Is Premorbid Glenoid Anatomy Altered in Patients with Glenohumeral Osteoarthritis?

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Abstract

Background Restoration of native, premorbid glenoid anatomy may be a goal in component placement during total shoulder arthroplasty. However, if patients with unilateral glenohumeral osteoarthritis are predisposed to the development of arthritis owing to abnormal native glenoid anatomy, this recommendation may be inappropriate.

Questions/purposes The purpose of this study was to determine if patients with glenohumeral osteoarthritis have abnormal premorbid glenoid version or inclination, thereby

predisposing them to subsequent glenoid disorders. We specifically tested whether: (1) premorbid glenoid version or inclination in the pathologic shoulder of patients with unilateral osteoarthritis, as determined by the glenoid vault model, is different from glenoid version or inclination in the contralateral nonpathologic shoulder of these patients; (2) there are differences between glenoid version or inclination in normal cadaver shoulders and the nonpathologic side of patients with unilateral osteoarthritis; and (3) there are differences between glenoid version or inclination in normal cadaver shoulders and the premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis, as determined by the glenoid vault model.

Methods Bilateral CT scans were obtained in 27 patients with unilateral glenohumeral osteoarthritis. Thirty normal cadaver control shoulders also underwent CT scans. Premorbid glenoid version and inclination in the pathologic shoulder, as measured by the glenoid vault model, were compared with the contralateral nonpathologic shoulder and the normal cadaver control shoulders. Glenoid version and inclination of the normal shoulders were compared with the nonpathologic side from patients with unilateral osteoarthritis. Measurements were made by two different methods using three-dimensional surgical simulation software: (1) a direct measurement technique and (2) measurements derived from placement of a glenoid vault model. Mean differences in these parameters were compared between shoulder groups using paired and unpaired Student's t-tests.

Results Premorbid glenoid version and inclination in the pathologic shoulder as measured by the vault model averaged -7° (SD, 5) and 10° (SD, 6), respectively, compared with -7° (SD, 5) and 12° (SD, 6) as directly measured on the nonpathologic side, and -7° (SD, 4) and 12° (SD, 5) as directly measured in the normal cadaver control shoulders. There were no differences in glenoid version or inclination

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between the normal shoulders and the nonpathologic side of patients with unilateral osteoarthritis or between these shoulders and the premorbid version and inclination of the arthritic shoulder as measured by the vault model.

Conclusions Patients with glenohumeral osteoarthritis do not appear to have abnormal premorbid glenoid retroversion or inclination. The glenoid vault model can be used to determine premorbid glenoid version and inclination.

Clinical Relevance The glenoid vault model may be a clinically useful tool to estimate patient-specific premorbid glenoid anatomy, which may help in preoperative or intraoperative surgical planning for total shoulder arthroplasty.

Level of Evidence Level III, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Optimal placement of the glenoid component in a total shoulder arthroplasty (TSA) requires correction of pathologic glenoid anatomy. Prior studies have shown that correction of abnormal glenoid version during TSA improves glenohumeral biomechanics and is correlated with favorable patient outcomes [2, 6, 11, 13, 17, 20, 23]. Conversely, failure to correct excessive glenoid retroversion at the time of TSA has been shown to increase glenoid component shear stress and result in posterior displacement of the glenohumeral contact point, which can lead to early glenoid loosening and implant failure [7, 8, 10, 14, 19]. Normal humeral and glenoid version vary over a wide range of values [4, 21] and the combined glenohumeral version or alignment is specific to each patient's anatomy. The development of more anatomic components in TSA allows for restoration of native anatomy. However, this goal can be challenging as a result of difficulties in determining premorbid glenoid anatomy in the setting of increased glenoid retroversion and associated posterior glenoid bone loss that commonly is present in glenohumeral osteoarthritis.

Defining premorbid glenoid anatomy in the presence of severe glenohumeral osteoarthritis is not possible without evaluation of the unaffected, contralateral shoulder in patients with bilateral imaging and unilateral disease. Previous studies have shown that glenoid dimensions are not significantly different between paired scapulae of normal, healthy individuals [24, 25]. Plain radiographs and two-dimensional CT scans have been shown to produce errors in glenoid version measurements, however, as a result of variations in the gantry angle at the time of CT or plain film acquisition [1, 3, 18]. In contrast, three-dimensional (3-D) reconstructions from CT scans are independent of scapular orientation and gantry angle, allowing for more accurate

measurement of glenoid dimensions [16], but preoperative 3-D CT imaging of the contralateral, unaffected shoulder is not routinely performed. The clinical value and reproducibility of use of the glenoid vault model to estimate the premorbid glenoid joint line, glenoid version, and degree of glenoid bone loss have been described [9, 21, 22]. However, previous work in patients with unilateral glenohumeral osteoarthritis has raised the possibility that the contralateral shoulder in this patient group may be predisposed to the development of osteoarthritis as a result of increased native glenoid retroversion [9].

The purpose of this study, therefore, was to determine if patients with glenohumeral osteoarthritis and acquired posterior glenoid bone loss with increased glenoid retroversion have abnormal premorbid glenoid retroversion or inclination that predisposes them to subsequent glenoid disorders. We postulated that if premorbid glenoid anatomy is equivalent to that of the population without shoulder disorders, then correction of patients' pathologic version to their premorbid version could be recommended as a goal in TSA. We specifically tested whether: (1) premorbid glenoid version or inclination in the pathologic shoulder of patients with unilateral osteoarthritis, as determined by the glenoid vault model, is different from glenoid version or inclination in the contralateral nonpathologic shoulder of these patients; (2) there are differences between glenoid version or inclination in healthy patients and the nonpathologic side of patients with unilateral osteoarthritis; and (3) there are differences between glenoid version or inclination in healthy patients and the premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis, as determined by the glenoid vault model.

Patients and Methods

Institutional Review Board (IRB) approval was obtained for this study. Bilateral shoulder CT scans were acquired from 27 patients (54 shoulders) with radiographic evidence of unilateral glenohumeral osteoarthritis and a clinically and radiographically normal shoulder on the contralateral side. Patients with glenoid dysplasia or arthritis owing to other causes, such as inflammatory, posttraumatic, or avascular necrosis, were excluded. Twelve patients underwent CT of the contralateral shoulder for a previous IRB-approved study [9], whereas the other 15 patients had CT of the contralateral shoulder performed before the TSA at the discretion of the treating surgeon to help determine the degree of pathologic glenoid retroversion and the desired surgical correction of version in the arthritic shoulder. All patients in the study were indicated for TSA as a result of failed nonoperative management for severe pain and limitation of function

attributable to their osteoarthritic shoulder. Additionally, bilateral shoulder CT scans of 15 normal control cadaver shoulders (30 shoulders) with no evidence of glenohumeral osteoarthritis or other disorder in either shoulder were obtained. These controls were cadavers from a previous IRB-approved study [15] and included only males younger than 60 years, who were 69 inches or taller. The field of view of each CT scan included the entire scapula. All images were obtained with a semismooth algorithm and B40 windows at 1-mm increments in the axial plane perpendicular to the plane of the scapula [5, 21, 22]. CT scans were stored in DICOM format, and the DICOM images then were transferred to custom-designed 3-D surgical simulation software for use in TSA (Arthroplan software; Cleveland Clinic, Cleveland, OH, USA).

Two independent observers (MDH, ETR) measured glenoid version and inclination in all shoulders by either (1) direct measurement or (2) use of the glenoid vault model.

With the direct measurement technique, the plane of the scapula and plane of the glenoid fossa were defined in the 3-D surgical simulation software as previously described [9, 22]. The plane of the scapula was defined by three points: the inferior angle of the scapula, the scapula trigonum (junction of the scapular spine and medial scapular border), and the center of the glenoid fossa (Fig. 1, blue plane) [4, 5, 9]. The plane of the glenoid fossa was defined by three points placed on the face of the glenoid on or near the glenoid rim in locations along the normal glenoid surface (Fig. 1, green plane). Points were specifically placed away from rim osteophytes on the glenoid if present, to avoid incorrect determination of the glenoid plane. Glenoid version and inclination then were determined based on these two planes. Two-dimensional images were created from the 3-D reconstruction in three planes orthogonal to the plane of the scapula. Glenoid version was measured as the angle between the plane of the scapula and the plane of the glenoid fossa in the axial plane with positive angles representing anteversion and negative angles representing retroversion (Fig. 2A). Glenoid inclination was measured as the angle between the plane of the scapula and the plane of the glenoid fossa in the coronal dimension with positive angles representing superior inclination and negative angles representing inferior inclination (Fig. 2B).

With the glenoid vault model measurement technique, glenoid version and inclination were determined based on best-fit placement of a 3-D glenoid vault template. The template is an averaged volumetric reconstruction of the normal glenoid vault derived from CT-based and direct anatomic measurements of the endosteal surfaces of the glenoids in normal adult male and female cadaver specimens, as described and validated by Codsi et al. [5].

Placement of the glenoid vault template was performed with the 3-D surgical simulation software, as described by Scalise et al. [22] (Fig. 3). Best-fit placement of the vault model was confirmed in all three orthogonal planes (axial, sagittal, coronal), and version and inclination were measured based on this position. The vault model measurement technique was used to estimate the premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis.

Version and inclination measurements derived from the direct technique and from the vault model technique were performed separately and randomly on all scapulae by two independent observers (MDH, ETR). The observers were blinded to which scapulae were paired. In all scapulae, interobserver results were highly correlated between the two independent observers for the directly measured glenoid version and inclination and the glenoid version and inclination determined from the vault model (Table 1). Therefore, the two independent measurements in each scapula were combined and presented as average values for the remainder of the analysis.

Glenoid measurements were compared between scapulae in the same subject and between the unilateral osteoarthritis population and the normal control cadaver shoulders. Specifically, direct measurements of version and inclination were compared between the contralateral nonpathologic shoulder in the unilateral osteoarthritis group and the bilateral normal control cadaver shoulders to determine if differences existed. Premorbid glenoid version and inclination, as measured by the vault model technique in the pathologic shoulder of patients with unilateral osteoarthritis, were compared with the direct measurements of version and inclination in the contralateral nonpathologic shoulder and the normal control cadaver shoulders to determine if differences existed.

Sample size calculation with a power of 90% and an alpha level set at 0.05 yielded a minimum total of 14 shoulders in each study group, based on mean nonpathologic glenoid version of -7° , mean pathologic glenoid version of -12° , and mean standard deviation (SD) for glenoid version of 4° .

Interobserver reproducibility was analyzed using interclass correlations with pairwise correlation coefficients.

Paired Student's *t*-tests were used to compare mean differences in direct version, direct inclination, vault version, and vault inclination between paired shoulders in the same population, either the unilateral osteoarthritis group or the bilateral normal control cadaver shoulders. Unpaired Student's *t*-tests were used to compare mean differences in these same parameters when comparisons were made between groups of unpaired shoulders. To assess side-to-side differences in the measured parameters for each patient, the percentages of patients with measurements

Fig. 1A–D (A) Lateral, (B) medial, (C) posterior, and (D) anterior views of a 3-D reconstruction of a representative scapula are shown. The plane of the scapula was defined by the inferior angle of the scapula, the scapula trigonum, and the glenoid fossa center (blue plane). The plane of the glenoid fossa was defined by three points placed on the glenoid surface (green plane).

within 5° and within 10° across shoulders also were reported for each parameter, based on previously reported data [8, 9]. A regression analysis was performed to determine whether the 3-D vault model was a significant predictor of glenoid version and/or inclination in the contralateral shoulder of subjects with unilateral osteoarthritis.

Statistical significance was set at p less than 0.05. Correlation coefficients that achieved p less than 0.05 indicated there was statistically significant agreement between independent observers in the parameters measured.

Results

Premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis are not different from the contralateral nonpathologic shoulder

Glenoid version by direct measurement in the nonpathologic shoulder of patients with unilateral osteoarthritis averaged -7° (SD, 5), compared with -16° (SD, 11) in the arthritic shoulder by direct measurement (Table 2). Average premorbid version of the pathologic shoulder as measured by the vault model was -7° (SD, 5), which was not significantly different from the direct measurement of version in the contralateral shoulder ($p = 0.98$). The vault model was accurate in estimating the version of the opposite nonpathologic shoulder of the same patient to within 5° in 16 of 27 (59%)

patients and to within 10° in 26 of 27 (96%) patients. Glenoid inclination by direct measurement in the nonpathologic shoulder of the patients with osteoarthritis averaged 12° (SD, 6), compared with 11.0° (SD, 7) in the arthritic shoulder by direct measurement, which was not significantly different ($p = 0.22$) (Table 2). Average premorbid inclination of the pathologic shoulder as measured by the vault model was 10° (SD, 6), which was significantly different from the direct measurement of inclination in the contralateral shoulder ($p = 0.01$). The vault model was accurate in predicting the inclination of the opposite nonpathologic shoulder of the same patient to within 5° in 15 of 27 (56%) patients and to within 10° in 26 of 27 (96%) patients. Regression analysis indicated that the 3-D glenoid vault model was a significant predictor of glenoid version ($p = 0.002$) and inclination ($p = 0.0001$) of the contralateral shoulder in the unilateral osteoarthritis group.

Glenoid version and inclination in the nonpathologic shoulder of patients with unilateral osteoarthritis are not different from normal control cadaver shoulders

Glenoid version by direct measurement in the normal control cadaver shoulders averaged -8° (SD, 4) on the right side and -7° (SD, 4) on the left ($p = 0.24$) (Table 2), with 13 of 15 (87%) measurements within 5° and 15 of 15 (100%) within 10° between shoulders in the same patient. Glenoid version by direct measurement in the nonpathologic shoulder of patients with unilateral osteoarthritis averaged -7° (SD, 5),

Fig. 2A–B (A) Glenoid version was measured directly as the angle between the plane of the scapula (white line) and the plane of the glenoid fossa (green line) in the axial plane. Positive values represented anteversion and negative values represented retroversion. (B) Glenoid inclination was measured directly as the angle between the plane of the scapula (white line) and the plane of the glenoid fossa (green line) in the coronal plane. Positive angles represented superior inclination and negative angles represented inferior inclination.

compared with a combined average of -7° (SD, 4) for the normal control cadaver shoulders, which was not statistically significant ($p = 0.88$). Glenoid inclination by direct measurement in the normal control cadaver shoulders averaged 11° (SD, 5) on the right side and 13° (SD, 5) on the left ($p = 0.001$) (Table 2), with 13 of 15 (87%) measurements within 5° and 15 of 15 (100%) within 10° between shoulders in the same patient. Glenoid inclination by direct measurement in the nonpathologic shoulder of patients with unilateral osteoarthritis averaged 12° (SD, 6), compared with a combined average of 12° (SD, 5) for the normal control cadaver shoulders, which was not statistically significant ($p = 0.91$).

Premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis are not different from those of normal control cadaver shoulders

In patients with unilateral osteoarthritis, average premorbid version of the pathologic shoulder as measured by the vault model (-7° , SD 5), was not significantly different from the direct measurement of version in the normal control cadaver shoulders (-7° , SD 4; $p = 0.90$) (Table 2). Similarly, average premorbid inclination of the pathologic shoulder as measured by the vault model (10° , SD 6) was not significantly different from the direct measurement of inclination in the normal control cadaver shoulders (12° , SD 5; $p = 0.06$) (Table 2).

Discussion

The purpose of this study was to determine if patients with glenohumeral osteoarthritis and acquired posterior glenoid bone loss with increased glenoid retroversion have abnormal premorbid glenoid anatomy that predisposes them to subsequent glenoid disorders. We specifically tested this objective with three questions and showed that: (1) premorbid glenoid version and inclination in the pathologic shoulder of patients with unilateral osteoarthritis, as determined by the glenoid vault model, were similar to the direct measurements in the patients' nonpathologic contralateral shoulder; (2) glenoid version and inclination in the nonpathologic shoulder of these patients was not significantly different than these measurements in normal control cadaver shoulders; and (3) the premorbid glenoid version and inclination in the pathologic shoulder of the patients with unilateral osteoarthritis was not significantly different than direct measurements in normal control cadaver shoulders. These findings support that patients with acquired posterior glenoid bone loss secondary to osteoarthritis do not, on average, have increased native glenoid retroversion or altered glenoid inclination that would predispose them to a pathologic state.

A limitation of the current study was seen in some of the statistical comparisons of the measured parameters. Two of the group comparisons of glenoid version and/or inclination showed statistically significant differences ($p < 0.05$), however, we do not believe these findings represent meaningful clinical differences. In the patients with unilateral osteoarthritis, mean vault version of the pathologic glenoids (-7°) was not statistically different ($p = 0.98$) than mean direct version of the contralateral shoulder (-7°), but the same comparison for inclination (10° versus 12°) was statistically different ($p = 0.01$). Similarly, side-to-side comparisons in the normal control cadaver shoulders

Fig. 3A–C Placement of the glenoid vault model is shown. Best-fit placement was confirmed in all three orthogonal planes (axial, sagittal, coronal). **(A)** On the axial images, the anterior, posterior, and medial contours of the vault model (blue) are aligned with the corresponding endosteal surfaces of the bony glenoid. **(B)** On the sagittal images, the vault model (blue) is rotated to align with the tapering medial confines of the bony glenoid. **(C)** On the coronal

images, the suprascapular notch also is used with the endosteal surfaces of bony glenoid to align the vault model (blue). On all three images, blue dots represent landmarks on the 3-D reconstruction (inferior angle of the scapula, scapula trigonum, glenoid fossa center) used to define the plane of the scapula, while green dots represent peripheral points on the glenoid surface on the 3-D reconstruction used to define the plane of the glenoid fossa.

Table 1. Interobserver reliability of glenoid version and inclination measurements

Glenoid characteristics	Patients with unilateral osteoarthritis (n = 27)		Bilateral control cadaver shoulders (n = 15)	
	Arthritic side	Normal side	Right	Left
Direct version (degrees)	0.98 (0.00001)	0.90 (0.00001)	0.79 (0.00001)	0.89 (0.00001)
Direct inclination (degrees)	0.84 (0.00001)	0.81 (0.00001)	0.87 (0.00001)	0.88 (0.00001)
Premorbid vault version (degrees)	0.87 (0.0001)	0.70 (0.00001)	0.70 (0.004)	0.74 (0.002)
Premorbid vault inclination (degrees)	0.77 (0.00001)	0.89 (0.00001)	0.74 (0.002)	0.66 (0.008)

Pairwise correlation coefficients are presented for each measurement with p values in parentheses.

Table 2. Glenoid version and inclination measurements of the sample populations

Glenoid characteristics	Patients with unilateral osteoarthritis (n = 27)		Bilateral control cadaver shoulders (n = 15)		
	Arthritic side	Normal side	Right	Left	Combined
Direct version (degrees)	−16 (11)	−7 (5)	−8 (4)	−7 (4)	−7 (4)
Direct inclination (degrees)	11 (7)	12 (6)	11 (5)	13 (5)	12 (5)
Premorbid vault version (degrees)	−7 (5)				
Premorbid vault inclination (degrees)	10 (6)				

Mean values are presented for each measurement with SDs in parentheses.

showed no significant differences between the right and left shoulders in mean direct version (-8° versus -7° ; $p = 0.24$), but a significant difference was found for mean

direct inclination (11° versus 13° ; $p = 0.001$). In both of these comparisons, we do not believe that a difference of 2° is clinically significant, as this is within the reported variation of measurements of glenoid version and inclination in prior studies [4, 25]. From a surgical standpoint, these differences also fall within the error of placement of a glenoid component when trying to match a CT-based preoperative plan [12]. Another potential limitation of the current study is the inclusion of patients only with unilateral glenohumeral osteoarthritis. Although this was done to assess the contralateral shoulder for occult disorders and as a marker of the premorbid state, patients with bilateral glenohumeral osteoarthritis were not evaluated. It is possible that patients with bilateral disease may represent a separate clinical entity with premorbid anatomy that is different from that of patients with unilateral osteoarthritis. Finally, the normal control group consisted of cadavers with no evidence of glenohumeral osteoarthritis or other disorder in either shoulder on direct inspection. However, extensive background history was not available in these cases. Therefore, we do not know if any of the subjects had a significant family history or other predisposing factor for osteoarthritis

that could have led to one or both shoulders being in an early disease state.

The current findings support and expand on the results seen in prior studies evaluating the use of the glenoid vault model as a predictor of nonpathologic glenoid anatomy [9, 22]. In a group of 14 patients with unilateral glenohumeral osteoarthritis that underwent bilateral shoulder CTs, Scalise et al. [22] found that the glenoid vault model accurately predicted native glenoid version in the pathologic shoulder. No significant differences were seen in mean premorbid version in the pathologic shoulder, as estimated by the vault model, and mean version measured directly in the contralateral normal shoulder (-7.2° versus -7.0° ; $p = 0.99$), including mean within-sample comparisons. In a followup study, Ganapathi et al. [9] also evaluated the ability of the glenoid vault model to predict native glenoid version in an osteoarthritic shoulder while assessing additional prediction techniques. No significant differences were seen in mean premorbid version as estimated by the vault model and mean direct version of the contralateral normal shoulder (-5.32° versus -6.88° ; $p = 0.115$) in patients with unilateral glenohumeral osteoarthritis, and 100% (19 of 19 patients) of vault version measurements in the pathologic glenoid were within 10° of the directly measured version of the contralateral shoulder [9]. The current study reinforces the findings of these prior studies regarding glenoid version, and provides new data showing the predictive use of the glenoid vault model for glenoid inclination. Our results also support that glenoid inclination is not altered to a clinically relevant degree in glenohumeral osteoarthritis, with no significant difference in mean direct glenoid inclination between shoulders in patients with unilateral osteoarthritis.

The findings reported by Scalise et al. [22] and Ganapathi et al. [9] were based on the assumption that the contralateral shoulder in patients with unilateral glenohumeral osteoarthritis is nonpathologic and, therefore, representative of premorbid anatomy for the arthritic side. However, a set of 58 normal scapulae also were evaluated by Ganapathi et al. [9] and mean glenoid version was -2.59° in this control group, significantly different than mean glenoid version of the contralateral shoulders of the unilateral osteoarthritic group (-6.88°). Churchill et al. [4] measured mean version of -1.23° in a group of normal scapulae using a direct measurement technique, while Kwon et al. [16] measured mean version of -1.6° and -1.0° in a group of normal scapulae using a direct measurement technique and 3-D CT imaging technique, respectively. These measurements of normal glenoid version by Ganapathi et al. [9], Churchill et al. [4], and Kwon et al. [16] may suggest that the contralateral shoulder in patients with unilateral glenohumeral osteoarthritis is abnormally retroverted despite radiographic absence of arthritis, and this increased retroversion may

predispose to the development of glenohumeral osteoarthritis. However, different populations with normal scapulae may exist with different values of premorbid glenoid version. The normal scapulae used by Ganapathi et al. [9], Churchill et al. [4], and Kwon et al. [16] were obtained from the Hamann-Todd Osteological Collection, a group of specimens from the unclaimed dead of Cleveland during the early 20th century, and therefore may be anatomically different from a modern patient population. We used a modern patient population, and mean glenoid version and inclination in the nonpathologic shoulder of patients with unilateral osteoarthritis were not significantly different from measurements in normal control cadaver shoulders. These results clarify the discrepancies seen in prior studies and suggest that the contralateral shoulder in patients with glenohumeral osteoarthritis does not have an occult or subclinical disorder, such as increased native glenoid retroversion, that predisposes to the development of arthritis.

The use of normal control cadaver shoulders in this study further reinforced the predictive use of the glenoid vault model as a measure of premorbid anatomy. We observed no significant differences in measurements of glenoid version and inclination made with the vault model in the pathologic shoulder of patients with unilateral osteoarthritis and those made by direct measurement in normal control cadaver shoulders. Similar data have not been reported and further support the concept that patients with glenohumeral osteoarthritis do not have an altered premorbid state.

The glenoid vault model placed in an osteoarthritic glenoid can accurately predict premorbid glenoid version and inclination. The findings of our study suggest that premorbid glenoid version of the pathologic osteoarthritic shoulder is within the range of measurement for normal shoulders and may be the goal for glenoid reconstruction during TSA. This concept is analogous to patient-specific placement of the humeral component with respect to humeral version. The glenoid vault model, therefore, appears to provide a clinically useful tool to estimate patient-specific premorbid glenoid anatomy from the pathologic state, which may help in preoperative or intraoperative surgical planning.

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