

Glenoid Pathology Is Similar Between Osteoarthritis and Postcapsulorrhaphy Arthropathy: A Propensity-Matched Analysis

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Approved by the Institutional Review Board of the New England Baptist Hospital Project Number #2308231.

J Am Acad Orthop Surg 2026;34:e2261-e2269

DOI: 10.5435/JAAOS-D-25-01169

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ABSTRACT

Background: Postcapsulorrhaphy arthropathy (PCA) may result as a long-term sequela of instability surgery, eventually necessitating shoulder arthroplasty. Alterations to the soft tissue and bony anatomy during the index surgery may lead to unique wear patterns of the glenohumeral joint compared with what is observed in primary glenohumeral osteoarthritis (GHOA). We sought to characterize the three-dimensional glenoid morphology of patients with PCA to understand whether arthritic wear patterns are distinct from those observed in GHOA.

Methods: Patients diagnosed with GHOA or PCA were retrospectively propensity matched in a 4:1 ratio by age and sex. Radiographic measurements—including glenoid inclination, version, humeral head subluxation, glenoid vault loss, and maximum erosion depth—were assessed using Materialise Surgicase Preoperative Planner. The presence of biplanar glenoid deformity, defined as glenoid inclination and version $\geq 10^\circ$ was assessed. The PCA cohort was further stratified by capsulorrhaphy technique (open vs. arthroscopic). Univariate analysis was conducted to compare glenoid morphology between cohorts and subcohorts.

Results: After matching, the GHOA and PCA cohorts consisted of 264 and 67 patients, respectively, with no notable differences in age (GHOA 64.9 ± 7.0 years vs. PCA 63.6 ± 8.1 years; $P = 0.236$) or sex (85.0% male GHOA vs. 82.1% male PCA; $P = 0.714$). The PCA cohort demonstrated a markedly greater degree of superior inclination compared with the GHOA cohort (7.5 ± 5.4 vs. 4.3 ± 5.7 ; $P < 0.001$), although this is not likely clinically relevant. No other notable differences in any of the other radiographic measurements or parameters between GHOA and PCA cohorts were found. The arthroscopic and open PCA subcohorts consisted of 34 and 25 patients, respectively, with no notable differences in radiographic parameters observed between the open and arthroscopic cohorts ($P > 0.05$).

Conclusion: Arthritic glenoid wear patterns in patients with PCA and GHOA demonstrate no notable differences despite the altered soft tissue and bony anatomy inherent to instability surgery. Subcohort analysis of open versus arthroscopic capsulorrhaphy revealed no notable differences in glenoid morphology. Although PCA presents unique surgical challenges, these may be more closely tied to soft-tissue alterations than to variations in glenoid morphology.

Level of Evidence: Level III; Retrospective Comparative Study.

Postcapsulorrhaphy arthropathy (PCA) is recognized as a common sequela of shoulder instability surgery.¹⁻⁷ In these procedures—whether open or arthroscopic—the primary objective is to stabilize the glenohumeral joint and protect against recurrent dislocations; however, the tightening of the capsule in addition to other soft tissue and bony changes can alter joint reactive forces and kinematics. Over time, these alterations can contribute to degenerative changes of the shoulder, ultimately necessitating shoulder arthroplasty.

Glenoid morphology in the setting of primary glenohumeral osteoarthritis (GHOA) has been previously characterized by the Walch classification and has been recognized as a pivotal factor in surgical planning and implant design.⁸⁻¹¹ The way we conceptualize glenoid wear patterns and the position of the humeral head relative to the plane of the scapular body in the setting of GHOA may not be applicable to other arthritic conditions of the glenohumeral joint. In PCA, it is feasible that capsular tightening and other bony or soft-tissue changes may alter joint contact pressures, resulting in atypical erosion patterns over time. Whether these changes truly yield more pronounced changes in version, inclination, joint line medialization, or biplanar wear, defined as concurrent version and inclination pathologies of $\geq 10^\circ$, remains unclear.

We sought to characterize the three-dimensional glenoid morphology in patients with PCA relative to those with primary GHOA to understand whether PCA is associated with different glenoid wear patterns. We hypothesized that patients with PCA would exhibit distinct glenoid morphologic wear patterns compared with a propensity-matched cohort of patients with GHOA.

Methods

Patient Selection

Following Institutional Review Board approval, a retrospective radiographic analysis was conducted. Patients were identified through a prospectively maintained institutional database (Outcomes Based Electronic

Research Database). Inclusion criteria consisted of patients enrolled in the total shoulder arthroplasty database between 2015 and 2024 for the treatment of either primary GHOA with an intact rotator cuff or PCA from a prior anterior shoulder instability procedure, with available preoperative CT imaging for glenoid morphology assessment. As this study was limited to radiographic evaluation, clinical data were not included, nor was clinical follow-up required for inclusion. PCA patients were further stratified based on whether their initial instability procedure was performed through an open or arthroscopic approach. Exclusion criteria included patients with a diagnosis other than primary GHOA or PCA, PCA from a posterior instability procedure, a documented preoperative or intraoperative rotator cuff tear, or unavailable preoperative CT imaging. All procedures were performed by one of two high-volume, fellowship-trained shoulder and elbow surgeons (A.J. or J.M.K.).

Radiographic Evaluation

Standardized CT imaging that was obtained for preoperative planning was used for analysis. Radiographic measurements—including glenoid inclination, version, humeral head subluxation percentage, glenoid vault loss percentage, and maximum glenoid erosion depth—were obtained using the Materialise Surgicase Preoperative Planner (Materialise). This software generates three-dimensional reconstructions of patients' anatomy to allow precise preoperative measurements of glenoid morphology and allows surgeons to simulate implant positioning for both reverse shoulder arthroplasty (RSA) and total shoulder arthroplasty. The process begins when a surgeon uploads a patient's CT images. From these images, three-dimensional models of the scapula and humerus are automatically segmented, along with crucial scapula landmarks, the glenoid face plane, and the humeral axis. The measurement of glenoid inclination and version is based on the methods published by Frankle et al.¹²

First, three bony landmarks are identified: the glenoid center point, the trigonum spinae, and the distal scapula

point. Based on these three points, the scapular (coronal) plane is created. The medial-lateral axis of the scapula is determined by a line connecting the glenoid center with the trigonum spinae. The anterior-posterior scapular axis is defined as the normal vector of the scapular plane, and the superior-inferior axis is defined as orthogonal to both the mediolateral and anterior-posterior scapular axis. Correspondingly, the scapular axial plane is the plane orthogonal to the scapular plane and through the medial-lateral axis (Figure 1). Finally, the sagittal plane is defined as the plane orthogonal to the scapular and axial plane. Then, the glenoid face plane is defined as the best-fit plane through the glenoid face surface. After identifying the scapular coordinate system and the glenoid face plane on the pathologic scapula, glenoid inclination and version are quantified. The inclination angle is defined as the angle between the medial-lateral axis and the normal direction of the glenoid face plane, measured in the coronal plane. The version angle is defined as the angle between the medial-lateral axis and the normal direction of the glenoid face plane, measured in the axial plane (Figure 1).

In addition, premorbid scapula reconstruction is performed using a statistical shape model with the three-dimensional pathologic scapula model as input. The premorbid shape can subsequently be used to estimate the percentage of vault loss and the maximum erosion depth by comparison of the pathologic and premorbid

glenoid. A detailed description of the methods is described by Plessers et al.¹³

In addition to quantitative measurements, patients were further evaluated for the presence of superior versus inferior inclination, retroversion versus anteversion, and biplanar deformity. Biplanar deformity was defined as the presence of both glenoid inclination and version greater than or equal to 10°.

Matching

Patients who met the inclusion and exclusion criteria were then propensity score matched in a 4:1 ratio based on age and sex. Matching was done using a greedy, nearest-neighbor algorithm without replacement, applying a predetermined caliper width of 0.2 times the SD of the logit of the propensity scores for the entire population. Using a caliper prevents poor or suboptimal matches when the closest eligible neighbor is not sufficiently similar to the target treatment subject. In addition, research has shown that as caliper width decreases, precision increases, with an optimal range of 0.2 to 0.5 times the SD of the logit of the propensity score for effectively controlling variance within a sample set.

Data and Statistical Analysis

Descriptive statistics were done for each cohort separately and expressed as mean and SD, or number and percentage of group when appropriate based on data

Figure 1

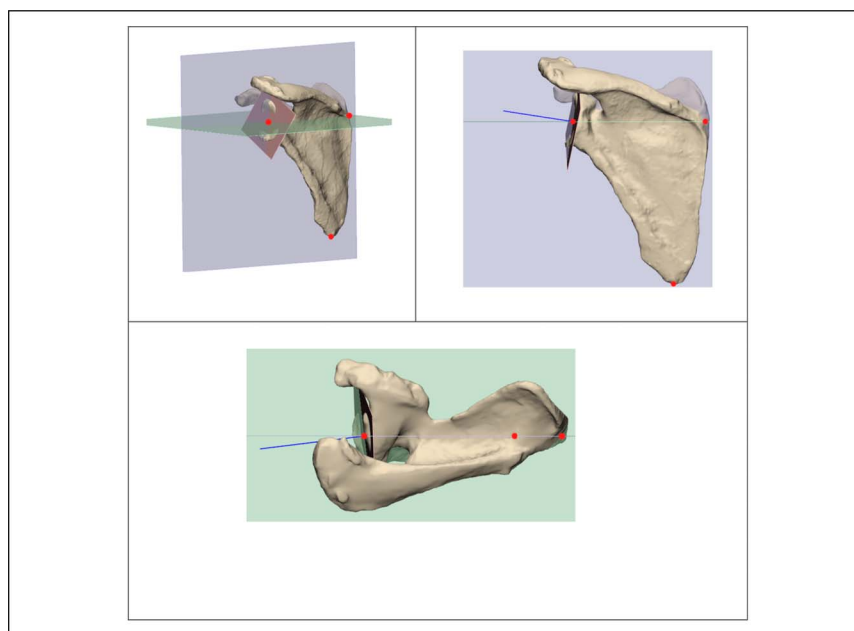


Image showing scapula coordinate system, measurement of inclination (positive inclination angle corresponds to superior inclination), and measurement of version (positive version angle corresponds to anteversion, negative angle corresponds to retroversion).

type and distribution. Univariate analysis was done to compare baseline demographics and radiographic parameters using *t*-test, Mann-Whitney *U* test, Chi-Squared test, and Fisher exact test, as indicated by the data type and distribution. All statistical analyses used an alpha-risk level of 0.05 to estimate significance. All statistical analyses were done using R statistical software (version 4.2.2; R Foundation for Statistical Computing).

Results

Demographics

After propensity score matching, the final study population consisted of 264 patients in the GHOA cohort and 67 patients in the PCA cohort. No statistically significant differences were found in age between the two groups (GHOA: 64.9 ± 7.0 years; PCA: 63.6 ± 8.1 years; $P = 0.236$). Sex distribution was also similar, with 85.0% male patients in the GHOA cohort and 82.1% in the PCA cohort ($P = 0.714$) (Table 1).

Postcapsulorrhaphy Arthropathy Versus Glenohumeral Osteoarthritis Cohorts

Radiographic evaluation showed that the PCA cohort had a greater mean superior glenoid inclination com-

pared with the GHOA cohort ($P < 0.001$). None of the PCA patients had inferior inclination, whereas a portion of the GHOA group did ($P < 0.001$). The two groups were otherwise similar in glenoid version ($P = 0.390$), prevalence of retroversion or anteversion ($P = 0.196$), rates of biplanar deformity ($P = 0.656$), percent subluxation ($P = 0.252$), vault loss ($P = 0.586$), and maximum erosion depth ($P = 0.238$) (Table 1).

Open Versus Arthroscopic Sub-cohorts

The PCA cohort was subsequently subdivided into arthroscopic and open surgery subgroups. No notable differences were observed between the groups in terms of age ($P = 0.138$), sex ($P = 0.090$), glenoid inclination ($P = 0.069$), version ($P = 0.099$), or the prevalence of retroverted or anteverted glenoids ($P > 0.999$). Rates of biplanar deformity ($P = 0.099$), humeral head subluxation ($P = 0.636$), vault loss ($P = 0.101$), and maximum erosion depth were also similar between the two surgical approaches ($P = 0.195$) (Table 2).

Discussion

Glenoid morphology in arthritic shoulders following prior anterior capsulorrhaphy does not differ markedly

Table 1. Comparing Radiographic Parameters of the Postcapsulorrhaphy Arthropathy and Glenohumeral Osteoarthritis Cohorts

Parameter	GHOA	PCA	P Value
	n = 264	n = 67	
Age, yr ^a	64.9 ± 7.0	63.6 ± 8.1	0.236
Sex ^a			
Male	85.0% (224)	82.1% (55)	0.714
Female	15.1% (40)	17.9% (12)	
Inclination angle (°)	4.3 ± 5.7	7.5 ± 5.4	<0.001 ^b
Superior	80.1% (213)	100.0% (67)	<0.001 ^b
Inferior	19.3% (51)	0.0%	
Version angle (°)	-14.8 ± 10.7	-13.8 ± 8.0	0.390
Retro	93.5% (247)	98.5% (66)	0.196
Ante	6.4% (17)	1.5% (1)	
Biplanar deformity	14.8% (39)	17.9% (12)	0.656
% Subluxation	67.1 ± 11.0	65.3 ± 11.0	0.252
% Vault loss	12.0 ± 12.8	10.9 ± 10.4	0.586
Max erosion depth	4.6 ± 3.5	3.9 ± 2.9	0.238

GHOA = glenohumeral osteoarthritis, PCA = postcapsulorrhaphy arthropathy.

^aVariables used to propensity score-match PCA and GHOA patients. Biplanar deformity defined as inclination and version angle $\geq 10^\circ$.

^bBold *P*-value < 0.05 denotes statistical significance; n (%) represents count and frequency; $x \pm s$ represents mean and SD.

Table 2. Comparing Radiographic Parameters of Open Versus Arthroscopic Capsulorrhaphy Procedures

Parameter	Arthroscopic	Open	P Value
	n = 34	n = 25	
Age, yr ^a	61.9 ± 9.5	65.0 ± 6.3	0.138
Sex ^a			
Male	70.6% (24)	92.0% (23)	0.090
Female	29.4% (10)	8.0% (2)	
Inclination angle (°)	6.9 ± 5.5	9.4 ± 5.1	0.069
Superior	100.0% (34)	100.0% (25)	>0.999
Inferior	0.0%	0.0%	
Version angle (°)	−12.0 ± 8.7	−15.9 ± 6.9	0.099
Retro	97.1% (33)	98.5% (25)	>0.999
Ante	2.9% (1)	0.0%	
Biplanar deformity	11.8% (4)	32.0% (8)	0.099
% Subluxation	64.6 ± 11.5	66.0 ± 10.7	0.636
% Vault loss	8.8 ± 10.0	13.1 ± 11.1	0.101
Max erosion depth	3.4 ± 2.9	4.5 ± 3.2	0.195

GHOA = glenohumeral osteoarthritis, PCA = postcapsulorrhaphy arthropathy

^aVariables used to propensity score-match PCA and GHOA patients. Biplanar deformity defined as inclination and version angle ≥10°.

from those shoulders with primary GHOA. The pathogenesis of primary GHOA is largely unknown; however, PCA is a known long-term sequela of arthroscopic or open shoulder instability surgery.^{1-5,7,14} These procedures alter the tension of the anterior capsule and surrounding soft tissues, including the subscapularis during certain open procedures, which may result in altered joint reactive forces and glenohumeral kinematics.^{3,15-18} However, the findings of this study refute our hypothesis and demonstrate largely similar three-dimensional glenoid morphology in shoulders with PCA and GHOA.

GHOA is the most common surgical indication for shoulder arthroplasty procedures including both anatomic shoulder arthroplasty and RSA.^{8,19-25} Understanding glenoid wear patterns and morphology in patients undergoing shoulder arthroplasty is crucial, given the need to address glenoid deformity to achieve ideal implant positioning and clinical outcomes.^{22,26-29} In addition, as the indications for shoulder arthroplasty continue to expand, a thorough grasp of glenoid morphology for all indications becomes even more essential.³⁰ PCA is one of the indications for shoulder arthroplasty, yet there is a lack of literature assessing the glenoid wear patterns and morphology associated with this pathology.^{15,31-33}

Many studies have evaluated wear patterns in GHOA using the Walch classification system^{8,23,34}; however, it

is imperative to understand that this classification is based on wear patterns seen in primary osteoarthritis. Previously, it was largely unknown whether the morphologic changes to the arthritic glenoid following prior anterior shoulder stabilization followed a similar wear pattern to those shoulders with primary GHOA. To ensure a comprehensive analysis, we used three-dimensional surgical planning software to ensure consistency and accuracy while calculating a range of commonly assessed morphological parameters. Automated three-dimensional measurements have been previously validated for assessing version, inclination, humeral subluxation, predicted vault loss, and maximum erosion depth.³⁵⁻⁴⁰ We selected these parameters to provide an in-depth, multidirectional evaluation of glenoid morphology, aligning with the critical information surgeons need for intraoperative decision making.

Essentially, every three-dimensional metric evaluated in this study demonstrated clinically similar parameters of glenoid wear when comparing PCA and GHOA. In addition, we found no notable differences when further stratifying wear patterns based on whether the prior anterior stabilization was done through an open or arthroscopic approach. Our study demonstrated that the PCA cohort had a markedly greater degree of superior inclination compared with the GHOA cohort,

although this difference has limited clinical significance. The slightly greater superior inclination and absence of inferior inclination in the PCA cohort may reflect subtle alterations in joint mechanics following capsulorrhaphy, as anterior capsular tightening and changes in soft-tissue balance could shift joint reaction forces superiorly and limit inferior wear. It is also possible that PCA patients present for arthroplasty earlier due to stiffness or prior instability, reducing the time for more advanced inferior erosion to develop. Although a component of this finding may be incidental, these mechanisms provide a plausible biologic explanation.

Despite statistical significance, the absolute difference in inclination was small (approximately 3°) and well below our threshold for pathologic inclination ($\geq 10^\circ$). In addition, substantial overlap was found between the groups, and no difference in the prevalence of biplanar deformity was found. From a clinical standpoint, a difference between 4.3° and 7.5° would not meaningfully alter arthroplasty reconstruction strategy, implant selection, or the need for correction, which is why we concluded that this difference lacks clinical significance.

Interestingly, none of the patients in the PCA cohort had any amount of inferior inclination, in contrast to the GHOA cohort, which had 19.3% of glenoids with inferior inclination. All other radiographic parameters, including version, percent with biplanar deformity, percent with retroversion or anteversion, percentage of humeral head subluxation, vault loss percentage, and maximum erosion depth, showed no notable differences between the PCA and GHOA cohorts.

Previous studies have extensively examined glenoid morphology in GHOA, particularly in relation to version, inclination, humeral subluxation, vault loss, and erosion depth.^{9,11,41-45} Studies evaluating version in GHOA have demonstrated a progressive increase in retroversion with more severe wear patterns, particularly in the B3 and C classifications.¹¹ Retroversion beyond 15° has been shown to be associated with eccentric wear and may pose challenges for implant positioning.⁴⁶⁻⁴⁸ Both bony and modular augments are commonly used to correct for this imbalanced fixation.⁴⁹⁻⁵¹ Superior inclination is frequently observed in shoulders with osteoarthritis while inferior inclination is much rarer, which aligns with our results as only approximately 20% of GHOA glenoids had inferior inclination.⁴²⁻⁴⁵ Increased humeral head subluxation percentages have also been reported in patients with more severe glenoid wear.¹¹ Walker et al¹¹ found an association between the initial presentation of posterior humeral head subluxation and the later development of

posterior glenoid bone loss. Posterior subluxation is a hallmark of Walch B2 patterns, whereas anterior-posterior balance is better maintained in A1 and A2 cases. Predicted vault loss has been a focus in surgical planning, as it provides an estimate of available bone stock.^{9,41} This factor is critical in preoperative planning for ensuring implant fixation and longevity. Erosion depth has been used to quantify the severity of glenoid wear, particularly in cases progressing from A1 to B3 patterns.⁵²

A notable gap in the literature exists specifically addressing glenoid morphology and wear patterns in PCA. Although prior studies have documented soft-tissue alterations and joint stiffness following instability surgery,⁵³⁻⁵⁵ comprehensive analyses of PCA's glenoid morphology are sparse. Open procedures may have a higher incidence of postoperative stiffness, whereas arthroscopic approaches may have higher recurrence rates.⁵⁶ A randomized clinical trial comparing open and arthroscopic stabilization procedures reported recurrence rates of 11% in the open group and 23% in the arthroscopic group at 2 years, indicating a higher recurrence rate with arthroscopic approaches.⁵⁷ Zimmerman et al⁷ reported markedly fewer complications following open stabilization procedures (11% vs. 42%) and overall better outcomes compared with arthroscopic approaches. However, Wagner et al found that although arthroscopic stabilization is less damaging to soft tissue, it does not markedly affect glenoid bone structure. Morphological analyses comparing the two approaches are limited, but existing evidence suggests that the extent of bony and soft-tissue alterations can vary.^{4,6} Open procedures are more likely to produce capsular contracture and glenoid remodeling. Cohen et al⁵⁸ comparing arthroscopic plication and open lateral capsular shift found that open procedures resulted in a 49.9% reduction in capsular volume, markedly greater than the 22.8% reduction observed with arthroscopic techniques. This substantial decrease in capsular volume with open procedures may lead to increased capsular tightness and subsequent glenoid remodeling.

Standard anterior stabilization procedures may have resulted in excessive tightening of the anterior capsular structures by shortening or transferring the subscapularis tendon. This may cause obligate posterior translation of the humeral head during external rotation.^{18,59} This shift causes the humeral head to adopt an eccentric position within the glenoid fossa, articulating with the posterior glenoid rather than its deepest concavity. Over time, this altered alignment may contribute to posterior glenoid

erosion and weakening of the posterior capsular and tendinous structures.⁵⁹ However, our study did not support these previous findings, as the percentage of humeral head subluxation and glenoid morphology remained consistent between the PCA and GHOA cohorts.

This study has several limitations. First, the retrospective nature of the study introduces inherent selection biases and limits control over confounding variables. Second, the sample size, although sufficient for statistical analysis, may not be large enough to capture the full spectrum of variability in PCA and GHOA morphology. Third, although three-dimensional surgical planning software was used for morphological assessments, differences in imaging protocols and scanning techniques between patients could introduce variability in measurements. The lack of established classification systems like the Walch system for PCA further complicates direct comparisons with GHOA. In addition, although the study focused on bony morphology, soft-tissue factors—such as capsular contracture—were not directly assessed and may play a notable role in the functional outcomes of these patients. The PCA cohort included patients who underwent prior instability surgery performed by different surgeons, at different institutions, and over varying time periods, using a range of surgical techniques, all of which may have influenced baseline joint mechanics, soft-tissue balance, and pre-operative range of motion. Although inclusion was limited to patients with documented prior anterior soft-tissue capsulorrhaphy, the specific details of the index stabilization procedure—such as labral tear size, number of anchors, degree of capsular mobilization, or use of thermal capsulorrhaphy—could not be consistently confirmed because prior surgical reports were unavailable. In addition, because patients were identified from an arthroplasty database, this study is subject to selection bias by capturing only individuals with advanced disease who elected to undergo surgery, which limits generalizability to earlier stages of pathology or non-surgical populations. Finally, the study does not account for differences in surgical techniques or rehabilitation protocols following prior instability procedures, which could influence the observed glenoid morphology. Given the lack of previous surgical report availability, we were not able to comment on the interval between the initial capsulorrhaphy procedure and subsequent RSA, which may influence the degree of soft-tissue changes and clinical outcomes. Future studies that incorporate prospective designs, larger sample sizes, and soft-tissue evaluations could provide a more compre-

hensive understanding of PCA and its differences from GHOA. Further research should also aim to characterize PCA morphology in greater detail and validate classification systems for its glenoid wear patterns. In addition, a deeper exploration of the interplay between soft-tissue integrity and glenoid morphology could enhance surgical planning and improve outcomes for patients undergoing shoulder arthroplasty for PCA.

Conclusion

The arthritic glenoid morphology in the setting of PCA and GHOA is largely similar, despite the different pathogenesis associated with each condition. Furthermore, subcohort analysis revealed no meaningful differences when we compared the wear characteristics of shoulders with prior open or arthroscopic anterior stabilization procedures. Although PCA presents unique surgical challenges, these may be more closely tied to soft-tissue alterations than to variations in glenoid morphology.

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