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Do Changes in Pelvic Rotation and Tilt Affect Measurement of the Anterior Center Edge Angle on False Profile Radiographs? A Cadaveric Study

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Abstract

Background The false profile radiograph assesses acetabular coverage in prearthritic hip conditions. Precise rotation of this radiograph is difficult to obtain, so the clinician must interpret radiographs with nonstandard pelvic rotation or tilt, despite limited evidence of how this may affect the anterior center edge angle measurement.

Questions/purposes (1) Does pelvic rotation alter the measurement of the anterior center edge angle on false profile views? (2) Does pelvic tilt alter the measurement of the anterior center edge angle on false profile views? (3) Is there an objective way to assess appropriate pelvic rotation for the false profile view?

Methods Eight cadaver hips (four female, four male; one hip randomly selected per pelvis) were included in the study. Hips with degenerative changes, evidence of previous fracture or trauma, or previous surgical intervention were excluded. Specimens were between 68 to 92 years of age (median, 76 years). The specimens were fixed to a custom jig, and radiographs were taken at 5° intervals of rotation (45–85°) and 5° intervals of pelvic tilt (+10° to -10°). The primary outcome variable, anterior center edge angle, was measured for each rotation and tilt.

Results Every degree increase in pelvic rotation toward a true lateral resulted in 0.18° increase in the anterior center edge angle (95% confidence interval [CI], 0.07–0.29; p = 0.002). For every degree increase in pelvic tilt, the anterior center edge angle increased 0.65° (95% CI, 0.5–0.8; p < 0.001). We verified that standard pelvic rotation of 65° for a

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false profile radiograph was present when the space between the femoral heads is 66% to 100% of the diameter of the femoral head being imaged.

Conclusions This study shows that the anterior center edge angle increases as pelvic tilt increases, with a 6° increase in anterior center edge angle for each 10° increase in pelvic tilt. Since the false profile radiograph is obtained standing, the patient should be counseled to avoid adopting a forced posture, ensuring the radiograph remains an accurate functional representation of the patient's anatomy. In contrast, pelvic rotation did not influence the anterior center edge angle by an important margin, and while we recommend that radiographs continue to be obtained with standardized pelvic rotation, aberrant pelvic rotation will likely not result in a clinically meaningful difference in anterior center edge angle measurements. In the future, studies to identify the specific regions of acetabular anatomy that constitute the radiographic measurement of the anterior center edge angle would enhance current understanding of the associated radiographic anatomy, and consequently improve the ability of the surgeon to treat the specific area of pathology.

Clinical Relevance In practice, the clinician should pay close attention to pelvic tilt, as a 10° change in tilt may cause 6° of change in the anterior center edge angle. However, false profile radiographs obtained within ± 20° of the targeted 65° of rotation will result in less than 4° change in the anterior center edge angle.

Introduction

Hip pain and dysfunction in the young adult can be caused by many disorders, including structural deformities such as acetabular dysplasia and femoroacetabular impingement (FAI) [2]. When these two entities are in the differential, a complete radiographic exam is fundamental to guide accurate diagnosis and treatment after obtaining a thorough history and performing a physical examination [1, 2]. A standard set of films might include an AP view of the pelvis (AP pelvic view), a cross-table lateral view, a 45° or 90° Dunn view, a frog-leg lateral view, and a false profile view. The latter is key to establishing the degree of anterior acetabular coverage.

The false profile radiograph, obtained by rotating the pelvis 65° from an AP view [10], is the principal radiographic image to evaluate anterior acetabular coverage of the femoral head and is commonly used in the evaluation of young adults with hip pain. Normal values for the anterior center edge angle are greater than 25°, borderline dysplasia is suggested between 20° to 25°, and insufficient anterior coverage is considered when values are less than 20° [1, 4]. The precise degree of rotation makes a true false profile radiograph difficult to obtain in clinical practice [12], and the clinician must often interpret false profile radiographs with suboptimal pelvic rotation, despite no current understanding of how this affects radiographic measurements. Lequesne and de Seze [10] suggested that the pelvis is appropriately rotated when the distance between the medial borders of the femoral heads is two- to three-thirds the diameter of the imaged femoral head. However, this recommendation lacks validation. Additionally, despite the importance of the anterior center edge angle in establishing a diagnosis and dictating patient management, to our knowledge there is no information in the evidence regarding the effect of pelvic tilt or rotation on the anterior center edge angle measurement.

We therefore asked: (1) Does pelvic rotation alter the measurement of the anterior center edge angle on the false profile view? (2) Does pelvic tilt alter the measurement of the anterior center edge angle on the false profile view? (3) Is there an objective way to determine if a false profile radiograph has appropriate pelvic rotation?

Materials and Methods

Cadaver Specimens

Institutional Review Board approval was waived for the cadaveric study. All cadaveric specimens underwent a screening AP pelvis radiograph to ensure that none had signs of osteoarthritis (defined as Tönnis grade ≥ 2, or joint space narrowing compared with the contralateral hip), labral ossification, acetabular rim fractures, or previous surgical intervention affecting the bony hip morphology. We included specimens without these abnormalities in the current study. Fifteen hips from eight cadaveric specimens (four female and four male pelvises, and eight right and seven left hips), ranging in age from 68 to 92 years (median, 76 years) without radiographic evidence of osteoarthritis were eligible for inclusion in the study. One hip was excluded due to prior instrumentation of the proximal femur with a sliding hip screw for fracture fixation.

Soft tissues were dissected from the pelvis, leaving the hip capsule, pubic symphysis, and sacroiliac joint ligaments intact. The sacrum was disarticulated through the lumbosacral junction, and the proximal femur was transected 10 cm distal to the lesser trochanter. A capsulotomy was performed, and the hip was subluxated to allow complete visualization of the acetabulum, providing accurate localization of the acetabular rim. We defined the 6 o'clock clockface position as the midpoint of the transverse acetabular ligament and 12 o'clock was directly superior to 6 o'clock. Regardless of laterality, we defined 3 o'clock as anterior and 9 o'clock as posterior. For purposes of a separate study, the acetabular labrum was sharply incised from 9 o'clock to 3 o'clock, removing all soft tissue

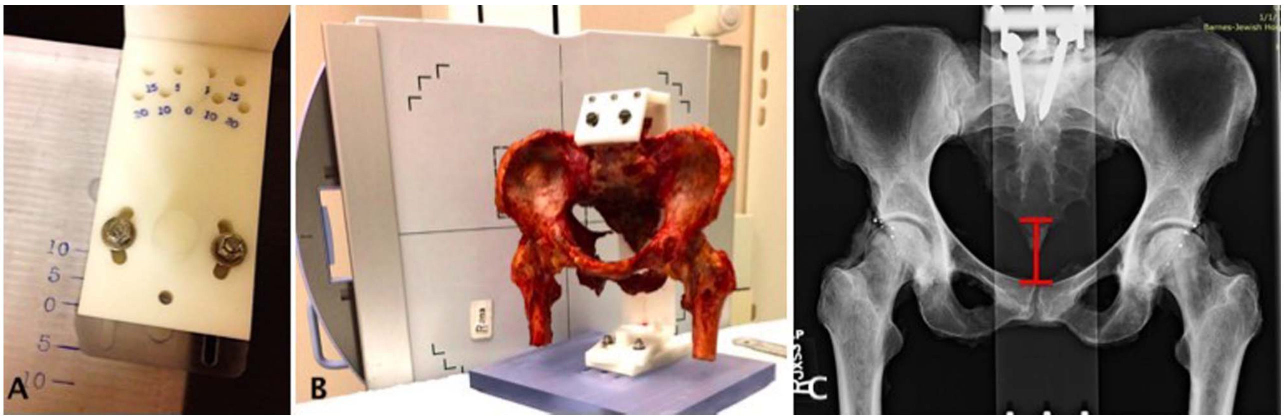

Fig. 1 A-C **(A)** A custom jig provided reproducible pelvic rotation in 5° intervals from 45° to 85° pelvic rotation and +/- 10° pelvic tilt, simulating increasing and decreasing lumbar lordosis. **(B)** Shown here is the sample pelvic specimen fixed to the jig. **(C)** We obtained an AP pelvis radiograph to confirm standardized positioning of each pelvis with the sacrum in line with the pubic symphysis, and the sacrococcygeal joint within 3 to 5 cm of the pubic symphysis.

adjacent to the acetabular rim. Alternating 1/16- and 3/32-inch round metallic markers (MSC Industrial Supply, Melville, NY, USA) were impacted into the subchondral bone of the acetabular rim at each clockface location from the 9 o'clock to 3 o'clock positions, as previously described in anatomic studies [7-9, 16, 18]. Subsequently, the labrum was reattached, and the capsulotomy was closed to accurately reduce the femoral head within the acetabulum. This was done to facilitate accuracy of the measurement of distances between the femoral heads and measurement of the anterior center edge angle. In all specimens, appropriate hip reduction without subluxation was confirmed on initial radiographic images.

Image Acquisition

A custom jig was designed to allow for precise and reproducible positioning of the pelvis during radiographs (Fig. 1). The pelvis was provisionally secured to the jig through the sacrum in a position of neutral pelvic tilt and rotation confirmed on AP radiographs. Neutral tilt was defined as the top of the pubic symphysis within 5 cm of the sacrococcygeal joint, and neutral tilt was defined as the midpoint of the pubic symphysis within 1 cm of the midpoint of the sacrococcygeal joint [1, 17] (Fig. 1).

For each specimen, we obtained a standardized AP pelvis as described above, and for each hip, a standardized false profile radiograph was taken with the pelvis rotated 65° relative to the AP pelvis radiograph, with the beam centered on the femoral head of the hip being evaluated. No hips were dysplastic based on measurements of LCEA, Tönnis angle, or the anterior center edge angle at 65°. The mean LCEA was 33° (range, 25-43°) and the mean Tönnis angle was 2° (-6 to 6°). The mean anterior center edge angle on true false profile radiographs was 32° (range, 25–41°). Two hips had a high crossover sign, and two hips had a positive ischial spine sign (Table 1).

Table 1. Demographics of cadaveric specimens and values for standard radiographic parameters of acetabular morphology as measured on the AP pelvis and 65° false profile radiograph

Specimen	Hip (right/left)	Age (years)	Sex (M/F)	LCEA (°)	Tönnis angle (°)	Crossover sign (Y/N)	Ischial spine sign (Y/N)	ACEA (65° rotation)
Pelvis 1	Left	78	F	34.3	3.6	N	N	34.4
Pelvis 2	Left	91	M	27.8	2.0	Y	Y	34.6
Pelvis 3	Right	74	F	31.5	4.5	N	N	30.3
Pelvis 4	Right	81	F	42.1	1.2	N	N	40.8
Pelvis 5	Right	92	M	27.7	-0.7	N	N	35.8
Pelvis 6	Left	68	M	29.5	1.1	N	N	35.8
Pelvis 7	Left	80	F	28.0	5.6	N	N	36.4
Pelvis 8	Right	69	M	39.8	-5.6	Y	Y	23.9

LCEA = lateral center edge angle; ACEA = anterior center edge angle.

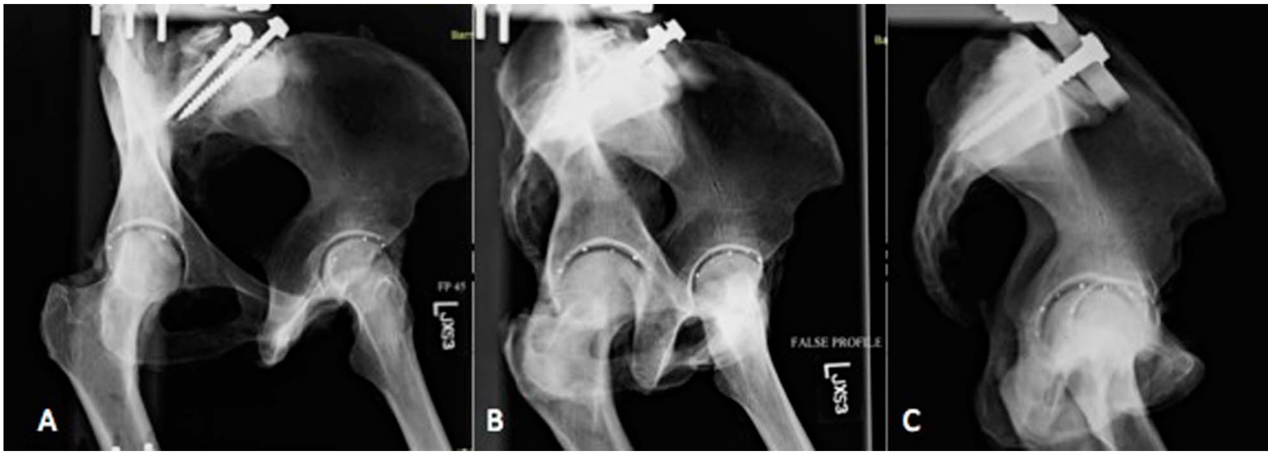

Fig. 2 Radiographs of cadaveric hips were obtained in 5° intervals from 45° of pelvic rotation to 85° of rotation. Images are examples of (A) a modified false profile radiograph at 45° rotation, (B) a standard false profile radiograph at 65° rotation, and (C) a modified false profile radiograph at 85° rotation.

The pelvis was then rotated in 5° increments ranging from +20° to -20° from the starting false profile rotation of 65° to obtain modified false profile views, spanning pelvic rotation from 45° to 85° (Fig. 2). Finally, various pelvic tilts from +10° to -10° were obtained with the pelvis rotated at the standard 65° false profile view. For purposes of further discussion, "over-rotated" refers to rotation from 70° to 85° (approaching a true lateral radiograph), while "under-rotated" refers to rotation from 45° to 60° (approaching a Judet view). Tilt from + 5° to +10° refers to posterior pelvic tilt (decreasing lumbar lordosis), while tilt from -5° to -10° refers to anterior pelvic tilt (increasing lumbar lordosis).

Measurements

A single reader (SMP) completed the radiographic analysis using OsiriX (Pixmeo, Geneva, Switzerland). We analyzed acetabular morphology on the AP pelvis radiograph as described by Clohisy et al. [1], including measurement of the lateral center-edge angle, Tönnis angle, and assessment of the crossover sign and prominent ischial spine sign. On the true and modified false profile views, the diameter of the imaged femoral head and the horizontal distance between the medial aspects of the femoral heads were measured, and the proportional relationship between these two variables was calculated as originally described by Lequesne and Laredo [11] for judgment of rotation of the false profile radiograph.

The anterior center edge angle was measured on the false profile and modified false profile views by calculating the angle formed between a vertical line and a line connecting the center of the femoral head to the anterior aspect of the sclerotic acetabular sourcil [6, 10].

Statistical Analysis

We assessed the reliability of measurement of the anterior center edge angle with an intraclass correlation coefficient (ICC). The ICC was calculated for a subset of 15 false profile radiographs by repeat measurement by the primary reader (SMP) at two separate points. The ICC was rated as poor (< 0.2), fair (0.21–0.4), moderate (0.41–0.6), good (0.61–0.8), or very good (0.81–1) [5]. Intraclass correlation coefficient for measurement of the anterior center edge angle was 0.983, indicating almost-perfect agreement within measurements of the anterior center edge angle at different points.

The primary outcome variable, the anterior center edge angle, was measured on each hip specimen in each position. Analyses of the anterior center edge angle outcome for tilt and rotation were conducted using a repeated measures model with a first-order autoregressive covariance structure (PROC MIXED, SAS 9.4; SAS Institute Inc, Cary, NC, USA). For subjects with bilateral data, a random hip (right or left) was selected resulting in a total of eight hips included for the data analyses.

Results

Effect of Rotation and Tilt on Anterior Center Edge Angle

As pelvic rotation increased toward that of a true lateral, the anterior center edge angle likewise increased by a mean of 0.18° per degree of rotation (95% confidence interval [CI], 0.07–0.29; p = 0.002) (Table 2).

As pelvic tilt increased (or with increasing lumbar lordosis), the anterior center edge angle increased by 0.65° per

Table 2. Univariable repeated-measures analysis results for pelvic rotation

Variable	Slope estimate	95% confidence interval	p value
Pelvic rotation	0.18	0.07-0.29	0.002
Tönnis angle	0.08	-1.3 to 1.45	0.896
ISS: yes	-1.34	-11.64 to 8.95	0.759
Female	-1.8	-10.67 to 7.07	0.637
LCEA	-0.24	-1.06 to 0.58	0.504

LCEA = lateral center edge angle.

degree of increased pelvic tilt (95% CI, 0.5–0.8; $p < 0.001$) (Table 3). Sex, LCEA, Tönnis angle, and the presence of an ischial spine sign or crossover sign were not associated with change in the anterior center edge angle.

Determination of Rotation

Appropriate pelvic rotation has been obtained on a false profile radiograph (65° rotation) when the distance between the femoral heads is two- to three-thirds the diameter of the imaged femoral head. By rotating pelvic specimens from 45° to 85°, we found that the distance between the femoral heads averaged 82 ± 19% of the diameter of the referenced femoral head. Of the eight hips in our study, 25% of specimens at 60° rotation (n = 2), 75% of specimens at 65° rotation (n = 6), and 13% of specimens at 70° rotation (n = 1) fell within this range. No hips fell within this range at rotations less than 60° or greater than 70° (Fig. 3).

Discussion

A standardized and accurate radiographic exam is fundamental in establishing a diagnosis and treatment plan for structural hip deformities in young adult patients [1-3, 14, 15]. The false profile radiograph is used to evaluate anterior acetabular coverage; however, the precise degree of pelvic rotation required makes a true false profile radiograph difficult to obtain in clinical practice [12], and clinicians are oftentimes faced with interpreting false profile radiographs with pelvic rotations other than 65°. The purpose of this study was to determine if pelvic rotation or tilt affected measurement of the anterior center edge angle. We found that when pelvic rotation was increased toward a true lateral of the pelvis, the anterior center edge angle also increased, although to a small degree. Alterations in pelvic tilt had a more pronounced effect, with increasing pelvic tilt resulting in an increased anterior center edge angle. We also validated that, when assessing a false profile radiograph, appropriate pelvic rotation may be assumed when the distance between the femoral heads is two- to three-thirds the diameter of the imaged femoral head.

Table 3. Univariable repeated-measures analysis results for pelvic tilt

Variable	Slope estimate	95% confidence interval	p value
Pelvic tilt	0.65	0.5-0.8	< 0.001
Tönnis angle	0.51	-1.31 to 2.33	0.509
ISS: yes	-5.37	-18.59 to 7.86	0.351
Female	2.69	-9.42 to 14.82	0.600
LCEA	-0.01	-1.19 to 1.16	0.981

LCEA = lateral center edge angle.

The study has several limitations. First, as in many cadaveric studies, the sample size was small. We had similar numbers of male and female hips and did not find sex to be a contributing factor to changes in anterior center edge angle, but we are unable to say whether a difference between sexes or even different races or ethnicities would become noticeable with a larger sample size. Second, although two of the eight pelvises had positive crossover and ischial spine signs indicative of mild acetabular retroversion, there were no dysplastic hips included in the study. The false profile is frequently the most scrutinized in cases of borderline dysplasia, where having an accurate measurement of the anterior center edge angle is critical and attention to pelvic positioning is most crucial. In these instances, the imaged hips are not grossly dysplastic. However, we are unable to say whether the observed changes in anterior center edge angle with differing pelvic position might be different or more or less pronounced in the setting of obvious dysplasia. Third, our study had one individual perform the radiographic analysis; however, our study was not seeking to determine the interobserver reproducibility of the anterior center edge angle, but rather the change in anterior center edge angle within a specific hip over a range of pelvic rotation and tilt. In this case, we considered it important to have a consistent observer with demonstrated intraobserver reliability perform the measurements and do not feel that additional observers would have added to the findings. Fourth, the ages of the specimens were older than the typical patient population evaluated for structural hip deformities; however, in the absence of degenerative or traumatic changes, acetabular morphology remains constant with advancing age after skeletal maturity. Fifth, obtaining a false profile radiograph rotated specifically to 65° is difficult in everyday clinical practice. Given that our results demonstrate pelvic position does influence measurement of the anterior center edge angle, it is important to remain critical of the quality of the radiograph, and our finding that validates the ratio of the

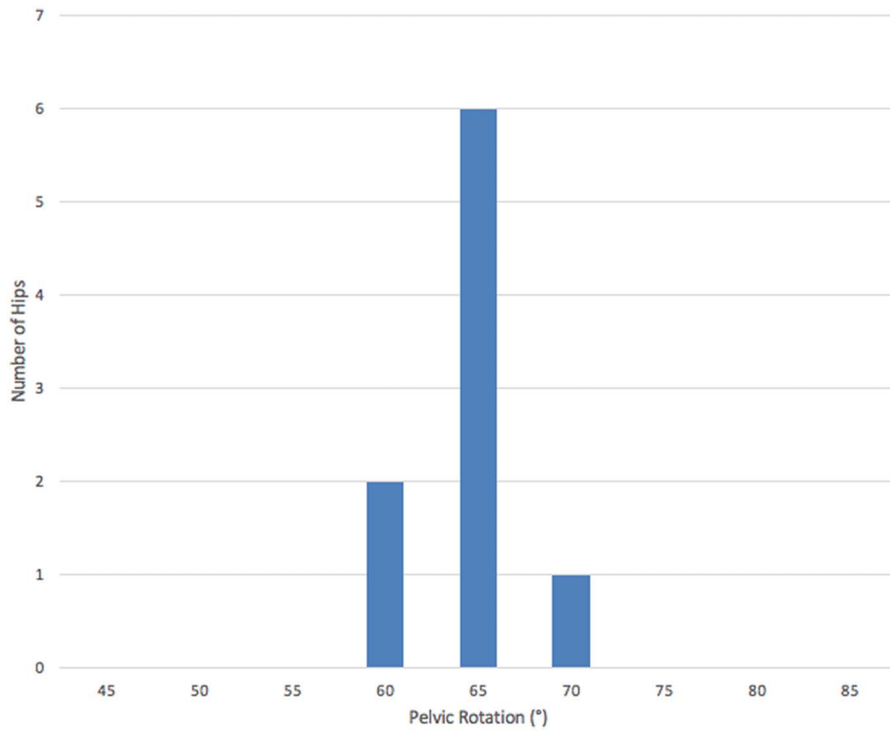

Fig. 3 Appropriate pelvic rotation is objectively confirmed when the ratio of the distance between the medial borders of the femoral heads to the diameter of the index femoral head is 66% to 100%. This is a representation of the number of hips in which the calculated ratio fell between 66% to 100% at each rotation. One hip had a ratio between 66% to 100% at both 60° and 65°. No hips met criteria at rotations less than 60° or greater than 70°.

distance between the femoral heads to the diameter of the imaged femoral head when the pelvis is rotated 65° is helpful in determining the adequacy of a false profile radiograph for interpretation.

We found that pelvic rotation altered the measurement of the anterior center edge angle on false profile views, but to a surprisingly small degree. A previous study by Monazzam et al. [13] found that standard parameters of acetabular coverage, including the LCEA and crossover sign, were affected by as little as 10° rotation or 5° tilt of an AP pelvis radiograph. In contrast with their findings that rotation affected measurements on the AP radiograph, our study found that false profile radiographs could be rotated up to 20° from the standard 65° of rotation and result in less than 4° change in the anterior center edge angle (with an increase in the anterior center edge angle observed as the rotation trends towards a lateral radiograph). It is probable that clinical decision making based on the anterior center edge angle would not be overly affected even in the setting of a fairly large discrepancy between desired and actual pelvic rotation.

In contrast, we found that pelvic tilt substantially altered the measurement of the anterior center-edge angle on false profile views. Siebenrock et al. [17] similarly described the effect of pelvic tilt on the presence or absence of a crossover sign in AP pelvis radiographs, with increasing forward tilt resulting in an increased number of false positive crossover signs. Zingg et al. [19] varied pelvic tilt for false profile radiographs in cadaveric specimens and found that the anterior center edge angle changed linearly by 0.63° for every degree change in pelvic tilt. Although their study adjusted tilt by varying the inclination of the x-ray beam, their result is nearly identical to the change observed in the current study (0.65° for every degree of increased pelvic tilt). In contrast to varied rotation, which has a small effect on the measurement of the anterior center edge angle, alterations in pelvic tilt resulted in much larger changes, with a 10° increase in anterior pelvic tilt resulting in a 6° increase in anterior center edge angle measurements. It is important to note that the false profile radiograph is a standing radiograph. As such, patients should be counseled not to assume a forced posture during the radiographic examination, which will not only ensure that the radiograph is a good functional representation of a patient's anatomy but will also minimize effects of altered tilt on measurement of the anterior center edge angle.

Although the precise degree of rotation and wide range in body habitus can make a false profile radiograph difficult to obtain in clinical practice [12], we validated the statement by Lequesne and de Seze [10] that a radiograph was appropriately rotated when the distance between the femoral heads was two- to three-thirds the diameter of the imaged femoral head. All pelvises that demonstrated this relationship were between rotations of 60° to 70°, and no pelvis demonstrated this relationship outside of that range. Although pelvic rotation has a small effect on the measurement of the anterior center edge angle, the clinician can reliably use this ratio to confirm appropriate pelvic positioning and to ensure standardized acquisition of false profile radiographs, improving consistency and accuracy of diagnostic measurements. Standardization and accuracy become of the utmost importance in patients with mild or borderline dysplasia. When the anterior center edge angle approaches clinically relevant thresholds, more sophisticated imaging with CT scan, 3-D reconstruction, and magnetic resonance imaging may be pursued.

This study shows that the anterior center edge angle increases as pelvic tilt increases, with a 6.5° increase in anterior center edge angle for each 10° increase in pelvic tilt. Since the false profile radiograph is obtained standing, the patient should be counseled to not adopt a forced posture, ensuring the radiograph remains an accurate functional representation of a patient's anatomy. In contrast, pelvic rotation did not influence the anterior center edge angle by an important margin, and while we recommend that an emphasis continue to be placed on obtaining radiographs with standardized pelvic rotation, aberrant pelvic rotation will likely not result in a clinically meaningful difference in anterior center edge angle measurements. In the future, studies to identify the specific regions of acetabular anatomy that reflect the radiographic measurement of the anterior center edge angle would enhance current understanding of the associated radiographic anatomy, and consequently, improve the ability of the surgeon to treat the specific area of pathology.

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