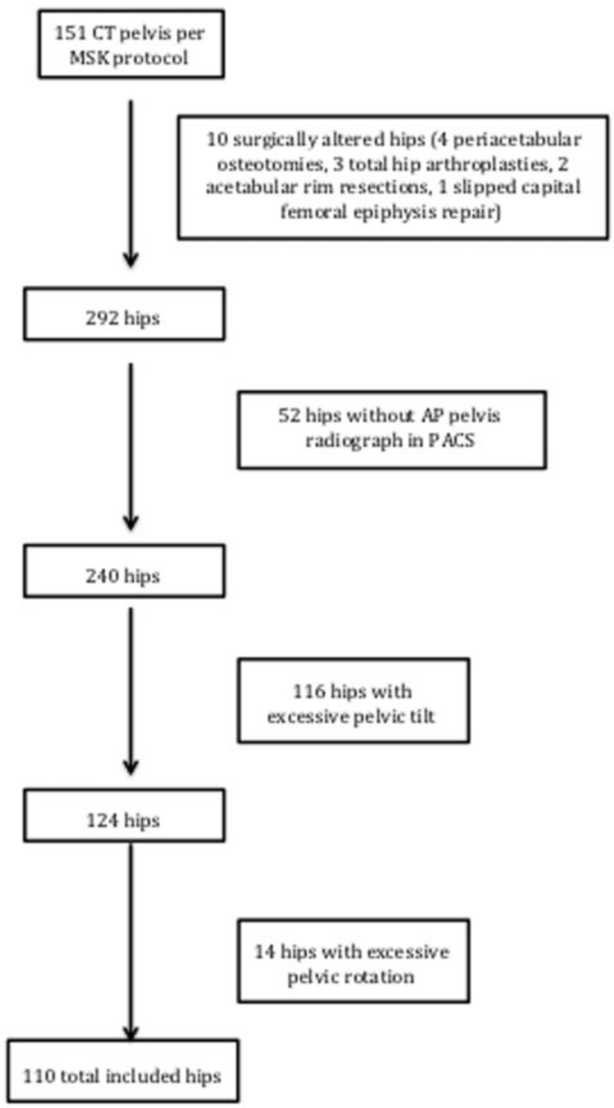

Fig. 1. Selection criteria.

Table I. Demographics

Hips (*n*)	110
Patients (*n*)	57
Age range (years)	14–55
Mean age (years)	32
Female (*n*, %)	72, 65.5
Male (*n*, %)	38, 34.5

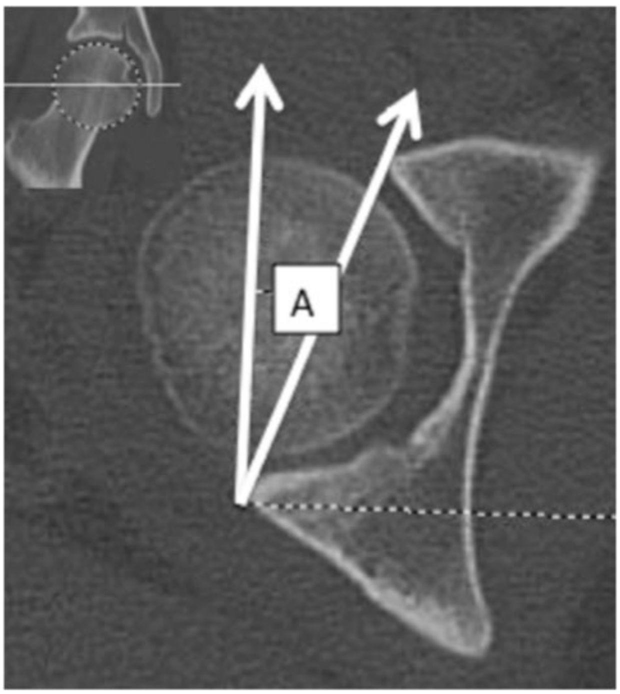

Fig. 2. CT acetabular version measurement technique. The axial cut extending through the center of a best-fit circle on the central coronal reconstructed cut (inset image) was used to calculate the equatorial acetabular version. The angle between a line drawn tangent to the anterior and posterior walls of the acetabulum and a true sagittal line was the CT acetabular equatorial version.

axis of the femoral neck, through the center of a best-fit circle of the femoral head. The distance between the points where the anterior and posterior walls intersected line N was measured, producing the NAD measurement (Fig. 3).

We used values previously defined by other authors for normal central (equatorial) acetabular version (13–20°), central acetabular retroversion (<13°), and central acetabular anteversion (>20°) [2, 10, 13, 15–17].

To minimize bias, one observer performed all CT measurements while the second observer performed all radiographic measurements. Interobserver reproducibility of

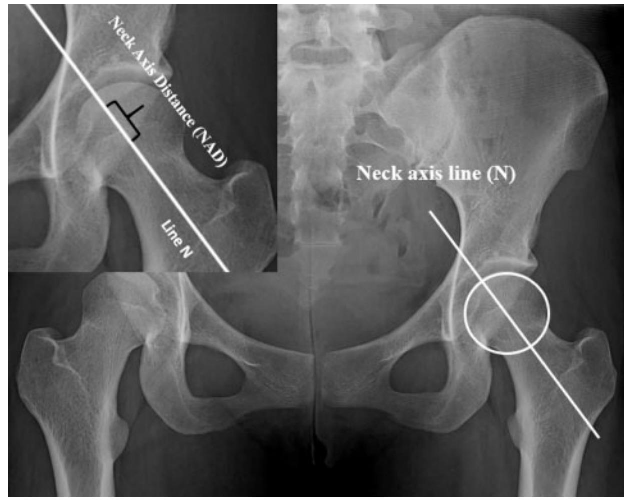

Fig. 3. NAD measurement technique. Line N is drawn along the axis of the femoral neck through the center of a best-fit circle of the femoral head. The distance between the points where the anterior and posterior acetabular walls intersect line *N* is the NAD.

radiographic and CT measurements were each evaluated by two observers in a blinded random subset of 20 hips using a two-way, mixed, consistency single-measures intraclass correlation coefficient (ICC). ICC values were interpreted as outlined by Landis and Koch, with values greater than 0.80 indicating excellent reliability; 0.61-0.80, substantial reliability; 0.41–0.60, moderate reliability; 0.21–0.40, fair reliability; and less than 0.20, poor reliability [18].

STATISTICAL ANALYSIS

We fit a general linear mixed model with an unstructured covariance nested within person, CT acetabular version as the outcome, and hip, NAD and hip by NAD interaction as predictors, in the full model in every cell. We used planned, backwards, stepwise analysis to examine the utility of including hip, and hip by NAD interaction in the model. In the final and best fitting model, we used a Wald test with Kenward Roger degrees of freedom [19] to assess whether NAD was significantly associated with CT equatorial version, to estimate the strength of the association between NAD and CT equatorial version, to produce 95% prediction intervals, and to provide the prediction equation.

To assess the ability of NAD to accurately predict the gold standard of CT-measured excessive acetabular anteversion (>20°), we used paired receiver operating characteristic (ROC) curve analysis. We used the Youden index to determine the best cut point for categorizing excessive acetabular anteversion by NAD [20]. We reported the optimal cut point for NAD and its associated specificity and sensitivity.

RESULTS

The average acetabular version in our study was 20.36 (range 10–34). Fifty-five hips had normal equatorial version (13–20°). Forty-nine hips were anteverted (>20°). Six hips were retroverted (<13°). The average NAD was 13.59 (range −3.8 to 28.3).

There was no significant difference between NAD measurements for right hips compared to left hips (F = 0.47, ndf = 1, ddf = 47.1, P = 0.50), and the association between NAD and CT acetabular version was independent of which hip (right versus left) was measured (F = 0.37, ndf = 1, ddf = 53, P = 0.54). NAD was significantly associated with CT equatorial version (β = 0.56, 95% CI = (0.43, 0.69), t = 8.69, P < 0.0001). Prediction intervals are shown in Fig. 4. For every one unit increase in NAD, CT equatorial version increases by 0.56. The predictive model is:

$$\text{CT Version} = 12.80 + (0.56 * \text{NAD})$$

The area under the curve (AUC) of the ROC curve for NAD was 0.82 (Fig. 4). A value of NAD greater than 14 mm indicated excessive acetabular anteversion. At the cut point of 14 mm, NAD had a sensitivity of 0.76 and a specificity of 0.78.

ICC demonstrated excellent reliability for NAD [ICC = 0.924; 95% confidence interval (CI) 0.819–0.969 and CT acetabular anteversion ICC = 0.961; 95% CI 0.901–0.984].

DISCUSSION

In this study, we have validated NAD as a simple, semi-quantitative radiographic predictor of acetabular anteversion with diagnostic accuracy of 82% compared to CT. We have produced a predictive equation to convert the radiographic NAD (mm) to acetabular version (in degrees). Finally, we have defined a cut-off point of 14 mm for NAD above which acetabular anteversion is likely, establishing a unique tool for identification of excessive acetabular anteversion. NAD can be easily obtained and interpreted in the clinical setting, providing a rapid, reliable measure of acetabular version while evaluating a patient with hip pain.

The assessment of acetabular version in patients with hip pain is critical, as abnormal version has been associated with FAI and DDH, possibly leading to early osteoarthrosis [1–9]. While cross-sectional imaging is ultimately required for conclusive and accurate preoperative planning, a quick, preliminary radiographic measure of acetabular version is needed. Subjective radiographic signs may indicate retroversion (crossover sign, ischial spine sign and posterior wall sign) but lack quantitative information [21, 22]. Furthermore, no tool has been designed specifically to identify excessive acetabular anteversion, an increasingly recognized finding in young patients with hip pain and anterior hip instability.

Multiple investigators have validated radiographic tools to measure acetabular version but none has become widely accepted. In 2006, Jamali *et al.* investigated a radiographic measurement adapted from a method originally described by Meunier in 1987 [10]. In their study of cadaveric

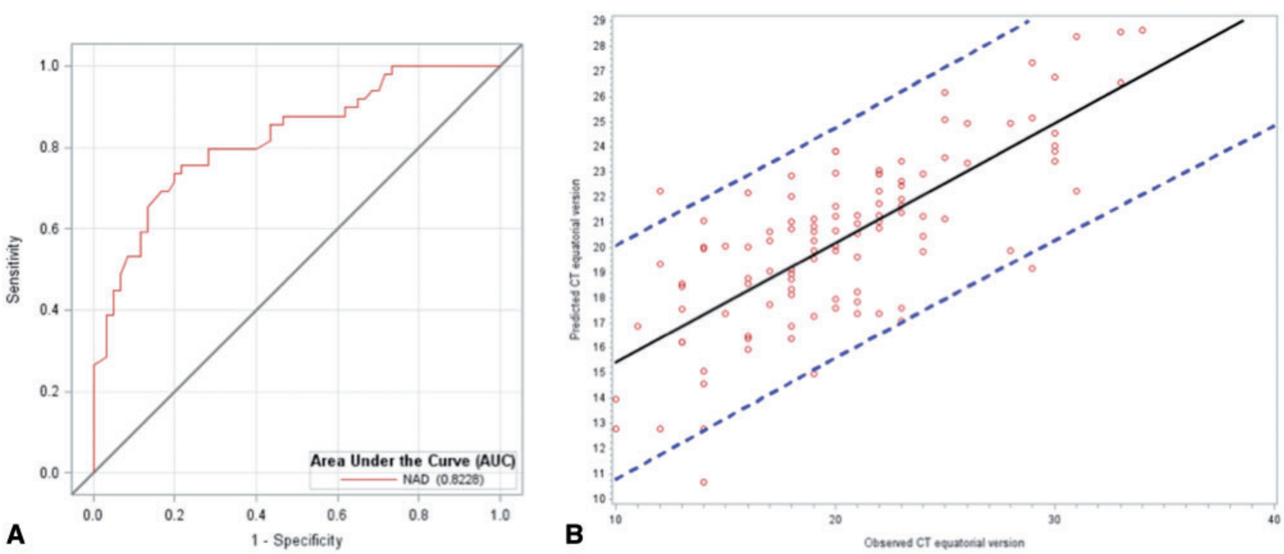

Fig. 4. (A) The AUC of the ROC curve demonstrates the accuracy of NAD as a diagnostic tool for predicting CT acetabular version. (**B**) Predicted values of NAD versus observed values with 95% prediction intervals.

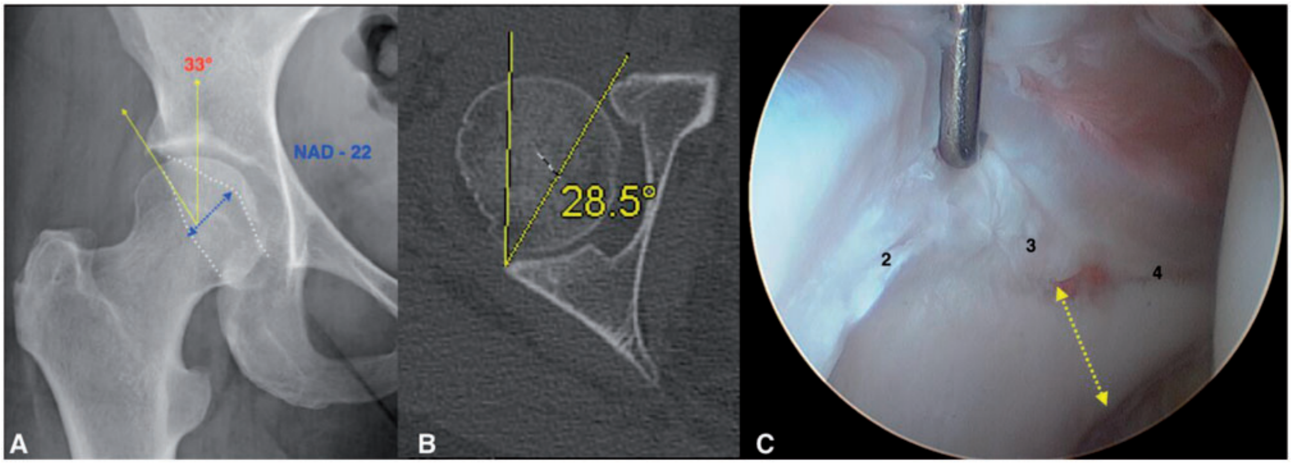

Fig. 5. (A) This AP pelvic radiograph of a patient with NAD = 22 mm (blue line) indicates excessive acetabular anteversion. Note the lateral instability sign in the form of a traction osteophyte, although the lateral center edge angle is normal (33 degrees). (**B**) A CT of the same patient with CT equatorial acetabular version angle of 28.5° confirms excessive acetabular version. (**C**) An arthroscopic view of the same patient shows an anterior displaced labral tear with very short distance from the acetabular rim to the acetabular fossa (yellow arrow). The hours of the clock are noted. This patient went on to have corrective osteotomy in the form of a periacetabular osteotomy.

pelvises, radiographic acetabular version was measured by drawing a series of lines and angles between a horizontal line connecting the centers of the acetabula, lines perpendicular to the intersections of the anterior and posterior walls with the horizontal line, and the intersections of the perpendicular lines with the contour of the acetabular diameter. While this tool yielded an acetabular version angle that directly and highly correlated with CT acetabular version, the intricate nature of the measurement made it impractical for daily use.

In 2012, Siebenrock *et al.* introduced two radiographic measurements of total anterior wall coverage and total posterior wall coverage, the anterior wall index (AWI) and the posterior wall index (PWI) [12]. To calculate these indices, a best-fit circle of the femoral head and a line along the axis of the femoral neck were drawn. The distance along this line between the medial intersection of the circle and the intersection of the anterior or posterior wall of the acetabulum was measured. This value was divided by the radius of the best-fit circle of the femoral head, yielding the AWI or PWI, respectively. These measurements highly correlated with the total anterior and posterior coverage as determined by a validated computer model in their population of patients with symptomatic hip disease. However, these indices represent an indirect measure of acetabular version and are hard to utilize quickly.

Koyama *et al.* [11] examined the p/a ratio among a population of patients with idiopathic osteonecrosis. They measured the p/a ratio on digitally reconstructed radiographs and compared this to CT acetabular version. The p/a ratio was calculated from the distance between the acetabular articular surface to the posterior wall (p) and the distance from the acetabular articular surface to the anterior wall (a), both measured along the perpendicular bisector of a line connecting the lateral edge of the acetabulum and the teardrop. Their results showed a high correlation between the p/a ratio and central acetabular version. However, the measurement remains too time-consuming for routine application.

There are several advantages of NAD compared to the tools described above. First, NAD is much simpler and more intuitive than other proposed measurements. NAD requires only a quick glance at the radiograph, making it better suited for routine use in the clinical setting. Second, we have demonstrated excellent interobserver reliability of NAD due to its ease-of-use. Third, because NAD is the absolute difference between the anterior and posterior acetabular walls, in contrast to previously described tools involving ratios, it is not affected by the shape or volume of the acetabulum. This may highlight a unique role for NAD in accurately predicting acetabular version in patients with dysplastic or mixed pathomorphologies of the hip. Finally, by defining a sensitive and specific threshold of 14 mm above which excessive acetabular version is expected, NAD is one of the first radiographic tools to specifically predict excessive acetabular anteversion.

Patients with excessive acetabular anteversion are a challenging subset of those with hip pain and require specific recognition to avoid misdiagnosis and subsequent mistreatment. Excessive acetabular anteversion can be associated with functional femoral anterior undercoverage, contributing to anterior hip instability. Iliopsoas (IP) snapping and tendinopathy, which can result in isolated anterior labral tears and IP tendon dysfunction, may be a result of excessive acetabular anteversion, and/or excessive femoral torsion [15, 23, 24]. Typical interventions used in cases of IP pathology, such as iliopsoas tenotomy, can produce worsening symptoms and subluxation, or even dislocation, in patients with excessive acetabular anteversion who are relying on the IP tendon, anterior labrum and capsule as critical anterior stabilizers. Accurate recognition of excessive acetabular anteversion at the point of clinical care and decision-making could prompt drastic changes to the established diagnosis and subsequent treatment strategy. As a result, different courses of treatment, such as femoral rotational or periacetabular osteotomies may be chosen to normalize hip forces, rather than isolated central and peripheral compartment arthroscopic interventions. An example of radiographic, CT and arthroscopic findings of acetabular anteversion is seen in Fig. 5.

Our study has several limitations. First, no correction was performed for pelvic tilt on CT or radiographic measurements. Although correction of pelvic tilt has been suggested to increase accuracy of version measurements, a recent study showed that the difference between corrected and uncorrected measurements for equatorial acetabular version was small, and less than half that of cranial acetabular version [25]. This indicates that correction of pelvic tilt is more important for cranial acetabular version than equatorial acetabular version. Nonetheless, our standardized imaging methods and technical adequacy requirements should have minimized the impact of pelvic tilt in this study [5, 16, 26]. Second, supine rather than standing radiographs were used in this study. While standing pelvis radiographs may provide functional information, our goal was to obtain anatomical information. Standing radiographs were not routinely obtained at our institute during the study period and would not have been directly comparable to CTs obtained in the supine position. Third, NAD was not corrected for patient height or body mass index. Normalization for patient size may increase the accuracy of NAD in future studies. Fourth, the ability of NAD to predict central acetabular retroversion could not be determined, as our study did not contain enough centrally retroverted hips for accurate assessment. Further investigation of the performance of NAD in predicting central acetabular retroversion is needed. Finally, because our population consisted of symptomatic patients with suspected FAI or DDH, the results of this study may not be generalizable to asymptomatic patients, or those with other causes of hip pain.

CONCLUSION

Our results validate NAD as a simple, semi-quantitative radiographic predictor of acetabular anteversion, quickly and easily measured on a standardized AP pelvis radiograph. Furthermore, we have established a clinical cut-point for NAD, strongly predictive of excessive acetabular anteversion. This makes NAD a unique and valuable tool for the assessment of acetabular anteversion.

ACKNOWLEDGEMENTS

This study was completed under Institutional Review Board (IRB) approval, Protocol 13-2854.

CONFLICT OF INTEREST STATEMENT

None declared.

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