

Is Quantitative Radiographic Measurement of Acetabular Version Reliable in Anteverted and Retroverted Hips?

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Abstract

Background The acetabular version is crucial for hip function, and its accurate assessment is necessary for treating patients with hip disorders. Current studies reveal discrepancies in the precision of quantitative radiographic measurements versus CT measurements, but there is a lack of focused analysis on anteverted versus retroverted hips. This study aims to fill this gap by directly comparing the reliability of these two methods in assessing varied hip configurations.

Questions/purposes (1) How reliable are quantitative radiographic and CT methods in measuring the acetabular version angle? (2) Is there any difference in the reliability of acetabular version angle measurements using

radiography compared with CT in anteverted and retroverted hips? (3) What is the extent of variation in acetabular version measurements when quantitative radiographic and CT methods are compared in anteverted and retroverted hips?

Methods We searched our image archives for patients who had received both radiographs and CT scans between January 2020 and June 2022 and found 84 patients who met the criteria. From these patients, we selected those who presented with hip pain of different causes and who had no previous elective and/or hip trauma surgery, no hip dysplasia, and results from adequate radiographic examinations. Accordingly, 73% (61 of 84) of the patients were included in this study, and angle measurements were performed on both hips of these patients (122 hips). Standardized positioning was meticulously verified for all plain radiographs and CT scans utilized in the measurement process. We measured quantitative angles and assessed qualitative signs of retroversion, including crossover, posterior wall, and ischial spine findings. We considered a hip with at least one of these findings a retroverted hip, and the hips without these findings were included in the anteverted hip group. Three clinicians took measurements independently. Measurement reliability and agreement were examined using intraobserver and interobserver intraclass correlation coefficients (ICCs), with statistical analyses including paired and independent t-tests. To investigate the reliability of quantitative radiographic and CT methods, we assessed both intraobserver and interobserver agreements. To explore the reliability disparities in measuring the acetabular version via radiography and CT in anteverted and retroverted hips, we analyzed the agreement between measurements from both modalities in the hip groups. Furthermore, to evaluate the degree of variation in acetabular version measurements when comparing quantitative radiographic and CT methods in anteverted and retroverted hips, we utilized paired

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and independent t-tests to examine the measurement differences within these hip categories. The difference between radiographic and CT measurements was also evaluated by Bland-Altman analysis.

Results Quantitative radiographic measurements showed intraobserver and interobserver reliabilities with ICCs of 0.87 (95% CI 0.84 to 0.91) and 0.78 (95% CI 0.75 to 0.82), respectively, and CT measurements demonstrated higher reliabilities with ICCs of 0.92 (95% CI 0.90 to 0.93) and 0.91 (95% CI 0.89 to 0.92), respectively. The reliability of measuring the acetabular version in anteverted hips was moderate, with an ICC of 0.59 (95% CI 0.49 to 0.68). In contrast, retroverted hips showed an ICC of -0.41 (95% CI -1.17 to 0.08), indicating a lack of consistency between quantitative radiographic and CT measurements. Variation in measurement on plain radiographs in anteverted hips was less than that of retroverted hips (mean $\pm$ SD absolute difference between anteverted hips and retroverted hips $3^\circ \pm 3^\circ$ versus $6^\circ \pm 4^\circ$; $p = 0.0001$), indicating greater variability in the radiographic measurement of retroverted hips. According to Bland-Altman analysis, we observed that the difference between radiographic and CT measurements was well outside the CI, especially in retroverted hips.

Conclusion Although quantitative radiographic measurement demonstrates acceptable intraobserver and interobserver reliabilities, its precision is lower than that of CT-based measurements. Specifically, quantitative radiographic methods are prone to a larger margin of error in retroverted hips. For more precise assessments of acetabular version, especially in retroverted hips, we recommend using CT measurement instead of the radiographic method.

Level of Evidence Level III, diagnostic study.

Introduction

The three-dimensional (3D) configuration of the acetabulum in relation to the pelvis, known as the acetabular version, is fundamental in defining the hip's structure, stability, ROM, and functional capacity [5]. Precise assessment of the acetabular version is integral, not only to the identification of developmental conditions but also to strategizing treatments for various hip disorders, thereby enhancing patient outcomes [5, 6]. Initial imaging typically involves standard radiographs, which easily measure parameters like Sharp angle, center-edge angle, and Shenton acetabular index [5]. However, gauging the acetabular version poses a notable challenge, especially when addressing a retroverted hip. The reliability of certain diagnostic indicators comes into question, as these tend to vary significantly with the radiographic interpreter's experience and the patient's positioning during the procedure [3, 14, 15].

Axial and 3D scans, such as CT and MRI [1-3, 7, 12, 15, 18], generally provide a more precise assessment of acetabular morphology compared with standard radiography [9-11, 13, 17]. Additionally, the use of automated software algorithms enhances the accuracy of these measurements [5]. On the other hand, certain studies [10, 13] indicate that data from quantitative radiographic techniques are comparable to measurements taken from CT scans. However, the effectiveness of these imaging techniques may not be consistent across all hip shapes. Although this issue may not substantially impact the assessment of anteverted hips, it can lead to inaccurate interpretations in retroverted hips because the complex 3D structure of the acetabulum is not fully appreciated in biplanar radiographs [11]. It is imperative to ascertain the reliability of quantitative radiographic measurements in anteverted and retroverted hip configurations. As far as we know, there has been no study comparing the evaluation of anteverted and retroverted hips.

We therefore asked the following questions: (1) How reliable are quantitative radiographic and CT methods in measuring the acetabular version angle? (2) Is there any difference in the reliability of acetabular version angle measurements using radiography compared with CT in anteverted versus retroverted hips? (3) What is the extent of variation in acetabular version measurements when quantitative radiographic and CT methods are compared in anteverted and retroverted hips?

Patients and Methods

Study Design and Setting

The study conducted a retrospective analysis of the electronic imaging records of patients who visited the orthopaedic outpatient clinics at the Yeditepe University Faculty of Medicine Hospitals. Three experienced clinicians analyzed the data to evaluate the clinical symptoms and imaging results of patients from an urban setting. The researchers reviewing the imaging data were all seasoned orthopaedists, each with a decade or more of experience and a focused interest in surgeries of the hip and lower limbs.

Patients

We conducted a thorough review of imaging records at Yeditepe University Hospital's orthopaedic outpatient clinic, focusing on White patients who underwent both radiographs and CT scans from January 2020 to June 2022. Of the initial pool, we identified 84 patients who matched our selection criteria: they experienced hip pain from

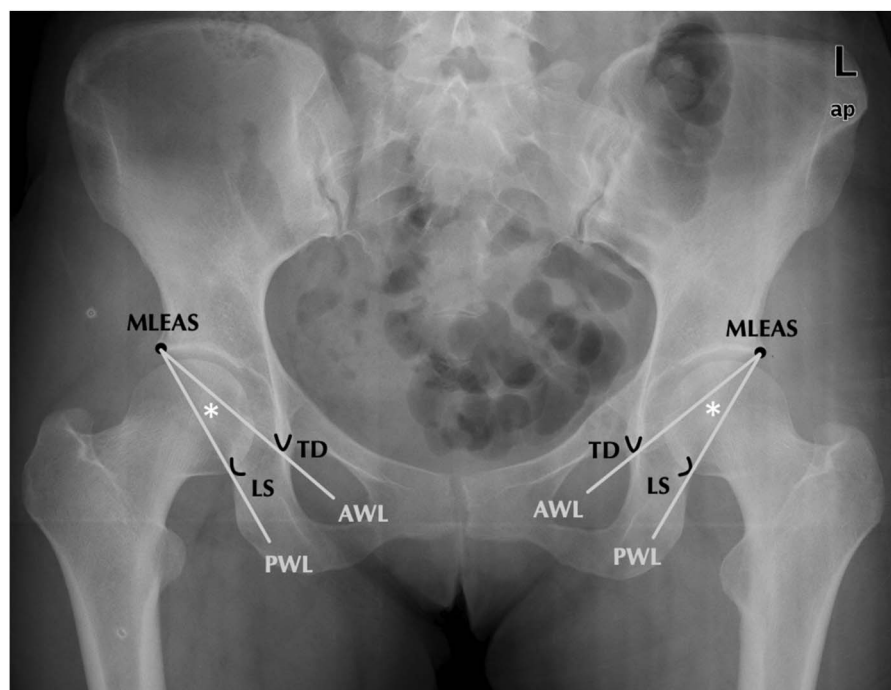


Fig. 1 This AP pelvic radiograph shows the measurement of the acetabular version angle. The angle between the anterior and posterior wall lines of the acetabulum, denoted by the *, is accepted as the radiographic acetabular version angle. MLEAS = most lateral edge of acetabular sclerosis; TD = teardrop; LS = lunate sclerosis; AWL = anterior wall line; PWL = posterior wall line.

various causes but had no history of elective or trauma-related hip and/or lumbar spine surgeries, and no hip dysplasia. From this group, 61 patients (accounting for 73% of the original cohort) qualified for our study, which involved conducting angle measurements on both hips, totaling 122 hips for our analysis. These patients were chosen excluding any patients with hip osteoarthritis, acetabular protrusion, results from inadequate radiographic evaluations, and those outside the age range of 18 to 80 years.

Descriptive Data

A total of 56% (34 of 61) of the hips were of female patients. The mean $\pm$ SD age of patients was 49 ± 16 years.

Variables

Radiographic evaluation was completed using an FDR Smart X digital radiography system (Fujifilm). The patients were placed in the supine position, and we took AP radiographs of the pelvis in which the iliac wings, obturator foramen, and teardrop figures were symmetrical; the legs were positioned in an internal rotation of 15° , and the

source-detector distance was 120 cm. The angle between the acetabulum's anterior and posterior wall lines was accepted as the radiographic acetabular version angle [13] (Fig. 1). In addition to quantitative measurements of acetabular version, we evaluated qualitative acetabular retroversion signs on plain radiographs, including crossover, ischial spine, and posterior wall signs [5] (Fig. 2).

Data Sources and Measurement

We utilized the records from the picture archiving and communication system (PACS) that reliably included images from the highest point of the iliac wing downward, covering the tuber ischium, which we regard as the benchmark for hip radiography. Our benchmark included several factors: the balance of the obturator foramen; the relationship between the trochanter major and minor indicating the hip's internal and external rotation; the visibility of the iliac wing's apex and the ischial tuberosity on the radiograph; and the evenness of the sacrum. These elements together constitute what we consider the standard for radiographs of the pelvis. The measurements were made bilaterally on plain AP radiographs of the pelvis and axial CT scans.



Fig. 2 A pelvic radiograph shows qualitative acetabular retroversion signs. **(A)** The crossover sign describes a more lateral position of the anterior wall (AW) than the posterior wall (PW). **(B)** The ischial spine sign indicates the presence of the triangular shape of the ischial spine medially to the pelvic ridge. **(C)** The PW sign is present when the PW of the acetabulum is medial to the center of the femoral head.

CT scans were performed using a SOMATOM Definition Flash dual-source scanner (Siemens). The scanning parameters included a tube voltage of 120 kVp and a tube current ranging from 100 to 150 mAs, adjusted by active tube modulation. Slices were acquired at a 0.6-mm thickness with a pitch factor of 0.9. For the field of view, we used a 450-mm setting along with a 512×512 matrix and reconstructed axial images of 1-mm thickness using a bone kernel, typically Br59. The scans were performed with the patient in a supine position with the legs parallel to each other and the hips in full extension, extending from the anterior superior iliac spine to the lesser trochanter. The images were collected on an IDS7 PACS workstation (Sectra) and transferred to the DICOM medical imaging viewer (Horos), and the measurements were taken using Horos Project Software. The acetabular version angle can be influenced by pelvic obliquity and pelvic tilt, which might lead to measurement errors if not considered [15]. Therefore, the images on the axial and coronal sections were subjected to angular synchronization. The 3D multiplanar reconstruction (MPR) feature of the Horos Project Software was used for image calibration. Before measuring the acetabular version, axial and coronal CT images were concurrently assessed using the 3D MPR tool to ensure synchronization (Fig. 3). The acetabular version was measured on axial planes that displayed a fully contoured femoral head with complete congruence to the acetabulum. Subsequently, the acetabular version was determined by the angle formed between a line spanning from the anterior to the posterior acetabular margin and a line perpendicular to the transverse axis along the posterior acetabular walls [8] (Fig. 4). Three clinicians (ÖY, MG, BA), each with a decade or more of clinical experience, took all measurements.

To evaluate the consistency of the radiographic and CT assessments, two independent sets of measurements were

taken by the clinicians, ensuring a minimum interval of 48 hours per patient between radiographs and CT scans, and not within the same session. These measurements were spaced 3 weeks apart, following standard measurement procedures, and were completed without the clinicians being aware of each other's results. Data for statistical analysis were compiled by the observer (KY), who was not involved in the final round of measurements.

Primary and Secondary Study Outcomes

The primary goal of our research was to evaluate the reliability of quantitative radiography and CT scanning in calculating the acetabular version angle. To this end, we analyzed the degree of intraobserver and interobserver agreements for radiographic and CT measurements. The secondary goal of our study was to compare the reliability of radiography and tomography in hips with anteversion and retroversion. For this purpose, we created hip groups according to the presence of retroversion signs including ischial spine, crossover, and posterior wall signs. We considered a hip with at least one of these findings as a retroverted hip. The retroverted hip group included 28 hips in 14 patients (seven female patients and seven male patients; mean $\pm$ SD age 45 ± 15 years). All three findings were present in 50% (14 of 28) of the hips, two findings were present in 21% (6 of 28) of the hips, and one finding was present in 29% (8 of 28) of the hips. The hips without these findings were included in the anteverted hip group, which included 94 hips of 47 patients (27 female patients and 20 male patients; mean $\pm$ SD age 50 ± 16 years). The third goal of our study was to examine the extent of variation in measurements of acetabular version when using

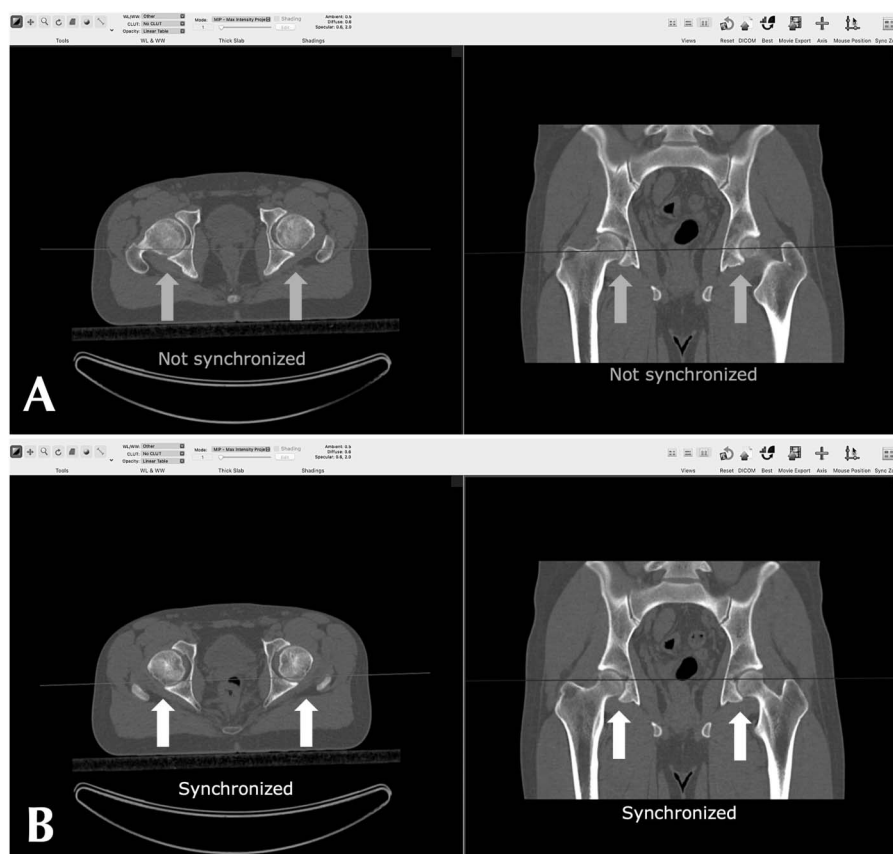


Fig. 3 These axial and coronal CT scans demonstrate synchronized imaging using the 3D MPR functionality of the Horos medical imaging viewer. The alignment of reference lines can be adjusted by clicking and dragging on any point along the lines. This synchronization links the two series of images, ensuring that adjustments in one plane are reciprocally updated in the other. This method allows axial and coronal images that are initially (A) not synchronized to be (B) brought into synchronization. Subsequently, the acetabular version is measured on the axial plane that is tangential to the coronal plane at the level of the greater trochanter.

quantitative radiographic and CT methods for both anteverted and retroverted hips. The difference between radiographic and CT measurements was also evaluated by Bland-Altman analysis.

Ethical Approval

Ethical approval was obtained from the Yeditepe University Ethics Committee, Istanbul, Turkey. All patients provided informed consent via a form sanctioned by the institution's human subjects review board.

Statistical Analysis

The statistical analysis was performed using NCSS 2007 software (NCSS Statistical Software). We

computed descriptive statistics using the mean $\pm$ SD. We examined the distribution of variables using the Shapiro-Wilk normality test. The radiographic and CT measurements with normal distribution were evaluated with paired t-tests. An independent t-test determined the scale value comparison of anteverted and retroverted hips. We also evaluated the differences between measurement methods using Bland-Altman analysis. Intraclass correlation coefficients (ICCs) and 95% CIs were used to determine the agreement between measurement methods and intraobserver and interobserver reliabilities. The results were evaluated at a significance level of $\alpha < 0.05$.

The post hoc power analysis was performed using G*Power software, version 3.1.9.6 (Heinrich-Heine-Universität Düsseldorf). The alpha error probability, effect size d value, and statistical power of the study ($1 - \beta$) were 0.05, 0.8, and 0.83, respectively.

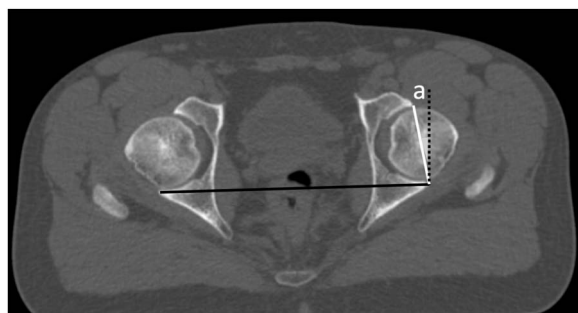


Fig. 4 The acetabular version angle (a) is the angle between a line connecting the anterior and posterior acetabular margins (white line) and the perpendicular (dashed black line) to a transverse reference line through the posterior acetabular walls (black line) on an axial CT scan.

Results

Reliability of Radiography and CT in Determining Acetabular Version

The quantitative radiographic measurement method had intraobserver and interobserver ICCs of 0.87 (95% CI 0.84 to 0.91) and 0.78 (95% CI 0.75 to 0.82), respectively (Table 1). The reliability of radiographic measurement was less than that of CT when measuring the acetabular version.

Difference in Reliability Between Anteverted and Retroverted Hips

The reliability of measuring the acetabular version in anteverted hips was moderate, with an ICC of 0.59 (95% CI 0.49 to 0.68). In contrast, retroverted hips showed an ICC of -0.41 (95% CI -1.17 to 0.08), indicating a lack of consistency between quantitative radiographic and CT measurements (Table 2).

Variation in Measurement Between Anteverted and Retroverted Hips

Variation in measurement on plain radiographs in anteverted hips was less than that of retroverted hips (mean $\pm$ SD absolute difference between anteverted hips and retroverted hips $3^\circ \pm 3^\circ$ versus $6^\circ \pm 4^\circ$; $p = 0.0001$), indicating greater variability in the radiographic measurement of retroverted hips (Table 3). According to Bland-Altman analysis, it was observed that the difference between radiographic and CT measurements was well outside the CI, especially in retroverted hips (Fig. 5).

Table 1. Intraobserver and interobserver agreements of CT and radiographic measurements

	Intraobserver	Interobserver
CT measurements		0.91 (0.89-0.92)
1 st observer	0.97 (0.96-0.98)	
2 nd observer	0.93 (0.90-0.95)	
3 rd observer	0.87 (0.82-0.91)	
All observers	0.92 (0.90-0.93)	
Radiographic measurements		0.78 (0.75-0.82)
1 st observer	0.92 (0.89-0.94)	
2 nd observer	0.86 (0.81-0.90)	
3 rd observer	0.84 (0.81-0.88)	
All observers	0.87 (0.84-0.91)	

Data presented as intraclass correlation coefficient (95% CI).

Discussion

The hip has a complex anatomy because of its 3D structure, which must be understood correctly to investigate, diagnose, and treat hip disorders. The acetabular version is a critical parameter for the evaluation of hip functionality [4]. The acetabulum's configuration increases its anteversion from superior to inferior because of its 3D shape. On plain pelvic radiographs, the anterior wall of anteverted hips appears medially, and the posterior wall laterally. This orientation permits the identification of an approximate actual value within a V-shaped conformation upon radiographic examination. Conversely, determining the precise acetabular configuration in hips with retroversion is challenging on plain radiographs, as the acetabular walls are interposed within the acetabular fossa on the frontal plane. Our

Table 2. Agreement between radiographic and CT measurements in the hip groups

	Value
Anteverted hips	
1 st observer	0.58 (0.36 to 0.72)
2 nd observer	0.68 (0.57 to 0.85)
3 rd observer	0.47 (0.21 to 0.65)
All observers	0.59 (0.49 to 0.68)
Retroverted hips	
1 st observer	-0.75 (-2.79 to 0.18)
2 nd observer	-0.15 (-1.50 to 0.46)
3 rd observer	-0.26 (-1.73 to 0.41)
All observers	-0.41 (-1.17 to 0.08)

Data presented as intraclass correlation coefficient (95% CI).

Table 3. Differences between CT and radiographic measurements in the hip groups

	CT	Radiographic	Difference ^a	Absolute difference ^b	p value
Anteverted hips in °	19 ± 4	20 ± 3	-2 ± 4	3 ± 3	0.0001
Retroverted hips in °	13 ± 4	17 ± 3	-4 ± 6	6 ± 4	0.0001

Data presented as mean ± SD.

^aPaired t-test.

^bIndependent t-test.

research indicates that even though quantitative radiographic measurement demonstrates acceptable intra-observer and interobserver reliability, its precision pales in comparison with CT-based measurements. Specifically, quantitative radiographic methods are prone to a larger margin of error in retroverted hips.

Limitations

There are several limitations to this study. Notably, the sample size is smaller than in similar research cited in the existing evidence [5]. Assessment of the relationship between the anterior and posterior walls of the acetabulum and their position relative to the pelvis may be affected by the quality of the radiographic acquisition, anatomic variations, and postural pelvic tilt [3, 14, 15]. Although CT scans are preferred for their objective evaluative quality, the precision of these measurements can also be compromised by the specific level at which they are taken [3]. Nonetheless, our study's implementation of standardized protocols for radiographic and CT assessments has yielded high consistency within and between observers in these measurement techniques.

Reliability of Radiography and CT in Determining Acetabular Version

The quantitative radiographic method showed acceptable reliability in measuring acetabular version, with higher consistency seen in CT compared with radiograph assessments.

Radiographic assessment is often the initial diagnostic step and remains useful when CT is unavailable. The effectiveness of radiography varies with technique and observer experience. Factors such as patient positioning and anatomic differences can influence the results, leading to variability. For accurate measurements of acetabular version angle, identifying key anatomic landmarks is crucial. Standardized imaging protocols and clear guidelines for landmark identification are essential to improvement of reliability in radiographic measurement.

Several methods [10, 13] have been proposed to measure the acetabular version radiographically. Our preferred approach, also highlighted in the literature [13], offers a straightforward and practical solution using standard AP radiographs of the pelvis. The authors assessed the reliability of this method by comparing radiographic readings with CT measurements in 78 hips. The findings indicated a strong correlation, suggesting that it is a less

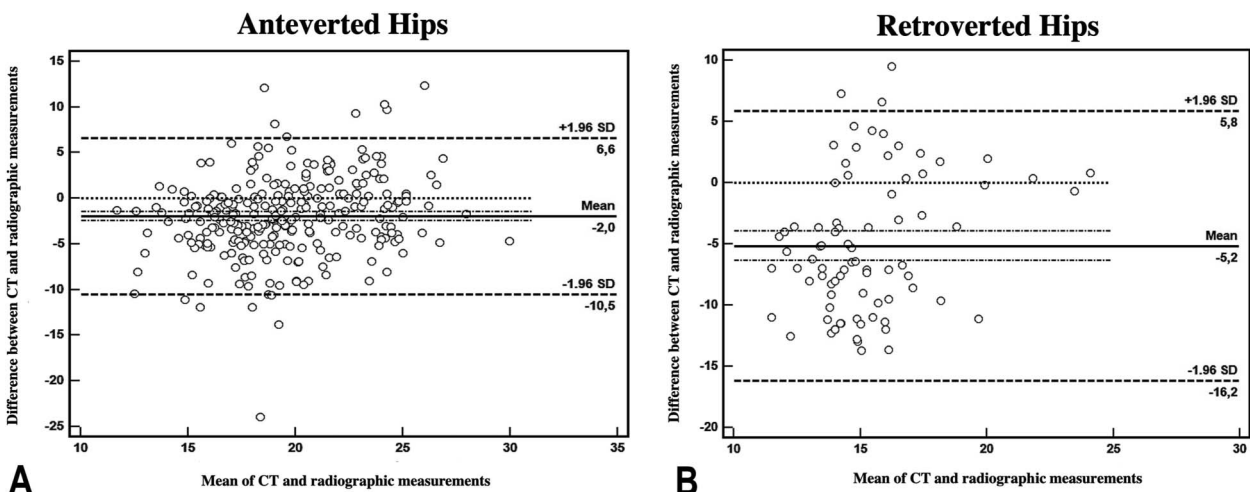


Fig. 5 This figure shows the Bland-Altman plot analysis of CT and radiographic measurements in (A) anteverted hips and (B) retroverted hips.

invasive and an efficient alternative for measuring the acetabular version. However, its effectiveness in retroverted hips was not specifically addressed.

Difference in Reliability Between Anteverted and Retroverted Hips

There was a moderate level of agreement between radiography and CT when assessing acetabular version in anteverted hips, but not in retroverted hips.

Acetabular retroversion, an abnormality in the hip's structure leading to anterior overcoverage of the femoral head, is primarily diagnosed through radiographic analysis [16]. Key markers on AP radiographs of the pelvis, such as crossover, posterior wall, and ischial spine signs, are indicative of this condition [5, 9, 17]. However, the accuracy of quantitative radiographic measurements is limited due to the hip's complex 3D anatomy, which is not completely captured in two-dimensional radiographs.

Variation in Measurement Between Anteverted and Retroverted Hips

For both anteverted and retroverted hips, measured angles were bigger on plain radiographs than on CT. In addition, the differences between measurements on plain radiographs compared with CT were bigger in the retroverted group.

CT scans provide detailed cross-sectional views of the hip, and the MPR technique enables users to reconstruct and visualize medical images in axial, sagittal, and coronal planes. Such capabilities facilitate a thorough assessment of anatomic structures and abnormalities. Comparative studies [2, 7, 18] have emphasized the superiority of CT-based measurements in accuracy and reliability, particularly in cases of excessive pelvic tilt or rotation. CT also provides 3D information and allows for better visualization of the entire acetabulum [5]. However, it is essential to consider the radiation exposure and cost associated with CT imaging compared with plain radiographs, and the choice of imaging modality should be based on the specific clinical scenario and available resources [10].

Conclusion

In our study, we observed satisfactory intraobserver and interobserver agreement for both measurement techniques. It should be noted, however, that the reliability of measuring acetabular version with radiographic techniques does not equal that of CT-based measurements. This discrepancy is more evident in hips with retroversion. Even

though radiographic assessments can approximate the true acetabular version in anteverted hips, they are considerably less accurate in retroverted hips, often leading to a substantial margin of error (Supplemental Table 1; <http://links.lww.com/CORR/B314>). Therefore, CT scans should be utilized for evaluating patients with retroverted hips.

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