Comparison of measurements of the glenopolar angle in 3D CT reconstructions of the scapula and 2D plain radiographic views

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Aims
The aim of this study was to analyse the effect of altered viewing perspectives on the measurement of the glenopolar angle (GPA) and the differences between these measurements made on 3D CT reconstructions and anteroposterior (AP) scapular view radiographs.

Materials and Methods
The influence of the viewing perspective on the GPA was assessed, as were the differences in the measurements of the GPA between 3D CT reconstructions and AP scapular view radiographs in 68 cadaveric scapulae.

Results
The median GPA in 3D reconstructions and AP scapular views were 42.7° (95% confidence intervals (CI), 42.0° to 43.5°) and 41.3° (95% CI 40.4° to 42.0°) respectively (p < 0.001). All but five of 20 malpositions demonstrated a significant difference in GPA compared with the respective AP scapular view (p ≤ 0.005). The GPA was most susceptible to malposition in retroversion/anteversion. Inter- and intra-observer reliability for all measurements of the GPA was excellent for 3D CT reconstructions (intraclass correlation (ICC) 0.93 (95% CI 0.87 to 0.96) and 0.94 (95% CI 0.89 to 0.97), respectively) and higher than on AP scapular radiographs (p < 0.001). The intra- and inter-observer reliability was excellent in AP scapular views and malpositions in extension/flexion (ICC ≥ 0.84) but tended to decrease with increasing viewing angle in retroversion/anteversion.

Conclusion
These data suggest that 3D reconstructions are more reproducible than AP scapular radiographs in the assessment of the GPA and should be used to compare data in different studies, to predict outcome, define malunion, and act as an indication for surgery in patients with a scapular fracture.

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Scapular fractures represent 3% to 5% of injuries of the shoulder and < 1% of all fractures. However, malunion may lead to persistent pain, loss of function, and reduced activities of daily living. Malunion of fractures of the scapular neck leads to loss of function due to shortening of the rotator cuff muscles and changes in muscle activation.

The glenopolar angle (GPA) is a radiographic parameter which is used to evaluate deformity of the shoulder after fractures of the scapular neck and has been used as a criterion to recommend operative treatment. Therefore, accurate and reproducible measurement of this angle in these patients is required for pre- and post-operative assessment and for comparison of results from studies of clinical outcome. The GPA is defined on plain radiographs as the angle between a line connecting the most superior and inferior margins of the glenoid and a line between the most superior margin of the glenoid and the most caudal point of the scapular body.

The correlation between the GPA and the clinical outcome, the GPA threshold that affects the outcome and the definition of malunion in fractures of the scapular neck and floating shoulders are still debated. While a significant correlation between the GPA and the Constant-Murley score has been reported by some authors, others have reported no correlation. Romero, Schai and Imhoff
found that patients with a malaligned scapular neck fracture and a GPA < 20° had associated pain, reduced activities of daily living, and loss of movement of the shoulder. Kim et al.9 found that the Constant-Murley score18 decreased in patients with a GPA < 30°. A GPA differing by ≥ 10° from the uninjured shoulder has been used to define malunion,12 but the threshold of the GPA which should be used as an indication for surgery is debated. Different radiographic protocols have been described in each assessment of the GPA. The positioning of the patient during radiographic examination is sometimes described in detail,7,11 while other reports lack these details.8,10,12,14,19 The accuracy of the measurement of the GPA on plain radiographs depends on the spatial relationship of the scapula relative to the x-ray beam, and on the radiographic protocol.17,20 Spatial relationships can vary significantly, depending on the position and posture of the patient and the orientation of the scapula. Alterations in the projection of the margin of the glenoid and the inferior scapular angle may lead to errors in the measurement of the GPA. Interestingly, even when radiographs were obtained with a standard protocol, the mean angular offset from the viewing perspective to the true AP view was 38°.20 The same authors documented that the GPA varied significantly as the scapula was rotated 10°, 20°, 30°, 40° and 50° for each perspective. In total, 20 analyses describe how altered viewing perspectives (extension, flexion, retroversion, and anteversion) affect the absolute values and reproducibility of the GPA compared with AP scapular views. In addition, anteversion viewing perspectives were generated. When rotated about the y-axis, anteversion (+) and retroversion (-) views were generated. About the z-axis, flexion (+) and extension (-) views were generated. DRRs were generated at 10°, 20°, 30°, 40° and 50° for each perspective. In total, 20
In contrast to a previous 3D technique, 19 images were not acquired on a 3D system (Livermore Software Technology, Livermore, California). The 3D GPA was measured using the LS-PrePost software (Livermore Software Technology, Livermore, California). The normal GPA (43° to 41° as measured in 3D CT reconstructions and plain radiographs) was varied between 10° and 20° anteversion, and 10° and 20° anteverision, demonstrated a significant difference with their respective AP scapular view (p < 0.005). All but the incremental viewing perspectives between 10° and 20° flexion, 20° and 30° flexion, and 10° and 20° anteverision, differed significantly from their neighbouring views (p ≤ 0.013).

Inter- and intra-observer reliability of the measurements was excellent for AP scapular views (ICC 0.92 (95% CI 0.87 to 0.95) and 0.91 (95% CI 0.87 to 0.95), respectively) and 3D reconstructions (ICC 0.93 (95% CI 0.87 to 0.96) and 0.94 (95% CI 0.89 to 0.97), respectively). All extension/flexion viewing perspectives showed excellent inter- and intra-observer reliability coefficients (ICC ≥ 0.84), but both tended to decrease the more extreme the malposition in retroversion/anteversion (Fig. 4). Note that the lower limits of the CIs were fair to good when the viewing perspective deviated from the ideal orientation in extension and flexion and mainly poor in retroversion/anteversion malpositions. The highest inter- and intra-observer reliability corresponded to 10° anteversion.

The median GPA in 3D reconstructions and AP scapular views were 42.7° (95% CI 42.0° to 43.5°), and 41.3° (95% CI 40.4° to 42.0°), respectively (p < 0.001). The GPA was underestimated on AP scapular radiographs in 60 specimens (89%) (Fig. 5). The median difference between the two observers was -0.4° (95% CI -0.5° to 0.0°) in 3D CT scans of 68 non-pathological cadaveric scapulae were studied. There were 36 women and 32 men, with a mean age of 60 years (26 to 73), with 35 left and 33 right scapulae. The GPA tended to increase with viewing angle in extension/flexion, but to decrease with viewing angle in retroversion/anteversion (Fig. 3). As the viewing perspective increased, the range of the GPA typically increased with more values outside the normal range (Fig. 3). All but DRRs malpositioned in 20° and 30° flexion, 10° retroversion, and 10° and 20° anteverision, demonstrated a significant difference with their respective AP scapular view (p ≤ 0.005) (Fig. 3). All but the incremental viewing perspectives between 10° and 20° flexion, 20° and 30° flexion, and 10° and 20° anteverision, differed significantly from their neighbouring views (p ≤ 0.013).

Each DRR was blinded and randomised for viewing angle, and all 3D reconstructions and DRRs were assessed by two independent orthopedic surgeons (TS, JDW). All 3D reconstructions and DRRs were evaluated a second time by one of the original observers two weeks later. This provided data for inter- and intra-observer reliability and comparison of the two radiographic modalities.

Statistical analysis. This was carried out in the Study Design and Biostatistics Center at the University of Utah. Sample size was calculated based on prior studies of GPA as measured with 3D CT reconstructions and plain radiographs. The normal GPA (43° to 41°) has standard deviations (SDs) of approximately 5° in various measurement modalities. Operative treatment is often indicated when the GPA is < 30°, and a more conservative 10° change due to altered viewing perspective was chosen. Using a two-sided Wilcoxon rank sum test at a significance level of 0.05, a sample size of ten scapulae achieves more than 95% power to detect a change in GPA of 10° between an AP view and an altered viewing perspective.

Descriptive statistics were calculated, and generalised estimating equation regression models evaluated the effect of different viewing perspectives and radiographic modality on GPA measurements. Boot strap samples were used to compare the differences in intra- and inter-observer reliability in the measurement of the GPA with respect to viewing perspectives and radiographic modality. The intra-class correlation coefficient (ICC) and 95% confidence intervals (CIs) were calculated to assess agreement and the inter- and intra-observer reliability in the measurements for each viewing perspective and radiographic modality. ICCs were rated according to Cicchetti: 34 0.01 to 0.39 poor, 0.40 to 0.59 fair, 0.60 to 0.74 good, 0.75 to 1.00 excellent. A Bland-Altman graph was used to assess the reliability of the measurements of the GPA on 3D CT reconstructions and on AP scapular views as a function of the difference in the techniques of measurement on the same specimens. All data are presented as median (CIs), with a level of statistical significance of p ≤ 0.05. Analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, North Carolina) and the R statistical packages (R Foundation, Vienna, Austria).

Results
CT scans of 68 non-pathological cadaveric scapulae were studied. There were 36 women and 32 men, with a mean age of 60 years (26 to 73), with 35 left and 33 right scapulae. The GPA tended to increase with viewing angle in extension/flexion, but to decrease with viewing angle in retroversion/anteversion (Fig. 3). As the viewing perspective increased, the range of the GPA typically increased with more values outside the normal range (Fig. 3). All but DRRs malpositioned in 20° and 30° flexion, 10° retroversion, and 10° and 20° anteverision, demonstrated a significant difference with their respective AP scapular view (p ≤ 0.005) (Fig. 3). All but the incremental viewing perspectives between 10° and 20° flexion, 20° and 30° flexion, and 10° and 20° anteverision, differed significantly from their neighbouring views (p ≤ 0.013).

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CT reconstructions and 1.0° (95% CI 0.8° to 1.3°) in AP scapular views, respectively. Inter- and intra-observer reliability of GPA measurements on 3D CT reconstructions was significantly higher than on AP scapular radiographs (p < 0.001).

Discussion

Accurate and reproducible measurement of the GPA is required to compare clinical outcomes, define malunion, and determine the indications for operative treatment in patients with scapular fractures. This study is the first to show the sensitivity of the GPA to altered viewing perspectives in extension, flexion, and retroversion, where the reliability of the measurement rapidly decreased with retroversion and anteversion. In contrast, there was excellent reproducibility in all extension/flexion angles, AP scapular views, and 3D reconstructions, though the lower bounds of the 95% CIs were fair at extreme viewing angles. Finally, AP scapular views tended to underestimate the absolute GPA and showed lower reliability when compared with 3D reconstructions.

The GPA represents a 2D measurement of a 3D structure and is therefore subject to errors due to the orientation of the viewing plane with respect to the scapula. Wijdicks et al20...
define malunion. Wijdicks et al developed a method to treat, particularly where differences in the GPA of 10° anteversion, whereas Wijdicks et al found no significant differences up to 40° of anteversion. In contrast, we found no significant differences in incremental viewing perspectives from 0° to 20° of anteversion, and confirmed the tendency of the GPA to decrease with increased viewing perspective. In our study, the GPA was underestimated on AP scapular views. The median difference between measurement in AP scapular views and 3D CT reconstructions was only 42.7° (95% CI 42.0° to 43.5°), which is comparable to a previous report using CT reconstructions to measure the GPA in healthy volunteers. Although the median difference between measurement in AP scapular views and 3D CT reconstructions was only 1.5° (95% CI -1.8° to -1.2°), this difference was statistically significant (p < 0.001). AP scapular views underestimated the GPA compared with CT, which is consistent with the findings of Anavian et al who compared these two techniques in patients with an extracapsular scapular fracture.

Scapular fractures usually occur in high-energy trauma, and are therefore often associated with thoracic injuries and spinal fractures. Multi-trauma patients typically have a chest CT in the emergency department which can be used to generate a 3D CT reconstruction of the scapula. This may be useful in the measurement of the GPA to avoid unreliable measurements from radiographs. The median GPA in 3D CT reconstructions was 42.7° (95% CI 42.0° to 43.5°), which is comparable to a previous report using CT reconstructions to measure the GPA in healthy volunteers. Although the median difference between measurement in AP scapular views and 3D CT reconstructions was only 1.5° (95% CI -1.8° to -1.2°), this difference was statistically significant (p < 0.001). AP scapular views underestimated the GPA compared with CT, which is consistent with the findings of Anavian et al who compared these two techniques in patients with an extracapsular scapular fracture.

The estimated inter- and intra-observer reliability was generally excellent for all malpositions in extension/flexion and altered viewing perspectives up to 20° anteversion, though the lower bounds of the 95% CIs were at times only fair (Fig. 4). Reproducibility decreased as the viewing perspective was more extreme in ante/retroversion. We observed that the decrease arises in views where the anterior and posterior rims of the glenoid are not perfectly superimposed, leading to a double contour that makes it difficult to define the most superior and inferior margins of the glenoid clearly. We cannot compare this finding since previous studies typically only reported reproducibility of the measurement of the GPA in patients with a fracture without specifically mentioning the protocol used to obtain the radiographs.

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Finally, although the reliability of the measurements of the GPA on 3D CT reconstruction and AP scapular views were almost perfect, the reproducibility on 3D CT reconstructions was significantly higher. Similar results were described by Anavian et al19 in a series of 45 patients with an extra-articular scapular fracture. Visual alignment perpendicular to the scapular plane does not correct for glenoid retroversion, leading to an imperfect superimposed glenoid rim which may limit the ability to measure the GPA on an AP scapular view properly when compared with a 3D CT reconstruction.

There were limitations to this study. First, DRRs do not incorporate radiological complexities which may arise from overlying structures such as soft tissues, ribs, clavicle and humerus which may influence the measurement of the GPA. However, use of DRRs allowed us to control a single variable providing clear radiological anatomy of the scapula from controlled perspectives. Secondly, we analysed the GPA in healthy scapulae and not in the presence of fractures. We assessed the extent to which imaging rotations influence the GPA in a controlled setting since various radiological projections in AP shoulder radiographs, Neer I scapular views and AP chest radiographs previously did not standardise measurements of the GPA.3,4,7,9,14 Thirdly, the GPA is only one measurement to be used in the assessment of scapular neck fractures and the optimal treatment will involve other considerations. The GPA is one criterion which may be used to predict outcome in patients with floating shoulder injuries,9 to define malunion,12 and to indicate the need for operative treatment for scapular fractures.1,12-15,36

In conclusion, measurement of the GPA is susceptible to scapular malpositioning in extension, flexion, retroversion, and anteverision in 2D radiographs. Although the reproducibility in extension/flexion was excellent, the lower Cs only showed fair to good results and tended to decrease the more extreme the malposition. In addition, altered viewing perspectives in ante/retroversion decreased the reproducibility, illustrating the importance of the correct alignment of the scapula during radiological examination. The GPA increased in 3D CT reconstruction and showed significantly higher inter- and intra-observer reproducibility when compared with AP scapular views. Studies using the GPA to predict and compare the outcome of different forms of treatment, to define malunion and to act as an indication for operative treatment in patients with scapular fractures should, if possible, use 3D CT reconstructions for its optimal assessment.

Take home message:

The GPA, as measured on 3D reconstructions of CT scans, is more reproducible than those measured on plain radiographs and is not susceptible to changes in observer viewing perspective.

Author contributions:

T. Suter: Study design, Data collection, Data analysis, Statistical analysis, Writing the paper.
H. B. Henninger: Study design, Data analysis, Writing the paper.

Y. Zhang: Data analysis, Statistical analysis.
J. D. Wyllie: Data Collection, Data analysis.
R. Z. Tashjian: Study design, Data collection, Data analysis, Writing the paper.

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References


