# Conventional Humeral Retroversion Measurements Using Computed Tomography Slices or Ultrasound Images Are Not Correlated With the 3-Dimensional Humeral Retroversion Angle

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**Background:** Humeral retroversion angles determined by previous techniques are varied and/or biased by morphologic variations of the proximal and distal humerus, and their validity should be revisited. To overcome the limitations of previous studies associated with 2-dimensional (2D) images and the reference axes, a 3-dimensional (3D) measurement of humeral retroversion is required. However, comparisons of 2D imaging methods with the 3D computed tomography (CT) measurement as a reference standard have not been heretofore performed.

**Purpose:** To determine whether the 3D CT humeral retroversion angle in baseball players is correlated with conventional humeral retroversion measurements.

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

**Methods:** A total of 28 humeri from 14 male baseball players were used for measuring humeral retroversion. Participants underwent CT scans, and geometric bone models were created for measuring the 3D CT humeral retroversion angle. Using CT slices, the 2D CT humeral retroversion angle was also determined. Bicipital forearm angle was assessed using the indirect ultrasound technique. Linear regressions and Bland-Altman plots were used to determine whether there were agreements among 3 variables: the 3D CT retroversion, 2D CT retroversion, and bicipital forearm angles.

**Results:** In linear regression analyses, the 3D humeral retroversion angle was not predicted by the 2D CT retroversion ($R = 0.167$, $R^2 = 0.028$, $P = .395$) or the bicipital forearm angle ($R = 0.049$, $R^2 = 0.002$, $P = .805$). The bias of these 2 methods was 20.9° and –15.3°, respectively. Regression analysis demonstrated that the bicipital forearm angle was a significant predictor of the 2D CT retroversion angle ($R = 0.632$, $R^2 = 0.400$, $P < .001$).

**Conclusion:** The 3D CT humeral retroversion angle was found to be underestimated by the 2D CT retroversion angle and overestimated by the bicipital forearm angle obtained by the indirect ultrasound, although a previously observed relationship between the 2D CT retroversion and bicipital forearm angles was confirmed.

**Clinical Relevance:** Precise measurement of humeral retroversion angle is important because retroversion has been linked to upper extremity disorders, including throwing-related shoulder and elbow disorders in baseball players.

**Keywords:** shoulder; general; diagnostic ultrasound; computed tomography; baseball/softball; biomechanics of bone; clinical assessment/grading scales

Humeral retroversion is often discussed to understand shoulder and/or elbow disorders associated with throwing. Retroversion angle is generally defined as the angular difference between the orientation of the humeral head and the distal humeral axis projected onto the horizontal plane,[26] although the reference axis has been debated.[11,13,17,24,36] Generally, humeral retroversion decreases from birth through skeletal maturity.[8,9] The dominant limb of throwing athletes has been reported to exhibit greater humeral retroversion than the

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nondominant limb,[6,18,19,21,25,31,34-36] and this increased humeral retroversion has been linked to throwing-related shoulder and elbow disorders in baseball players.[19,23]

Humeral retroversion can be measured by various methods, including radiography,[21,25] computed tomography (CT),[2,6,17] and ultrasonography.[17-19,22,29-32,34-36] A standard measurement method has not yet been established,[2,17,24] and there is a need to validate a reliable and reproducible method. The cartilage/metaphyseal interface[2,17] and bicipital groove[17-19,22,29-32,34-36] have been commonly utilized for defining the reference line of the humerus. However, the retroversion angle measured with these anatomic landmarks varies depending on the exact position of the image slice at which it is measured.[11,13] The more proximal the cartilage/metaphyseal interface or groove selected in the axial plane, the greater the measured humeral retroversion angle. The humeral epicondyles[2,17] and ulna[17-19,22,29-32,34,35] are used as reference for the distal humeral axis: the transepicondylar axis in the CT method and the forearm axis in the indirect ultrasound assessment. However, morphological variability in the medial epicondylar epiphyses and some degree of elbow valgus laxity have been noted in the dominant elbow of baseball players,[1,5,10] which may reduce the reliability of conventional methods using CT slices or indirect ultrasound images. To overcome these limitations, a 3-dimensional (3D) measurement of humeral retroversion is required.

CT technology now allows 3D measurement of humeral retroversion.[14,23,25] A 3D CT technique was shown to provide accurate and reproducible measurements of humeral retroversion in dried humerus specimens.[24] However, the utility in baseball players remains unclear because the authors placed points on the surface of the volume-rendered bone to represent the medial epicondyle and the lateral epicondyle.[24] To eliminate morphological variability of the distal humerus, we developed our own method using 3D CT and established the reliability of this technique in baseball players.[28]

Reliability and precision were assessed for both indirect ultrasound and CT methods for determining humeral retroversion.[17,30] The bicipital forearm angle assessed by the ultrasound technique was a significant predictor of the degree of 2D CT humeral retroversion.[17] However, comparisons of these 2 methods with the 3D CT measurement as a reference standard have not been heretofore performed. Therefore, the purpose of the current study was to determine whether the 3D CT humeral retroversion angle of baseball players was predicted by conventional humeral retroversion measurements using 2D CT or indirect ultrasound methods.

## MATERIALS AND METHODS

### Participants

Fourteen male baseball players (mean age, 21.4 ± 1.5 years; mean height, 171.8 ± 6.3 cm; mean weight, 72.0 ± 7.3 kg) participated in this study. Both pitchers and position players were included. Patients with a history of shoulder surgery or a prior shoulder condition that may have affected humeral retroversion were excluded. We did not include controls because we have an interest in baseball players particularly. All participants read and signed the informed consent forms approved by our local institutional review board before participation. Bilateral upper extremities were assessed in each participant; therefore, 28 extremities were included in the analysis of humeral retroversion.

### Procedures

Humeral retroversion angle was assessed using 3D bone models constructed from CT images, 2D CT images, and the indirect ultrasound technique. In all participants, the CT scan and ultrasound assessments were performed on the same day. First, participants underwent a bilateral CT scan (Asteion super4; TSX-021B/4A; Toshiba) at 1.0-mm slice pitch while lying supine on the scan table with their arms held in a fixed position by a strap.[4] The humerus aligned parallel to the CT table. Next, the ultrasound assessment was performed. Then, the primary investigator, who was blinded to the results of the ultrasound assessment and the dominant arm of the participant, analyzed the CT images for 3D and 2D CT humeral retroversion angles. Geometric bone models of the humerus were created from 2D CT section data using the commercial software program 3D-Doctor (Able Software Corp).[20] The distal and proximal reference axes for measuring 3D humeral retroversion angle were defined as described below.

The distal axis of the humerus was defined by a method similar to that proposed by Eckhoff et al[7] for the distal femur. A set of 2 virtual cylinders sharing a coaxis was manipulated in virtual space by positioning and individually enlarging the cylinders to achieve a good fit around the distal humerus, leaving only a small rim of the capitulum and medial lip of trochlea outside the cylinder (Figure 1). The x-axis (flexion/extension axis of the elbow joint) was defined as the coaxis of the cylinders. The z-axis was perpendicular to the x-axis, parallel to the humeral shaft projected onto the sagittal plane. The y-axis was a cross product of the x- and z-axes. The test-retest reliability of this method was previously assessed by the primary investigator. For the 14 participants (28 humeri), the tester embedded the distal axis of the humerus twice, 1 day apart,

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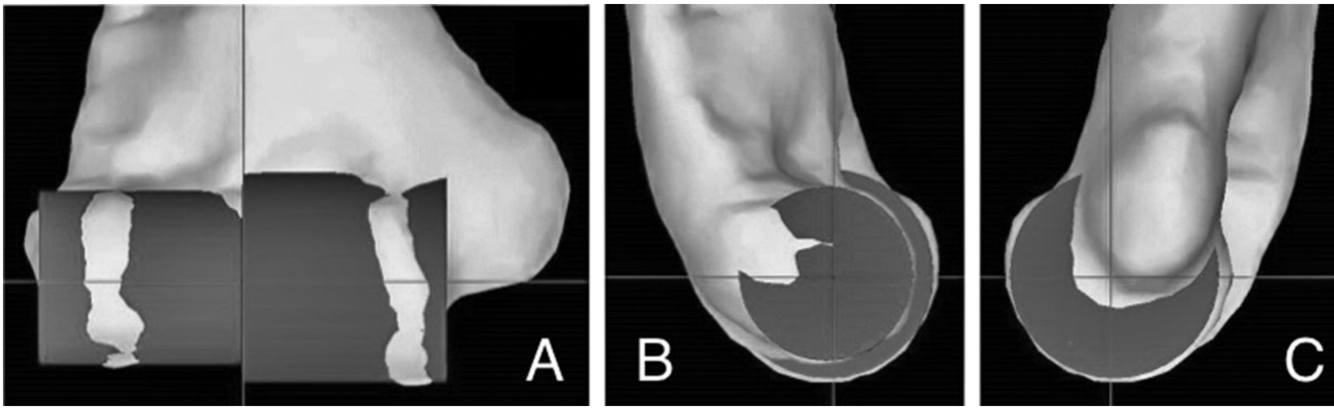


**Figure 1.** Definition of the distal humeral axis. A right humerus viewed from (A) ventral, (B) lateral, and (C) medial sides. A set of 2 virtual cylinders sharing a coaxis was manipulated in the virtual space by positioning and individually enlarging the cylinders to fit with the distal humerus so that a good fit was achieved, leaving only a small rim of the (B) capitulum and (C) medial lip of trochlea outside the cylinder.

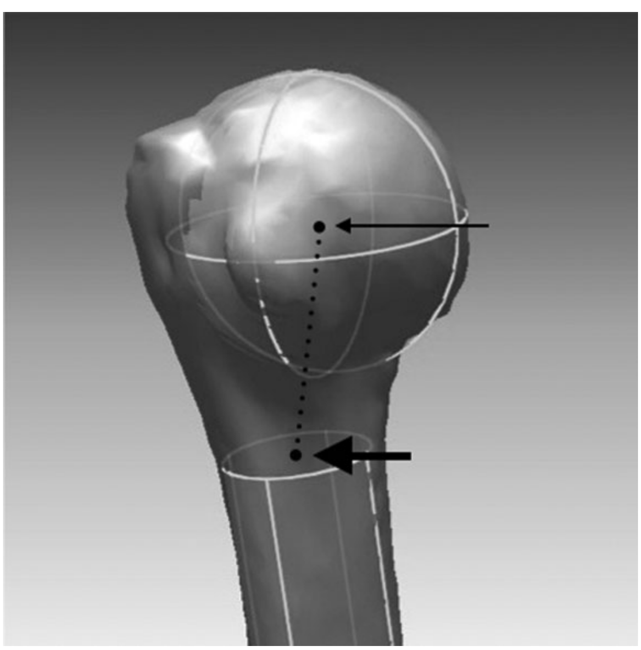

**Figure 2.** Projection of the proximal humerus (humeral neck line). The humeral neck line (dotted line) was formed by the spherical center of the humeral head (thin black arrow) and the proximal end of the humeral shaft axis (thick black arrow).

and calculated the root mean square error (RMSE) with 6 degrees of freedom. RMSEs for the distal humeral axis were less than 1.0 mm/1.0° for all translations/rotations, which confirmed that the error using the current method was small enough to not affect the retroversion measurements.

The proximal axis for the humerus was defined using the Rapidform software (Geomagic). First, the articular surface of the humeral head was virtually painted so that a best-fit sphere was automatically generated[13] (Figure 2). Then, the proximal humeral shaft was painted, and a best-fit cylinder was automatically generated. This cylinder location was commonly set at the proximal half of the humerus because there is a change in the frontal curvature of the humerus half way down from the top of the articular surface.[3] The line connecting the spherical center of the humeral head and the proximal end of the longitudinal axis of the cylinder (humeral neck line) was projected onto the *XY* plane, which is formed by the x-axis and the anteroposterior axis (the y-axis). The 3D CT retroversion angle was measured as the angle between the flexion/extension axis of the elbow joint and the projected humeral neck line on the *XY* plane (Figure 2). The angle formed by the 2 lines was calculated using a dot product ($\cos \theta = a * b/|a||b|$). Before the current study, a pilot study was performed to assess the reliability and precision of this method of retroversion assessment.[28] The intra- and intertester reliability yielded intraclass correlation coefficients (ICCs) of 0.99 and 0.96, respectively. The standard error of measurement (SEM) associated with the 3D retroversion measurements ranged from 1.0° to 2.8°.

The series of CT images were further analyzed to calculate the degree of 2D CT humeral retroversion according to previous reports.[2,4,17] The investigators selected the proximal and distal humeral slices that each thought best represented the required landmarks. The chosen slice and the slices immediately above and below it were used.[17] The proximal humeral axis was defined by first drawing a line between the 2 articular margins and then drawing a line perpendicular to this. The distal humeral axis was defined as the transepicondylar axis. The mean of the retroversion angle from the 3 series of slices represented the 2D CT humeral retroversion angle. Before the current study, a pilot study was performed to assess the intratester reliability and precision of this retroversion assessment. In the pilot, an investigator of the current study measured the retroversion angle for 10 humeri of participants in the current study. This was performed 2 times, both on the same day. The ICC and SEM were 0.90 and 2.8°, respectively (unpublished data).

The indirect ultrasound technique described in previous studies[17-19,29-32,35] was also utilized to assess the bicipital

TABLE 1
Descriptive Statistics of Humeral Retroversion Measured by 3 Techniques[a]

| | Dominant Arm, deg | Nondominant Arm, deg |
|---|---|---|
| 3D CT humeral retroversion | 55.1 ± 10.6 | 62.8 ± 18.3 |
| 2D CT humeral retroversion | 43.1 ± 8.6 | 33.0 ± 9.5 |
| US bicipital forearm angle | 78.5 ± 7.9 | 70.1 ± 7.8 |

[a]Values are reported as mean ± SD. 2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; US, ultrasound.

TABLE 2
Predicting 3D CT Humeral Retroversion Angle From 2D CT Humeral Retroversion and Ultrasound Bicipital Forearm Angle (Regression)[a]

| | $R$ | $R^2$ | Standard Error of Estimate | $P$ Value |
|---|---|---|---|---|
| 2D CT humeral retroversion | 0.167 | 0.028 | 15.28 | .395 |
| US bicipital forearm angle | 0.049 | 0.002 | 15.48 | .805 |

[a]2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; US, ultrasound.

forearm angle. One investigator placed the ultrasound probe on the anterior aspect of the participant's shoulder and rotated the participant's arm so that the bicipital groove could be visualized with the apexes of the greater and lesser tubercles parallel to the horizontal line on the ultrasound monitor screen. A second investigator placed a digital inclinometer on the ulnar side of the forearm. The forearm angle with respect to the horizontal plane was recorded. This measurement was performed bilaterally for all participants. Before the current study, a pilot study was performed to assess the intratester reliability and precision of this retroversion assessment. In the pilot, investigators of the current study measured the retroversion angle by this method in 10 humeri of asymptomatic collegiate students. These measurements were performed 2 times, both on the same day. The ICC was 0.96 and the SEM was 3.5° (unpublished data).

## Data Analysis

Linear regressions were utilized to determine whether there were agreements among 3 variables: the 3D CT retroversion, 2D CT retroversion, and bicipital forearm angles. The 3D CT retroversion angle was defined as the dependent variable. Agreement between the 2D CT retroversion and bicipital forearm angles was also determined using linear regressions to confirm the previous reports of a relationship between humeral retroversion obtained with ultrasound and CT.[17] Bland-Altman assessment for agreement was used to compare the 3 variables. The range of agreement was defined as the mean bias ±2 standard deviations (SDs). Statistical analysis was performed with PASW statistics 18 (SPSS Inc). An alpha level of 0.05 was set a priori for statistical significance.

## RESULTS

Descriptive statistics for the humeral retroversion angles appear in Table 1. In linear regression analysis, the 3D CT humeral retroversion angle was not predicted by the 2D CT retroversion angle ($R = 0.167$, $R^2 = 0.028$, $P = .395$) or the bicipital forearm angle ($R = 0.049$, $R^2 = 0.002$, $P = .805$). The regression statistics appear in Table 2. The Bland-Altman plots demonstrate a measurement bias of 20.9° for the 2D CT retroversion and –15.3° for the bicipital forearm angle (Figures 3 and 4).

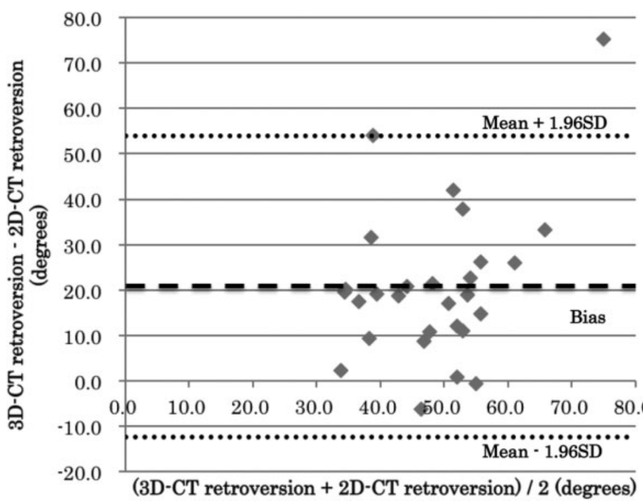


**Figure 3.** Bland-Altman plot demonstrating the bias and limits of agreement between the 3-dimensional computed tomography (3D CT) retroversion and 2-dimensional computed tomography (2D CT) retroversion measurements.

Secondary analysis by regression analysis demonstrated that the bicipital forearm angle was a significant predictor of the 2D CT retroversion angle ($R = 0.632$, $R^2 = 0.400$, $P < .001$).

## DISCUSSION

The purpose of this study was to determine whether the 3D CT humeral retroversion angle of baseball players was predicted by conventional humeral retroversion measurements using 2D CT slices or ultrasound images for the bicipital groove and ulna. The 3D CT humeral retroversion angle was not predicted by the 2D CT retroversion angle or the bicipital forearm angle. The bias was 20.9° and –15.3°, retrospectively, indicating that the 3D CT retroversion angle was underestimated by the 2D CT retroversion and overestimated by the bicipital forearm angle.

The 2D CT measurement using the series of CT images underestimated the 3D CT retroversion angle by approximately 20°. We suspect that this inconsistency stems from the definitions of the reference axes. First, in the 2D CT

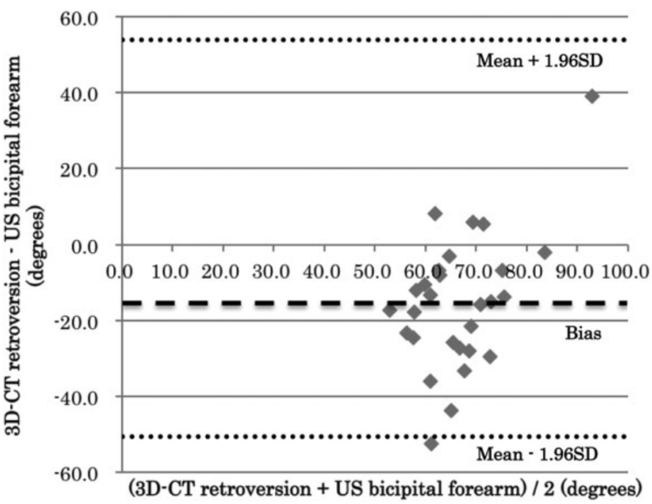


**Figure 4.** Bland-Altman plot demonstrating bias and limits of agreement between the 3-dimensional computed tomography (3D CT) retroversion and ultrasound (US) bicipital forearm angle.

methods, the anterior-posterior axis[2,11,17] at the cartilage/metaphyseal interface was utilized as the proximal humeral axis. However, the retroversion angle measured using the cartilage/metaphyseal interface varies depending on the level of the axial plane at which it is measured.[11] Thus, the anterior-posterior axis is less reliable and might contribute to measurement error. Conversely, in the 3D CT measurement, we utilized the humeral neck line (determined by a line between the humeral head center and the humeral shaft center) as the proximal humeral axis, which eliminated the potential plane-dependent error noted above. Second, in the 2D CT method, the humeral epicondyles are used as reference points for the distal humeral axis; this is called the transepicondylar axis.[2,11,13,27] Some degree of separation and fragmentation of the medial epicondylar epiphyses has been noted in 19% to 100% of throwing elbows,[1] and 56% of adolescent pitchers demonstrated hypertrophy of the distal humerus on the dominant side.[10] This morphologic variability of the humeral medial epicondyle reduces the reliability of the transepicondylar axis, particularly during bilateral comparisons. In the 3D CT measurement, we utilized the flexion/extension axis of the elbow joint by fitting the cylinder to the capitulum and medial lip of the trochlea, which achieved excellent intratester and intertester reliability with minimum RMSEs.[28] This suggests that the flexion/extension axis is suitable for measuring the humeral retroversion angle.

The bicipital forearm angle determined by the indirect ultrasound technique overestimated the 3D CT retroversion angle by approximately 15°. In the indirect ultrasound method, the bicipital groove is utilized as the proximal humeral reference.[¶] However, the bicipital groove has been noted to be externally rotated to a small degree at the proximal level and then progressively become internally rotated as it extends distally.[13] Thus, the more proximal the measurement is obtained, the greater the humeral retroversion angle would be. The other reason for the overestimation is the distal reference. The reference axis in the indirect ultrasound method is the longitudinal axis of the ulna,[17,30] thus, the elbow valgus angle is involved. Increased medial elbow laxity exists in the dominant arms of uninjured pitchers,[5] and elbow valgus laxity results in an overestimation of shoulder external rotation during range of motion measurement,[15] which would explain the overestimated humeral retroversion angle in the indirect ultrasound method. Variability in the ulnar varus angle (ranging from 11°-28°)[33] might be an additional cause of error.

Our secondary analysis showed that the bicipital forearm angle by the indirect ultrasound method was a significant predictor of the 2D CT retroversion angle ($R = 0.632$, $R^2 = 0.400$). Myers et al[17] likewise demonstrated that the bicipital forearm angle was a significant predictor of the 2D CT humeral retroversion ($R = 0.797$, $R^2 = 0.635$), which confirmed the relationship between conventional CT and ultrasound methods. However, these authors noted that 2D CT may not best represent a true gold standard, as the CT data exhibited lower reliability and greater error of measurement than the indirect ultrasound assessment. Considering the methodological issues in defining the reference axis in the CT assessment described above and the relationship between the 2 methods, the validity of retroversion angles presented in the literature should be carefully reviewed and reassessed.

Only a few studies investigated the accuracy of measuring humeral retroversion.[2,24] The 2D CT method was reported to allow accurate measurement in cadaveric humeri; however, the authors did not assess the reliability of the method.[2] Myers et al[17] assessed the retroversion in baseball players using a similar 2D CT method and demonstrated that the intra- and intertester reliability yielded ICCs of 0.93 and 0.80, respectively. The SEM associated with the 2D CT method ranged from 2.6° to 5.1°.[17] Although intratester reliability and precision in our 3D CT technique are similar (ICC, 0.99; SEM, 1.0°), intertester reliability and precision of the 3D CT technique (ICC, 0.96; SEM, 2.8°) are higher than that of the 2D CT methods, suggesting that the 3D CT method is useful.[28] Previously, Polster et al[24] demonstrated that a 3D volume-rendering CT technique was accurate and provided reproducible measurements of humeral retroversion in dried humerus specimens. The researchers did not report the SEM in their analysis, thus making it difficult to compare their results with those of our study. The utility of the 3D volume-rendering technique in baseball players remains unclear because the authors placed points on the surface of the volume-rendered bone to represent the medial epicondyle and the lateral epicondyle.[24] Further research is needed to establish a true reference standard for assessing humeral retroversion.

The 2D CT and indirect ultrasound technique in this study showed similar humeral retroversion angles with the previous studies. A typical adult baseball player has 45° of

[¶]References 13, 14, 17-19, 22, 29-32, 34-36.

2D CT humeral retroversion in the dominant shoulder and 34° in the nondominant shoulder,[4,17] which is quite similar to our findings (see Table 1). Bicipital forearm angle, as assessed by indirect ultrasound, in the dominant and nondominant shoulders were reportedly 74° to 88° and 61° to 79°, respectively.[12,16,17,19] These findings indicate that the participants in this study are representative of adult baseball players who have reached skeletal maturity, although only 14 players were included.

This study has several limitations that need to be acknowledged. First, we lack an established definition for true humeral retroversion. To our knowledge, other published methods, such as radiography, CT scans, and ultrasound assessment, have not been validated and a true reference standard has not been established. Second, we fitted a cylinder to the proximal humeral shaft in the process of defining the proximal humeral axis. As the humeral shaft is a curved structure at the middle point of the entire humeral length, the proximal axis could be defined erroneously. To minimize the potential error, the cylinder location was commonly set at the proximal half of the humerus. Third, the distance between the humeral head center and the humeral shaft axis was variable, and the measured retroversion angle may exhibit a larger error if the distance between the 2 points was small. However, the effect of variable distances would be small because the SEM associated with our 3D CT method ranged from 1.0° to 2.8°, which is considerably smaller than the differences of humeral retroversion between the techniques used in this study. Finally, only 28 extremities from 14 participants were included in this study. The costs and radiation exposure in the CT scan limited our sample size.

## CONCLUSION

Conventional humeral retroversion measurements described in the literature using either 2D CT slices or ultrasound images were not correlated with the 3D CT humeral retroversion angle. The 3D CT humeral retroversion angle was found to be underestimated by the 2D CT retroversion and overestimated by the bicipital forearm angle obtained by the indirect ultrasound method, although a previously observed relationship between the 2D CT retroversion and bicipital forearm angles was confirmed. Therefore, the accuracy of the previous techniques is questioned, and the results of the previous studies measuring humeral retroversion should be carefully reviewed and reassessed.

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