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FEATURED ARTICLES

Accuracy of CT-based measurements of glenoid version for total shoulder arthroplasty

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Background/Hypothesis: The arthritic glenoid is typically in retroversion and restoration to neutral version is recommended. While a method for measurement of glenoid version using axial computed tomography (CT) has been reported and has been widely accepted, its accuracy and reproducibility has not been established.

Methods: In 33 patients scheduled for shoulder arthroplasty, glenoid version and maximum wear of the glenoid articular surface were measured with respect to the scapular body axis on 2-dimensional- (2D) CT slices as well as on 3-dimensional- (3D) reconstructed models of the same CT slices.

Results: Clinical CT scans were axially aligned with the patient's torso but were almost never perpendicular to the scapular body. The average absolute error in version measured on the 2D-CT slice passing through the tip of the coracoid was 5.1° (range, 0 - 16°, $P < .001$). On high-resolution 3D-CT reconstructions, the location of maximum wear was most commonly posterior and was missed on the clinical 2D-CT slices in 52% of cases.

Conclusion: Error in measuring version and depth of maximum wear can substantially affect the determination of the degree of correction necessary in arthritic glenoids. Accurately measuring glenoid version and locating the direction of maximum wear requires a full 3D-CT reconstruction and analysis.

Level of Evidence: Level 1; Diagnostic Study.

Keywords: Total shoulder arthroplasty; shoulder arthritis; 3-D reconstruction; scapular axis; glenoid version

In end-stage glenohumeral arthritis, wear is usually greater in the posterior half of the glenoid articular surface effectively increasing glenoid retroversion.[11,12] Aligning the glenoid prosthesis to the face of the retroverted glenoid predisposes to instability of the joint and increases the risk for glenoid implant loosening secondary to abnormal forces across the implant and cement-bone interface.[3,9] Therefore, surgical reaming and glenoid prosthesis alignment, perpendicular to the scapular axis, are recommended to correct the retroversion.

Plain radiographs are ineffective in assessing glenoid version due to varying radiographic techniques, complex and variable scapular anatomy, mobile scapula, and overlapping bones.[8] Computed tomography (CT) scans are, therefore, essential for preoperative measurement of glenoid version. Glenoid version is typically recorded as the angle between a line drawn from the medial border of the

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scapula to the center of the glenoid and the line perpendicular to the face of the glenoid on the axial 2-dimensional- (2D) CT slice at or just below the tip of the coracoid.[5] Despite the wide acceptance of this method, the accuracy of a 2D axial CT slice has not been well established.

To align the glenoid prosthesis to neutral version and to ensure adequate seating of the bone requires reaming to the depth of the maximum wear. The location of maximum wear, while generally in the posterior direction (which contributes to the retroversion), may not always be consistent. Correction of excessive wear medializes the glenoid prosthesis and increases the risk of perforation of the fixation pegs or keel through the anterior or posterior glenoid surface.[7] Therefore, precisely identifying the location and depth of maximum wear is important for preoperative planning.

While the accuracy of surgical navigation techniques for alignment of hip and knee arthroplasty prostheses has been established, such techniques are still in the developmental phase for shoulder arthroplasty. Current practices include measurement of glenoid version on a preoperative CT scan. However, the relative merits of 2D axial CT slices and multiplanar 2D-CT reconstructions versus a full 3-dimensional (3D) reconstruction have not been studied.

We have previously established the accuracy of 3D-CT reconstruction of the shoulder in representing the bony anatomy and in identifying the potential for perforation.[7] In this study, our primary objective was to measure the accuracy of glenoid version on axial 2D-CT slices relative to a full 3D-CT reconstruction. Secondary objectives were to determine the variability in glenoid version measurement between adjacent CT slices and to determine whether a single axial CT slice at the level of the tip of the coracoid could consistently identify the area of maximum wear.

Methods

After Institutional Review Board approval, preoperative high-resolution axial CT scans of the shoulder were obtained from 33 consecutive patients with osteoarthritis scheduled for total shoulder arthroplasty. The mean patient age was 75 years ± 8.1 (range, 56-90 years). There were 11 males and 22 females. Four patients reported previous trauma to the shoulder. Two of these 4 patients sustained fractures of the humeral neck. One was treated with closed reduction and the other with open reduction and internal fixation. No fracture or instability was reported in the other 2 patients. No glenoid bone fracture was reported in any patient. Computed tomography was performed in a GE LightSpeed RT 16 scanner (GE Healthcare, Waukesha, WI) with 0.625-mm slice thickness. Glenoid version and maximum wear of the glenoid articular surface were measured with respect to the scapular body axis on 2D-CT slices at the tip of the coracoid and at 2.5-mm intervals over a 10-mm vertical distance below the coracoid (Figs 1, *A, B, C*) as previously described.[5] We selected slices 2.5 mm apart in the axial direction to simulate the resolution of a typical clinical CT scan. The 3D surfaces were reconstructed from high-resolution CT scans (0.625-mm axial resolution) in a commercially available program (MIMICS, Materialise, Leuven, Belgium). The details of the accuracy and reproducibility of the reconstructed geometry have been previously reported.[7]

"True" glenoid version was measured through the center of the glenoid in the 3D-CT reconstruction on a plane perpendicular to the plane of the scapular body (Figs 1, *D*, *E*). A vertical line was drawn on the glenoid face, centered in the AP direction. A transverse plane was generated perpendicular to the midpoint and passing through the center of the glenoid and the tip of the scapular spine. Version was measured as the inclination of the face of the glenoid at the level of the transverse plane (similar to the measurement on the 2D-CT slice). The location of maximum wear was also identified as the most medial point on the articular surface of the glenoid. The medial direction was specified by a line joining the center of the glenoid to the tip of the scapular spine. The direction of the location of maximum wear relative to the center of the glenoid was recorded on a clock face with 12 o'clock denoting a pure superior direction, 3 o'clock denoting a pure anterior direction, 6 o'clock denoting a pure inferior direction, and 9 o'clock denoting a pure posterior direction (Fig 2, *A*). The clock face was reversed for the left shoulder to maintain consistency in anterior and posterior directions. After identifying the maximum wear on the 3D reconstruction, we also determined if any of the 2D-CT slices at the tip of the coracoid and over a 10-mm vertical distance below the coracoid (at intervals of 2.5 mm) passed through the area of maximum wear. Since the objective of the study was to compare the accuracy of 2 methods of measuring retroversion, we measured all types of glenoid wear (including B2 type[11]) in the same manner. To test for inter-observer error, we analyzed data measured by 4 research staff that were blinded to each other's results.

A power analysis was performed to estimate the sample size necessary to detect a difference of 5° between 2D and 3D measured version. A sample size of 32 was required to obtain a statistically significant difference with a power of 80% at a P value of .05.

Results

In this cohort of patients, the true version (as measured on 3D-CT reconstruction) was mean −8.6° (±9.8°) (Table I). The average absolute error in the version measured on the 2D-CT slice passing through the tip of the coracoid was 5.1° (range, 0° - 16°; $P < .001$). Furthermore, when slices spanning a 10-mm vertical distance below the coracoid on the same subject were analyzed[5] within, subject glenoid retroversion varied by an average of 6.7° (±5.8°).

Clinical 2D axial CT slices at the tip of the coracoid do not necessarily pass through the center of the glenoid. The average absolute error from the center of the glenoid in the superoinferior direction was 5 ± 4 mm. Additionally, the direction of the 2D axial CT slice was almost never perpendicular to the scapular body but was angled 35° (±19°) from the transverse plane relative to the scapular body.