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# Glenoid Version Assessment When the CT Field of View Does Not Permit the Friedman Method

## The Robertson Method

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**Background:** To improve spatial resolution, current clinical shoulder cross-sectional imaging studies reduce the field of view of the shoulder, excluding the medial scapula border and preventing glenoid version measurement according to the Friedman method.

**Purpose:** To evaluate a method to accurately and reliably measure glenoid version on cross-sectional shoulder images when the medial scapula border is not included in the field of view, and to establish measurements equivalent to the Friedman method.

**Study Design:** Controlled laboratory study.

**Methods:** Sixty-five scapulae underwent computed tomography (CT) scanning with an optimal shoulder CT-positioning protocol. Glenoid version was measured on CT images of the full scapula using the Friedman method. We developed a measurement method (named the Robertson method) based on the glenoid vault version from partial scapula images, with a correction angle subtracted from the articular-surface-glenoid vault measurement. Comparison with the Friedman method defined the accuracy of the Robertson method. Three observers tested inter- and intraobserver reliability of the Robertson method. Accuracy was statistically evaluated with *t* tests and reliability with the intraclass correlation coefficient (ICC).

**Results:** The statistical distribution of glenoid version was similar to published data,  $-0.5^\circ \pm 3^\circ$  [mean  $\pm$  SD]. The initial measurement using the Robertson method resulted in a more retroverted angle compared with the Friedman method, and a correction angle of  $7^\circ$  was then applied. After this adjustment, the difference between the 2 methods was nonsignificant ( $0.1^\circ \pm 4^\circ$ ;  $P > .65$ ). Reliability of the Robertson method was excellent, as the interrater ICC was 0.77, the standard error of measurement (SEM) was  $1.1^\circ$  with  $P < .001$ . The intrarater ICC ranged between 0.84 and 0.92, the SEM ranged between  $0.9^\circ$  and  $1.2^\circ$  with  $P < .01$ .

**Conclusion:** A validated glenoid version measurement method is now available for current clinical shoulder CT protocols that reliably create Friedman-equivalent values.

**Clinical Relevance:** Friedman-equivalent values may be made from common clinical CTs of the shoulder and compared with prior and future Friedman measurements of the scapula.

**Keywords:** cross-sectioning imaging; CT; glenoid version; shoulder; shoulder replacement; total shoulder arthroplasty

Abnormalities in glenoid version have been implicated in glenohumeral instability,<sup>9,13,16,31,39,40</sup> rotator cuff tears,<sup>12,14,18,36,37</sup> osteoarthritis,<sup>6,8,11,22,23,27,30,31,38</sup> and glenoid prosthesis failure.<sup>7,10,20,24</sup> The clinical workup of shoulder disorders frequently includes computed tomography (CT) and magnetic resonance imaging (MRI) with an assessment of glenoid version. When performed properly, cross-sectional imaging is more accurate than radiography

for measuring glenoid version.<sup>8,23,34</sup> CT with three-dimensional (3D) reconstruction is common before total shoulder arthroplasty to aid in proper prosthesis positioning, especially when patient-specific instrumentation is used.

Glenoid version assessments are complicated by the glenoid's complex morphology, which is not fixed in space and does not have an axisymmetric plane.<sup>11,16,29,31,35</sup> As defined by Friedman et al<sup>8</sup> (Friedman method), glenoid version measurement requires the definition of a transverse scapular axis, the line connecting the glenoid fossa to the scapular spine medial endpoint, and in normal shoulders is a mean of 2 degrees of anteversion. There are other

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transverse scapular axis definitions that also require the scapular spine medial endpoint to be in the plane of view.<sup>17,27,29</sup>

Prior studies have described the accuracy and limitations of cross-sectional imaging and the Friedman method.<sup>1-3,11,23,29</sup> Glenoid version measurements vary with scapula positioning. Thus, accurate measurements require proper subject positioning before imaging or image reconstruction post-acquisition to correct for mispositioning. However, even with proper glenoid orientation, all but 1 current glenoid version assessment method requires identification of the medial border of the scapula.<sup>26</sup> In clinical practice, most cross-sectional shoulder imaging is performed on a reduced field of view to improve spatial resolution. Therefore, the medial border of the scapula is outside the field of view and not visualized, preventing replication of the published methods.

Poon and Ting<sup>26</sup> described a glenoid version assessment method based on the glenoid vault that is applicable to imaging fields of view that exclude the scapula medial border. This method is easy to perform and reliable<sup>26</sup>; however, values obtained using this method differ from glenoid version values obtained by the Friedman method, resulting in more retroverted measurements.<sup>26</sup> Glenoid version measured with the Friedman method requires the entire scapula be imaged, and the method described by Poon and Ting needs only the glenoid to be imaged. Thus, normal and abnormal range values are different from what clinicians currently know and use. In addition, the Poon and Ting method has not been validated, and although those authors made Friedman method measurements, they were not compared with any glenoid vault-based measurements. Currently, there is no validated method that produces glenoid version measurements equivalent to Friedman measurements for cross-sectional images when the medial scapular border is outside the field of view.

The purpose of this study was to validate a method to accurately and reliably measure glenoid version on cross-sectional CT scans of the shoulder when the field of view does not include the entire scapula. We also aimed to provide measurements with values statistically equivalent to those of the Friedman method. Our hypothesis was that, after subtraction of a correction angle, glenoid version measured on CT scans of the shoulder with partial views of the scapula (we called this the Robertson method) will be accurate to within 0.1° of the Friedman method and will produce reliable measurements.

## METHODS

### Scapulae Specimens and Imaging

Sixty-five scapulae from 40 unembalmed cadavers were obtained from our institution. There were 19 women and 21 men from the Midwestern and Eastern United States, with a mean age of 55 ± 17 years (range, 25-80 years) and mean height 171 ± 12 cm (range, 150-194 cm). Except for osteoarthritis, none of the specimens had any apparent bony abnormalities or radiographic detectable abnormalities. Fifty scapulae (25 scapular pairs) had none or minimal glenoid osteoarthritis (glenoid osteophytes <1 mm); 15 single scapulae had minimal to moderate osteoarthritis (glenoid osteophytes >1 mm and <2 mm).<sup>2,7</sup> A pilot study revealed that measurements of glenoid version on the axial cross-sectional images with the entire scapula or only a portion of the scapula is not affected by the presence or absence of osteoarthritis, as it does not affect the portion of the scapula not imaged. No specimen donor had any surgical procedure performed on his or her scapulae or humeri.

High-resolution CT axial images (contiguous slice thickness 0.625 mm, field of view 20 × 20 cm<sup>2</sup>) of each scapula were obtained. The scapulae were individually placed in a custom-designed fixture replicating the scapula's position during a patient's cross-sectional imaging study. The scapula was positioned to eliminate any version measurements' inaccuracies that may be caused by scapula rotation.<sup>1-3,11,23,29</sup> Glenoid version measurements were made using axial CT images of the entire scapula. To replicate current clinical cross-sectional imaging studies, where only a portion of the scapula is present on the axial cross-sectional images, the CT images selected for glenoid version measurement were cropped to exclude the medial portion, producing an image of the partial scapula identical to routine clinical shoulder CT and MRI studies (Figure 1).

CT was selected instead of MRI to test the Robertson method, as it has fewer artifacts from cadaver specimens (eg, air), was more accessible, and is more routine in the evaluation of the glenohumeral joint before total shoulder arthroplasty.<sup>19</sup> Axial slice positioning for the CT images was similar to clinical axial slice MRI protocols.

### Glenoid Version Measurement

Using the reconstructed 3D scapula computer models, the axial CT slice passing through the glenoid center<sup>35</sup> and

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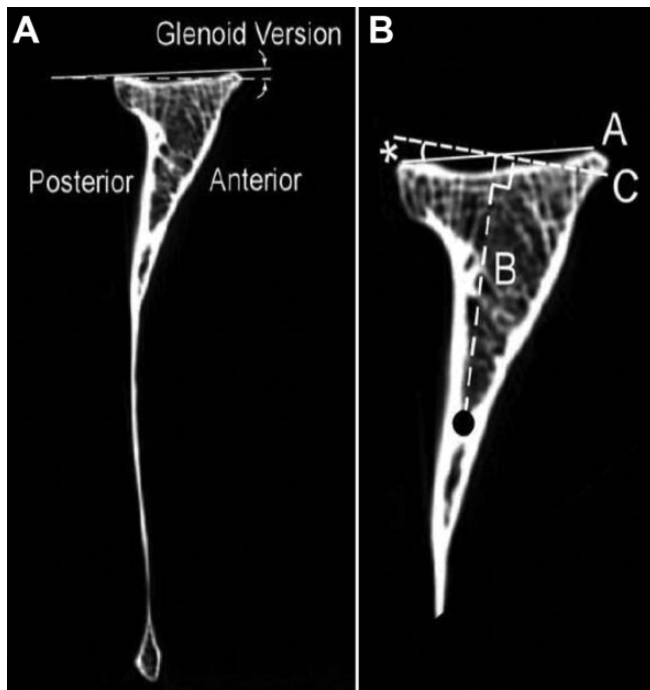
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Ethical approval was not sought for the present study.



**Figure 1.** Glenoid version measurements. (A) Friedman method of glenoid version is measured as the angle between the solid line drawn from the anterior to the posterior glenoid and the dashed line that is the perpendicular of a line drawn from the most medial scapula to the midpoint of the solid line.<sup>8</sup> (B) Articular surface-vault angle (asterisk), step 2 of the Robertson method. Line A (solid line) is from the anterior to the posterior glenoid. Line B joins the scapula neck cortical bone intersection (●) to the midpoint of line A. Line C is perpendicular to line B. The final step subtracts a fixed correction factor (not illustrated).

perpendicular to the scapular body plane was selected and used to measure glenoid version on full-scapula and partial-scapula field-of-view images. All measurements were made by 3 specialty-trained, experienced physicians (shoulder and elbow, sports medicine, and musculoskeletal radiology).

**Friedman Method (Full Scapula).** The full-scapula field-of-view glenoid version measurements were obtained using the Friedman method,<sup>8</sup> which requires the full medial scapula to be in the axial image (Figure 1A). Glenoid version was measured as the angle between a first line drawn from the anterior to the posterior glenoid and the perpendicular of a second line drawn from the most medial scapula to the midpoint of the first line.

**Robertson Method (Partial Scapula).** As the entire scapula, specifically the medial scapular border, was unavailable, we needed a transverse axis defined from the glenoid vault for the Robertson method. Three transverse axes were tested, all different from Poon and Ting.<sup>26</sup> Two axes used the most anterior or posterior medial point of the glenoid vault. The third axis was the most accurate and was the axis used and described in this study.

Like the Friedman method, the Robertson method uses a line connecting the anterior and posterior glenoid articular margins (line A in Figure 1B). Next, the new transverse axis based on the glenoid vault was defined by drawing line B from the point of intersection of the cortical bone within the scapula neck to the midpoint of the glenoid. Line C is drawn perpendicular to line B. The angle between lines A and C was measured and termed the articular surface-vault angle. Whereas the Friedman method has 2 steps, the Robertson method has a third step, the subtraction of a fixed correction factor (the correction angle).

The correction angle was determined from the articular surface-vault angle and Friedman method measurements. The correction angle was defined by the mean of the difference between each specimen's Friedman method measurement and its articular surface-vault angle. This fixed correction angle was subtracted from the articular-surface-vault angle measurements of the 3 observers to create the Robertson method of measuring the glenoid version.

### Statistical Analysis

The Friedman and Robertson methods for measuring glenoid version were computed as means and standard deviations (SDs). To further define our scapula samples in comparison with previous studies, we tested for differences in measurements according to sex and sidedness using 2-tailed independent and paired-samples *t* tests.

**Accuracy.** As clinical version assessments were image-based and not measured physically, we compared the Robertson method with the Friedman method using 2-tailed paired-samples *t* tests.

**Reliability.** To familiarize the observers with the measurements to be studied, each was provided with 5 sample cases not considered in the analysis and measurement instructions. Original and repeat version measurements were then made of 30 selected scapulae, 20 with none to minimal osteoarthritis and 10 with moderate to severe osteoarthritis. The time between the two sets of measurements made by each observer was at least 3 weeks. Case presentation order was shuffled for original and repeat measurement sessions.

Test-retest reliability (precision) was defined as the mean difference between repeated measurements of the Robertson method. Inter- and intraobserver reliability of the Robertson method (3 observers, 2 occasions, and 3 observers-2 occasions) were estimated using the intra-class correlation coefficient (ICC) and the standard error of measurement (SEM). ICC values below 0.50 were considered poor, between 0.50 and 0.75 were moderate, between 0.75 and 0.90 was good, and above 0.90 was excellent.

All the statistical analyses were carried out with the level of significance set at 0.05. In addition, we performed a basic power analysis of matched pairs 2-tailed *t* test with 80% power and using mean expected difference of 1° and SD of 1°. This resulted in a sample size of 11.

TABLE 1  
Articular Surface-Vault Angle Measurements and the Difference to Friedman Method Version<sup>a</sup>

	Observer 1	Observer 2	Observer 3
Articular surface-vault angle (step 2 Robertson method) <sup>b</sup>	-7.4° ± 3°	-7.3° ± 3°	-7.7° ± 3°
Friedman version minus articular surface-vault angle (Robertson method glenoid version)	0.003° ± 4°	0.3° ± 4°	-0.1° ± 4°

<sup>a</sup>Data are reported as mean ± SD.

<sup>b</sup>Negative angle denotes retroversion.

TABLE 2  
Reliability of Robertson Method Version Measurement<sup>a</sup>

	Interobserver (Observers 1-3)	Intraobserver		
		Observer 1	Observer 2	Observer 3
ICC	0.77	0.84	0.90	0.92
SEM	1.1°	1.2°	0.9°	0.9°
<i>P</i>	<b>.0001</b>	<b>.01</b>	<b>.0001</b>	<b>.0001</b>

<sup>a</sup>Bolded values indicate statistical significance ( $P < .05$ ). ICC, intraclass correlation coefficient; SEM, standard error of measurement.

## RESULTS

There was no statistical difference in glenoid version between right and left scapular pairs ( $P = .95$ ). Male scapular pairs were more retroverted (denoted by a negative sign) than female scapular pairs (mean ± SD, -3° ± 3° versus -0° ± 3°, respectively;  $P = .02$ ).

### Correction Angle and Robertson Method Accuracy and Reliability

For all scapulae, the mean (±SD) difference between the Friedman method version measurements and the Robertson method articular surface-vault angle measurements was +7° ± 4° (Table 1). When a fixed 7° correction angle was subtracted from each of the articular surface-vault angle measurements, the mean difference between the Friedman and Robertson methods was 0.1° ± 4°. The Robertson method measurements from the 3 observers (-0.5° ± 3°) were not significantly different than the Friedman method measurements (-0.4° ± 3°;  $P = .995$ ).

Robertson method measurements were reliable, with no significant difference between the 3 observers ( $P = .68$ ), 2 occasions ( $P = .15$ ), and 3 observers-2 occasions ( $P = .37$ ). ICC and SEM results are listed in Table 2.

## DISCUSSION

Glenoid version can be measured on current CT scans of the shoulder with partial views of the scapula. The Robertson method, which uses the glenoid vault and the articular surface plus a retroversion correction angle of 7°, had a high degree of accuracy when compared with the Friedman

method, with a difference of 0.1° ± 4° ( $P > .65$ ). Reliability of the Robertson method was excellent, as the interrater ICC was 0.77, the SEM was 1.1° with  $P < .001$ . The intrarater ICC ranged between 0.84 and 0.92 and the SEM ranged between 0.9° and 1.2° with  $P < .01$ .

Cross-sectional imaging studies when the medial scapular border is outside the field of view are commonly performed on the shoulder in evaluation, for example, of rotator cuff injuries.<sup>33</sup> However, as these studies do not allow glenoid version to be measured with the Friedman method, additional time, money, and radiation exposure is needed for additional studies. This study validates a new method that accurately and reliably measures glenoid version on these cross-sectional shoulder imaging studies when the field of view does not include the medial scapular border. Method accuracy was tested using corresponding Friedman values so that the Robertson method of glenoid version measurements<sup>4,32</sup> could be used clinically. This and method reliability are in agreement with prior values for glenoid version measurement.<sup>8,26,28</sup>

The Robertson method uses a vault-based scapular axis; however, the axis is different than in previous approaches. We measured the glenoid articular surface-vault angle and converted this into an equivalent Friedman measurement by the subtraction of a 7° fixed correction angle. The medial scapula has variable shape but generally curves anterior so when measurements are made with only the lateral portion of the scapula, the result is more retroversion. The Robertson method produces Friedman-equivalent measurements ensuring that prior patient-specific version values and literature values are directly comparable.

Like the method used by Poon and Ting,<sup>26</sup> the Robertson method uses a line connecting the anterior and posterior glenoid articular margins. Poon and Ting<sup>26</sup> placed an isosceles triangle within the medial end of the endosteal bone of the glenoid vault, medial to where the anterior and posterior cortices start to curve. They then drew a line from the medial corner of the glenoid vault bisecting the isosceles triangle. We used a line from the point of intersection of the cortical bone within the scapula neck to the midpoint of the glenoid. Clinicians commonly refer to bone loss that is common with glenohumeral joint osteoarthritis as an angle of retroversion. For example, when the glenoid version is measured as 10° of retroversion with the Friedman method, surgeons describe it as 10° of bone loss. Measuring the glenoid articular surface-vault angle with our method would give surgeons a measurement of 17° before the 7° correction angle was subtracted and yielding 10° of

retroversion This can also be described as a version angle of  $-10^\circ$  as the negative angle denotes retroversion. When the glenoid articular surface-vault angle is measured as  $4^\circ$  of retroversion, the Robertson method yields  $3^\circ$  of anteversion.

### Limitations

Although essential for determination of the accuracy and reliability of the measurements studied, a limitation of this study is the use of scapulae that were optimally positioned for imaging and 3D CT used to produce the CT axial slice perpendicular to the scapular body plane that contained the glenoid midpoint.<sup>1-3,11,16,23,29,31</sup> Results may be different in vivo when scapula axial slices are not perfectly perpendicular to the scapular body plane. Version may be measured in different parts of the glenoid and varies with the superior-inferior position of the selected axial glenoid slices.<sup>5,15,21,35</sup> Measurements of glenoid version on the same axial cross-sectional images are unlikely to be different whether the entire scapula or only a portion of the scapula is imaged when using our Robertson method whether or not there is pathology of the glenohumeral joint, but this may not be the case if there is pathology of the scapula body such as a fracture. Measure of glenoid version using the Friedman method is similar on both CT scans and MRI. However, when the entire scapula is not imaged on CT scans and MRI and glenoid version is measured using the most medial scapula imaged, we found more variation and retroversion with cadavers using the Robertson method.<sup>25</sup> Future studies are needed evaluating the Robertson method with MRI using appropriate sample size to address glenoid version variation.

### CONCLUSION

Previously, the medial scapula border was needed to be visualized to measure glenoid version with the Friedman method. In practice, most cross-sectional shoulder imaging excludes the medial scapula border to increase spatial resolution. A validated glenoid version measurement method is now available for current clinical shoulder CT protocols that reliably create Friedman-equivalent values. The Robertson method may be used for measurements using a partial scapula field of view, common with clinical CTs of the shoulder and compared with prior and future Friedman measurements of the scapula. Although CT was used in this study, the method is applicable to MRI as, in our study, scapula positioning was the same as routine shoulder MRI.

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