Original Article

Femoroacetabular Impingement Measurements Obtained From Two-Dimensional Radiographs Versus Three-Dimensional—Reconstructed Computed Tomography Images Result in Different Values

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Purpose: To compare the reliability and accuracy of radiographic measurements obtained from 2-dimensional (2D) radiographs and 3-dimensional (3D)-reconstructed computed tomography (CT) images in the assessment of femoroacetabular impingement syndrome (FAIS). **Methods:** Consecutive patients with FAIS from January 2018 to December 2020 were identified and included in this study. Two fellowship-trained surgeons and 2 fellows performed blinded radiographic measurements. Lateral center-edge angle (LCEA) and Tönnis angles were measured on anteroposterior pelvic radiographs, and alpha angles were measured on frog lateral radiographs. Reliability coefficients for individual measurement accuracy were performed using the Cronbach alpha and intra- and inter-rater intraclass correlation coefficients (ICCs). Composite measurements for LCEA, Tönnis angle, and alpha angle were compared with the corresponding 3D value using paired sample *t*-tests. **Results:** Fifty-three patients with FAIS with standardized 2D radiographic and 3D-reconstructed CT imaging were included. All reliability metrics met thresholds for internal reliability. Inter-rater ICCs for LCEA, Tönnis angle, and alpha angle were (0.928, 0.888, 0.857, all $P < .001$). When we compared 2D radiographic measurements with 3D-reconstructed CT values, there was a significant difference in the LCEA for 2 authors: surgeon 1 (mean [M] = −9.14, standard deviation [SD] = 5.7); t(52) = −11.6, $P < .001$, and surgeon 2 (M = −5.9°, SD = 4.7); t(52) = −9.2, $P < .001$. Significant differences were seen for Tönnis angle for 2 authors: fellow 2 (M = 3.9°, SD = 5.6); t(52) = 5.1, $P < .001$, and surgeon 2 (M = −2.6°, SD = 4.1); t(52) = −4.6, $P < .001$. Alpha angle measurements compared to the 3D-reconstructed alpha angle at 2 o'clock was significantly different for 3 authors: fellow 1 (M = 11.9°, SD = 16.2); t(52) = 5.3, $P < .001$; fellow 2 (M = 10.4°, SD = 18.6); t(52) = 4.1, $P = .002$; and surgeon 2 (M = −6.5°, SD = 16.2); t(52) = −2.9, $P = .005$. Positive mean values indicate 2D radiographic measurements overestimated 3D reconstruction values and negative mean values indicate underestimation. **Conclusions:** The use of 2D radiographs alone for preoperative planning of FAIS may lead to inaccuracies in radiographic measurements. **Level of Evidence:** Level, III retrospective cohort study.

Femoroacetabular impingement syndrome (FAIS) is a common clinical entity that can cause substantial pain and dysfunction for many patients. Accurate diagnosis relies on a triad of symptoms signs and imaging findings.[1] Multiple components are often involved, including both pelvic and femoral morphology in addition to chondrolabral pathology.

Pelvic anatomy can be very complex and the 3-dimensional morphology, particularly of the acetabulum, can be difficult to evaluate.[2,3] FAIS can involve a myriad of different morphologic features, including femoral cam deformity, variations in femoral or acetabular version, to global overcoverage with severe pincer deformity.[4,5] Radiographic imaging for FAIS typically involves an anteroposterior (AP) pelvis, lateral hip, and false profile view.[6] Appropriate diagnosis relies on a number of measurement values, the most common being Tönnis grade, lateral center-edge angle (LCEA), anterior center-edge angle, and Tönnis angle, among others.[3,6]

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Multiple studies have been published on the accuracy of radiographic imaging.[7,8] A growing number of hip-preservation surgeons are favoring 3-dimensional (3D) imaging, most commonly done with reconstructed computed tomography (CT) imaging, both for 3D analysis of acetabular deformity as well as preoperative planning.[9-12] Limited research is available directly comparing 2-dimensional (2D) radiographic measurements with 3D imaging. One study that compared the aforementioned measurements was performed in patients with hip dysplasia, with the authors concluding that LCEA on AP pelvic radiograph was reliable when correlated to the CT reconstruction value.[13] The purpose of this study was to compare the reliability and accuracy of radiographic measurements obtained from 2D radiographs and 3D-reconstructed CT images in the assessment of FAIS. We hypothesized that different values would be obtained from 2D radiographs and 3D-reconstructed CT images.

Methods

A retrospective review was performed for patients with FAIS after we obtained institutional review board approval (approved by WCG institutional review board with protocol number 20214560). Patients diagnosed with FAIS were identified and included if they had a complete set of hip imaging including an appropriate standing AP pelvis and a 45° frog lateral as well as a 3D CT scan with HipMap reconstruction (Stryker, Greenwood Village, CO, USA). All patients from a single institution between the dates of September 2020 and September 2021 were reviewed. Patients were diagnosed with FAIS based on the criteria outlined in the Warwick agreement consisting of a triad of clinical signs, symptoms, and imaging findings similar to international consensus.[1]

Radiographs of the pelvis were considered appropriate if the sacrum was centered at the pubic symphysis approximately 2 to 3 cm above the symphysis in a standing view.[6] Measurements were normalized for any pelvic tilt by setting the horizontal axis as a line connecting the 2 inferior tear drops of the acetabuli. LCEA was measured as the angle between a vertical line perpendicular to the horizontal axis of the pelvis and a line connecting the center of the femoral head and the lateral-most weight-bearing aspect of the acetabulum.[13] For the purposes of clarity and reproducibility, the original language from Wiberg's text regarding the lateral acetabulum was interpreted as stated by Clohisy et al.[6] to be the lateral-most aspect of the sclerotic rim (sourcil). Tönnis angle was measured with a line perpendicular to the horizontal axis of the pelvis through the inferior sourcil and a line connecting the inferior and lateral-most aspects of the sourcil.[6] Alpha angle was measured on the frog lateral as the angle formed by a line connecting the center of the femoral head and neck and its intersection with a line from the center of the femoral head to the point where the femoral head loses sphericity.[6] There are a variety of radiographic views available to the clinician evaluating hip pathology, and previous research has shown the maximum alpha angle corresponds to different radiographic views moving from 12 o'clock, 1 o'clock, 2 o'clock, and 3 o'clock on AP, Dunn, frog, and cross-table views, respectively.[14] In this study, the alpha angle was measured off of the frog view and thus the comparison of alpha angle was performed with the corresponding CT measurement at 2 o'clock.

Radiographic measurements were performed by 2 fellowship-trained sports medicine orthopaedic surgeons (R.C.G. and K.C.P.) with experience in hip arthroscopy and 2 orthopedic sports medicine fellows (D.M.F. and P.J.B.). Each measurement was blinded to previous measurements as well as patient demographics, and each patient was measured on 2 separate occasions at least 2 weeks apart, performed in a randomized sequence. Intra- and inter-rater intraclass correlation coefficients (ICCs) were calculated for all measurements. The mean of 2 separate measurements for LCEA, alpha, and Tönnis angle was compared with the corresponding 3D value for each patient. All statistics were performed using SPSS software, version 27 (IBM Corp., Armonk, NY, USA).

3D CT scan was performed according to guidelines outlined for the HipMap 3D reconstruction (Stryker). 3D reconstructions were analyzed and measured by the Stryker HipMap automated software based on parameters from the published literature.[15] Importantly, the pelvis was placed in an identical orientation for all 3D reconstructions such that all measurements were standardized. HipMap-generated variables that were extracted included LCEA, Tönnis, and alpha angle at 2 o'clock. Previous research has demonstrated the frog lateral radiographic view best characterizes the cam morphology at the 2-o'clock position and thus this was the variable of interest from the HipMap data.[16]

Previous published literature shows average LCEA for 2D radiographs and 3D CT in patients with FAI of 30.8° and 32.9°, respectively.[3] A priori analysis based on the ability to identify a statistically significant difference between measurements with a standard deviation of 5°, 80% power, and a significance of .05 would require 95 patients per group. Although this is a large number, it only represents the number necessary to be certain no

Table 1. Demographic Characteristics

No. of hips/patients	53/44
Age, y	32 ± 14
Male sex, %	29.5%
Right side, %	60.4%

NOTE. Values are expressed as a mean ± standard deviation (range) unless otherwise indicated.

Table 2. Intrarater Intraclass Correlation Coefficients for 2D Radiographic Measurements

	Intraclass Correlation	95% Confidence Interval		Sig
		Lower Bound	Upper Bound	
LCEA				
Surgeon 1	0.960	0.931	0.977	.000
Surgeon 2	0.984	0.973	0.991	.000
Fellow 1	0.873	0.779	0.927	.000
Fellow 2	0.966	0.890	0.985	.000
Tönnis				
Surgeon 1	0.890	0.809	0.936	.000
Surgeon 2	0.941	0.898	0.966	.000
Fellow 1	0.877	0.462	0.953	.000
Fellow 2	0.918	0.683	0.967	.000
Alpha				
Surgeon 1	0.912	0.847	0.949	.000
Surgeon 2	0.981	0.967	0.989	.000
Fellow 1	0.683	0.436	0.820	.000
Fellow 2	0.942	0.900	0.967	.000

2D, 2-dimensional; LCEA, lateral center-edge angle.

type II error is occurring, and this is only for LCEA. Unfortunately, baseline means for Tönnis angle measurement on CT images are not available.

Results

Fifty-three consecutive patients with FAIS who had both standardized radiographs and 3D-reconstructed CT imaging met inclusion criteria. Demographics are listed in Table 1. Nine patients included in the study had staged bilateral hip surgery.

All reliability metrics met the threshold for internal reliability for intra- and inter-rater measurements (Tables 2 and 3, respectively). The intra-rater reliability was strong to excellent and positively correlated between the first and second measurements (ICC 0.68-0.98, $P < .001$). Inter-rater reliability was also excellent for all variables (ICC for LCEA 0.93, Tönnis 0.89, alpha 0.86, $P < .001$).

The mean of the 2 separate 2D measurements for each variable and for each author was compared with 3D-generated data, which is shown in Table 4. LCEA values were significantly different for the 2 attending surgeons, but not for the 2 fellows: surgeon 1 (mean [M] = −9.14, standard deviation [SD] = 5.7); t(52) = −11.6, $P < .001$, and surgeon 2 (M = −5.9°, SD = 4.7); t(52) = −9.2, $P < .001$, fellow 1 (M = −0.78, SD = 6.3); t(52) = −0.9, $P = .38$, and fellow 2 (M = −0.40, SD = 5.9); t(52) = −0.5, $P = .63$. Positive mean values indicate 2D radiographic measurements overestimated 3D reconstruction values, and negative mean values indicate underestimation. 2D Tönnis values were significantly different from 3D values for 2 of the 4 authors: fellow 2 (M = 3.9°, SD = 5.6); t(52) = 5.1, $P < .001$, and surgeon 2 (M = −2.6°, SD = 4.1); t(52) = −4.6, $P < .001$. Three of four author measurements for alpha angle on 2D radiographs were significantly different than 3D reconstructions, with attending surgeon mean measurements resulting in an underestimation versus 3D reconstructions and the 2 fellows mean measurements resulting in an overestimation versus 3D reconstructions: fellow 1 (M = 11.9°, SD = 16.2); t(52)= 5.3, $P < .001$, fellow 2 (M = 10.4°, SD = 18.6); t(52) = 4.1, $P = .002$, and surgeon 2 (M = −6.5°, SD = 16.2); t(52) = −2.9, $P = .005$.

Table 3. Inter-rater Intraclass Correlation Coefficients for 2D Radiographic Measurements

	Intraclass Correlation	95% Confidence Interval		Sig
		Lower Bound	Upper Bound	
LCEA	0.928	0.891	0.955	.000
Tönnis	0.888	0.829	0.931	.000
Alpha	0.857	0.782	0.911	.000

2D, 2-dimensional; LCEA, lateral center-edge angle.

Discussion

The most important findings of this study were that radiographic measures were highly reliable but had limited accuracy for commonly used 2D radiographic measurements compared with 3D-reconstructed images. Two-dimensional radiographs are considered the gold standard, as 3D reconstruction data with this technology have yet to be validated. We specifically found high intra- and inter-rater reliability for all authors and for all variables, with lowest accuracy observed with the alpha angle, followed by LCEA and Tönnis angle.

Table 4. 2D vs 3D CT Comparison

	Mean	Std. Deviation	95% Confidence Interval		Sig. (2-tailed)
			Lower	Upper	
2D LCEA vs CT LCEA					
Surgeon 1	−9.14	5.72	−10.72	−7.56	.000
Surgeon 2	−5.97	4.71	−7.27	−4.68	.000
Fellow 1	−0.77	6.31	−2.51	0.97	.376
Fellow 2	−0.40	5.95	−2.04	1.24	.630
2D Tönnis vs CT Tönnis					
Surgeon 1	0.08	1.26	−0.27	0.42	.666
Surgeon 2	−2.60	4.09	−3.73	−1.48	.000
Fellow 1	−1.13	5.07	−2.53	0.27	.110
Fellow 2	3.92	5.59	2.37	5.48	.000
2D alpha vs CT alpha at 2 o'clock					
Surgeon 1	−6.49	16.29	−10.98	−2.00	.005
Surgeon 2	−3.49	17.32	−8.26	1.28	.148
Fellow 1	8.29	15.49	4.02	12.56	.000
Fellow 2	6.78	15.46	2.52	11.04	.002

NOTE. Positive and negative mean values are relative to the 3D-generated value where positive values are overestimations of the 3D value and negative values are underestimations of the 3D value.

2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; LCEA, lateral center-edge angle.

Early investigations demonstrated high intraobserver but poor interobserver reliability of radiographic measurements of the hip.[17] Subsequent studies also have demonstrated poor interobserver reliability of radiographic measurements, with one study in particular finding interobserver reliability to be particularly poor with regard to alpha angle, LCEA, and Tönnis angle (95% confidence intervals less than 55%).[7,18] Reliability studies are subject to inherent bias based on study design, and a recent systematic review has outlined best practices in order to minimize bias.[19] There is limited availability of studies that have appropriately minimized bias according to these best practices. This recent review also found that across studies investigating the reliability of commonly used measurements of the hip, the LCEA demonstrated the greatest reliability whereas the Tönnis angle was consistently poor.[19] Our study contrasts these previous studies, showing greater intra- and inter-rater scores for all authors for LCEA, Tönnis angle, and alpha angle. This suggests by using strict definitions and literature reference, these parameters can be used as a consistent means of evaluating hip morphology in a reliable manner.

In our study comparing the 2D measurements of LCEA with 3D CT scan, significant differences were seen in the senior authors, whereas no difference was seen among current fellows. This finding may be interpreted in several ways. It is possible that fellows overestimated the LCEA by more closely measuring the lateral margin of the acetabulum rather than the lateral margin of the sourcil. It is also possible that the 3D software overestimates the LCEA compared with radiographic views. The 2D images were performed as weight-bearing views, whereas the CT scan was performed with the patient supine. Recent literature has highlighted differences of radiographic acetabular parameters depending on the position of the pelvis at the time of imaging.[20-23] As a result of the relative flexion or extension of the pelvis, the 2D LCEA does not necessarily correlate with the 3D anatomy. Hip-preservation literature has recently advocated for the use of image analysis software intraoperatively to aid in the accuracy of periacetabular osteotomy placement.[24] Similar reasoning justifies the use of intraoperative imaging analysis software in hip arthroscopy to reduce or eliminate variability in pelvic positioning when on the operating table.

Accurate measurement of LCEA is a critical aspect in hip-preservation surgery as it pertains to both surgical indications and outcomes. The degree of acetabular coverage is defined by LCEA measurement: normal acetabular coverage (25°-40°), acetabular overcoverage (≥40°), borderline dysplasia (20°-24.9°), and frank dysplasia (<20°). Some studies have demonstrated poorer outcomes of hip-preservation surgeries for a subset of borderline dysplastic patients, emphasizing the importance of accurate measurement of LCEA.[25,26] Previous research has demonstrated interobserver standard error of measurement on plain radiographs to be 3° for LCEA.[27] With average values between 2D and 3D measurements exceeding 3° for the surgeons, this suggests the difference is beyond simple measurement error and may therefore be attributable to true morphological differences between 2D and 3D measurements. This understanding highlights the importance of recognizing differences in measurement tools for diagnosis and correction of acetabular pathology specific to patients for FAIS. Further, comparing 2D and 3D LCEA measurements may become especially valuable for those patients with acetabular morphology that may be straddling the line between borderline hip dysplasia and true dysplasia.

Early studies began to identify poor correlation of the alpha angle with 2D CT scan.[28] Many of these studies found differences in the plane of measurement and location of alpha angle measurement on 2D radiographs and 3D CT scans were not necessarily identical. Further research found the frog lateral radiograph most strongly correlates with the maximal alpha angle at 2 o'clock.[16,29] Our results demonstrated significant differences of the alpha angle on 2D versus 3D reconstruction in 3 of the 4 authors. Alpha angle showed the most varied intraobserver reliability among authors, which is possibly explained by level of experience. There are several potential sources of error when measuring alpha angle, including attention to detail in measuring the center of the head, identifying the exact point when the head becomes aspherical, and depending on the thickness of the best fit circle on imaging software, whether the outer or the inner diameter of the circle is used for measurement. Previous studies have shown the standard error of measurement for alpha angle to be 6°.[27] This degree of error may be the difference between a successful femoroplasty and an inadequate one.

Limitations

This study is not without limitation. Based on the availability of current literature, it is not possible to perform a power analysis for all variables of interest and this study is slightly underpowered with regards to LCEA. Based on the high intraobserver reliability and the strict definitions used to classify patients with FAIS, it is unlikely that more patients added to the study would yield a different result, although this cannot be said for certain. The second limitation is the use of software-generated measurements for 3D reconstructions, whereas manual measurements were used for 2D radiographs. This could have yielded different results if the authors manually performed measurements on 3D reconstructions; however, this is not routinely performed in clinical practice and therefore was not done to represent a more realistic clinical scenario. A third limitation is the difference of patient orientation between 2D radiographs and the 3D reconstructions. The 2D images were performed as weight-bearing views, whereas the CT scan was performed with the patient in the supine position. Pelvic inclination varies depending on standing or supine, and this can affect the measurements of LCEA, Tönnis angle, and alpha angle between the 2D radiographs and the 3D reconstructions. This was a limitation that was impossible to avoid, as this was a retrospective study and the patient orientation in each imaging modality is the standard of care.

Conclusions

The use of 2D radiographs alone for preoperative planning of FAIS may lead to inaccuracies in radiographic measurements.

Disclosure

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: K.C.P. reports Micromed Inc: 3 payments for education lectures. All other authors (D.M.F., P.J.B., R.C.G.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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