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Improving preoperative planning of revision surgery after previous anatomic total shoulder arthroplasty

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Background: The purpose of this study was to compare preoperative radiographic evaluation with intraoperative video and explant analysis in patients undergoing revision of a previous anatomic total shoulder arthroplasty (TSA).
Methods: We evaluated the preoperative radiographs of 165 revisions of failed TSAs for component loosening and glenohumeral registry (ie, the spatial relationship of the glenoid component and the prosthetic humeral head). Seventy-nine intraoperative videos were evaluated for component stability, rotator cuff (RC) integrity, synovitis, and glenoid bone loss. Eighty-seven explants were reviewed to assess wear patterns and presence of backside cement.
Results: Of 79 glenoid components, 47 were radiographically loose, but only 30 of 79 were loose intraoperatively. Thirty-two were radiographically fixed, but only 26 of 32 were fixed intraoperatively. If radiographically loose, 53% had severe glenoid bone loss. If radiographically fixed, 77% had mild to moderate bone loss ($P = .008$). Synovitis was associated with glenoid fixation: mild with a loose glenoid (6%) and severe with a fixed glenoid (30%, $P = .012$). Superior registry comprised 46%. RC deficiency was associated with posterior and anterior registry (88% and 79%, respectively). Explant examination revealed an eccentric wear pattern was predominant.
Conclusion: Radiographic evaluation of glenoid loosening in patients undergoing revision of TSAs will often differ from intraoperative findings (40% false-positive rate and 17% false-negative rate). Assessment of glenohumeral registry can help anticipate RC deficiency, with posterior and anterior registry associated with RC deficiency. Patients with a loose glenoid are more likely to have severe synovitis and more severe glenoid bone deficiencies. Failed TSAs are more likely to have asymmetrical wear of the glenoid component, suggesting altered pathomechanics that may have led to failure.

This study was determined to be exempt from review by the Western Institutional Review Board.

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The incidence of total shoulder arthroplasty (TSA) is rapidly increasing, as is the number of revision arthroplasties.[6] When revision of a previous TSA to a reverse shoulder arthroplasty is performed, preoperative planning is critical for the identification of potential intraoperative pathology and appropriate resource management.[1,5]

Preoperative planning in this scenario most often relies on plain radiographs, as the reliability of advanced imaging is regularly limited because of implant artifacts.[13] The accuracy of plain radiographs in estimating the likelihood of significant humeral and glenoid bone loss, stem and glenoid component stability, rotator cuff status, and anticipated bone loss is unknown.[2,8,9,11] There is a paucity of information in the literature about how indicative preoperative radiographic evaluation is of intraoperative pathology. Because it would rely on surgeons recording intraoperative observations, there exists the possibility of confirmation bias rooted in the preoperative radiographic assessment necessary to proceed with surgical treatment.

The purpose of this study was to compare preoperative radiographic evaluation with intraoperative videos and explant analysis in patients who underwent revision surgery for severe pain and shoulder dysfunction after previous anatomic TSA. We hypothesized that in patients whose radiographs had characteristics of a loose glenoid component via accepted classification schemes, intraoperative findings would confirm a loose glenoid. Our main objectives were (1) to determine how reliable radiographic loosening is in predicting intraoperative glenoid component loosening, (2) to determine the effect of different glenohumeral registries in various associated pathologies encountered intraoperatively, and (3) to determine whether explanted prostheses can help identify failure patterns.

Methods

This was a retrospective cohort study of 165 TSAs (mean age, 67.6 ± 10.7 years; 83 male and 82 female patients; 73 left and 92 right shoulders) that underwent revision for symptomatic failure performed by a single surgeon (M.A.F.) from 2004-2017. The mean preoperative American Shoulder and Elbow Surgeons score was 32.6 ± 16.7. Intraoperative videos were available for 79 patients (mean age, 67.1 ± 10.3 years; 38 male and 41 female patients; 36 left and 43 right shoulders), and 87 explants (mean age, 68.1 ± 10.5 years; 41 male and 46 female patients; 42 left and 45 right shoulders) were available for analysis. The study was divided into 3 stages in the context of the study aims.

Stage 1: radiographic evaluation

Clinical and radiographic features for every patient in the study were independently reviewed by 3 experienced shoulder surgeons who were blinded to the case information, and data were recorded using a standardized structured questionnaire. At least 3 views of the affected shoulder were available, including anteroposterior, Grashey, axillary, and scapular Y. Radiographic signs of glenoid component[7] and humeral stem[12,14] loosening, identification of the glenoid component type (pegged, keeled, or metal backed), and glenohumeral registry[10] (Fig. 1) were distinguished on these preoperative radiographs.[4,16] The following categories of glenohumeral registry were observed: anterior, posterior, medial, superior, and normal as defined by Matsen and Lippitt.[10] The reliability of radiographic evaluation was assessed ($\kappa = 0.754$).

Stage 2: intraoperative video evaluation

A total of 79 intraoperative videos were available and were independently evaluated by 3 experienced shoulder surgeons in a standardized fashion to assess the status of the glenoid[15] and humeral components, status of the rotator cuff tendons, severity of synovitis, and severity of glenoid bone loss. Reliability was assessed, and the κ correlation coefficient was calculated ($\kappa = 0.823$).

The glenoid component status was defined as loose (easily removed or dislodged) or not loose (removed with significant force or with the use of an instrument such as an osteotome). The humeral component status was defined as loose (easily removed or pulled) or well fixed (removed with extensive work). The status of the rotator cuff tendons was defined as intact or deficient, and the superior cuff was evaluated independently of the subscapularis. The presence of synovitis was categorized as mild (the capsule did not appear grossly inflamed), moderate (obvious inflammation of the capsule was present, but extensive dissection was not required to perform capsulectomy), or severe (gross capsular thickening and erythema were noted, and significant effort was required to resect the capsules with synovitis, particularly the inferior and posterior capsules). The severity of glenoid bone loss was categorized after implant removal as mild (the glenoid appears similar to a native glenoid after preparation for the implant), moderate (more glenoid loss is present than just that

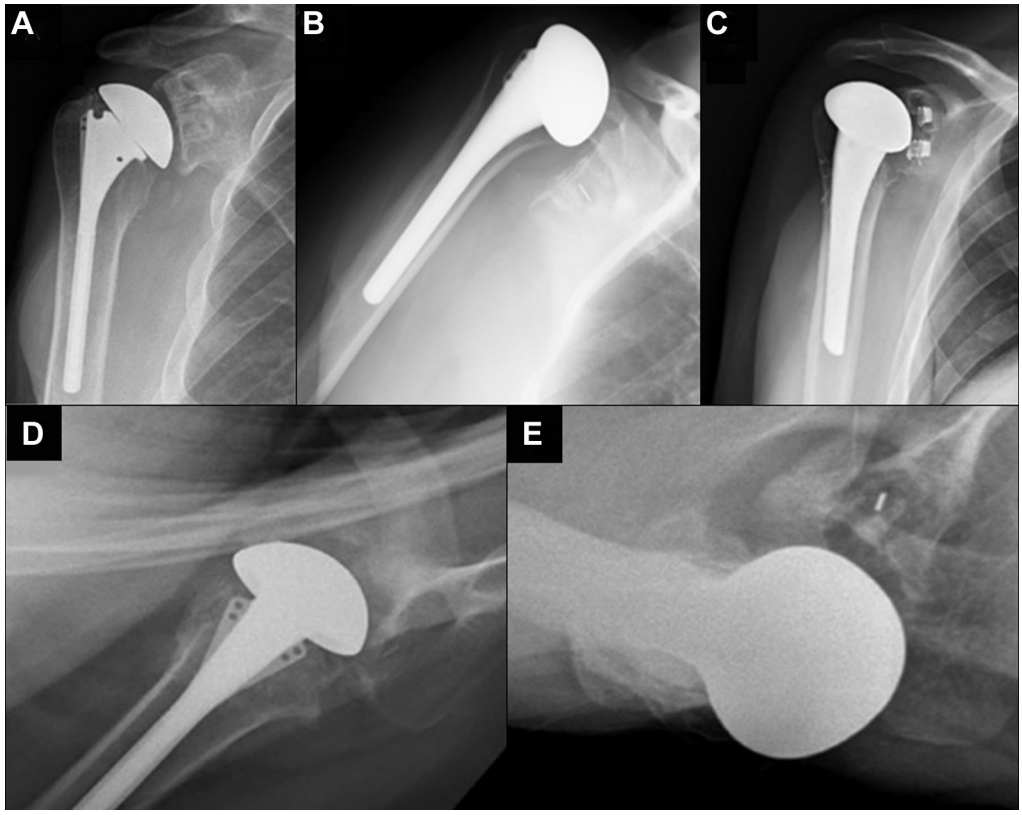

Figure 1 Radiographic evaluation of glenohumeral registry: normal (**A**), superior (**B**), medial (**C**), anterior (**D**), and posterior (**E**).

from prior fixation, and the periphery is easily identifiable), severe (extensive bone loss is present with a deep defect and loss of the surface, but the defect remains contained with the cortical margin evident), or uncontained (some loss of the cortical periphery is present requiring a graft or hooded component to compensate for the loss).

Stage 3: explant analysis

Explants are retained from revision surgical procedures in our institution for research purposes. They are cleaned, cataloged, and transported to a secure repository. Three experienced shoulder surgeons, blinded to the case information, independently examined the 87 explants available using standardized methodology. Among these explants, there were 85 humeral heads, 60 glenoid components, and 72 humeral stems. Evaluation of the glenoid component consisted of wear pattern (Fig. 2) (none, eccentric, or concentric) and presence of backside cement (yes or no). The humeral head was evaluated for wear pattern (none, eccentric, or concentric), and in cases in which both the head and glenoid were available, assessment for a matched wear pattern was performed. Reliability was assessed ($\kappa = 0.792$).

Statistical analysis

Descriptive statistics were used to characterize the demographic characteristics of the patients; means and standard deviations were presented for continuous variables, and frequencies were charted for categorical variables. Significance testing was performed using a standard 2-tailed *t* test or 1-way analysis of variance for continuous variables and the χ^2 test or Fisher exact test for categorical variables.

Results

Stage 1: radiographic evaluation

Radiographically, 102 glenoid components and 2 humeral stems were classified as loose. In contrast, 63 glenoid components and 163 humeral stems were fixed. There were 26 metal-backed, 42 keeled, and 97 pegged glenoid components. On evaluation of 165 patient radiographs, the most common registry was reported as superior (n = 76, 46%), followed by anterior (n = 41, 25%) and medial (n = 20, 12%) (Table I).

Stage 2: intraoperative video evaluation

Among the 79 patients with available intraoperative videos, 36 glenoid components and 5 humeral components were assessed as loose. The rotator cuff status was deemed intact

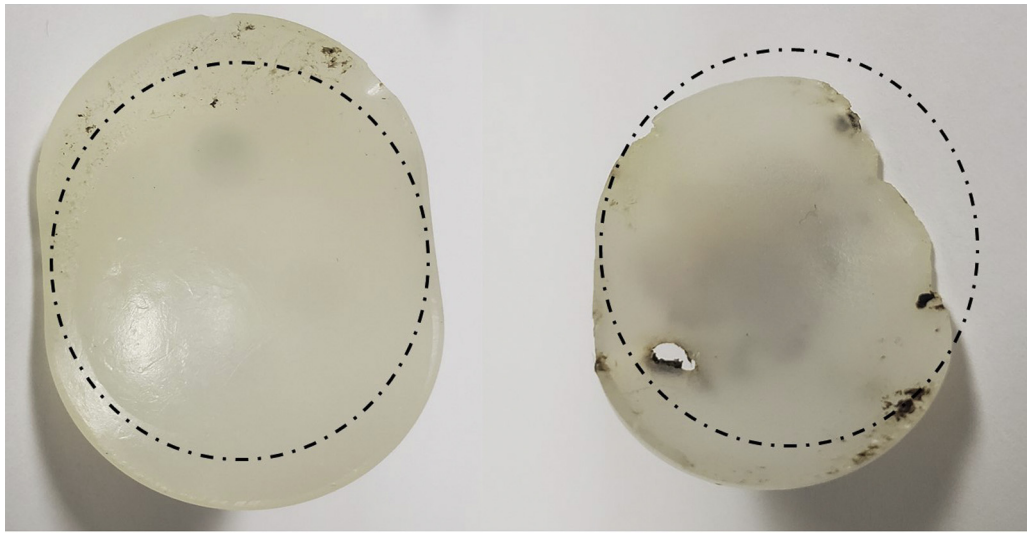

Figure 2 Evaluation of glenoid component wear patterns: concentric (*left*) and eccentric (*right*). Concentric wear is defined with symmetric wear within the circle, while eccentric wear was defined as asymmetric wear within the circle.

in 35 of 79 patients (44%) (Table II). Synovitis was evaluated as mild in 9 of 79 (11%), moderate in 34 of 79 (43%), and severe in 36 of 79 (46%). Glenoid bone loss was classified as mild in 24 of 79 (30%), moderate in 20 of 79 (25%), severe in 15 of 79 (19%), and uncontained in 15 of 79 (19%). In 5 cases, the glenoid was not visualized for assessment.

Stage 3: explant analysis

Explant analysis of both the humeral head and glenoid component revealed that an eccentric wear pattern was predominant in components, occurring in 35 of 60 pairs (58%, $P < .001$). Of the 60 glenoid component explants available, 17 (28%) had evidence of backside cement.

Objective 1: assessment of glenoid component loosening and its effects

Among the 79 patients with available intraoperative videos, 47 glenoid components were radiographically assessed as loose; however, this was confirmed intraoperatively in only 64% of cases (n = 30, 40% false-positive rate). Conversely, 32 glenoid components were radiographically evaluated as fixed, and this finding was confirmed on intraoperative video in 81% of cases (n = 26, 17% false-negative rate) (Table III).

Of patients with an intraoperatively observed well-fixed glenoid component, 70% had mild synovitis, whereas only 6% of patients with a loose glenoid component had mild synovitis ($P = .01$, Table IV). For purposes of analysis, glenoid bone loss was grouped as mild or moderate bone loss and severe or uncontained bone loss. If the glenoid component was radiographically graded as loose, then intraoperatively, 53% of patients had severe or uncontained glenoid bone loss. However, if the glenoid was radiographically graded as fixed, then 23% of patients had severe or uncontained bone loss intraoperatively ($P = .008$).

Table I Radiographic evaluation of glenohumeral registry

	Radiographic evaluation n (%)
Registry	
Superior	76 (46)
Anterior	41 (25)
Medial	20 (12)
Posterior	19 (11)
Normal	9 (6)
Total	165 (100)

Table II Comparison of radiographic glenohumeral registry and rotator cuff deficiency

	Rotator cuff deficiency*	No deficiency	% Rotator cuff deficiency within registry group
Registry			
Anterior	15	4	79
Medial	3	11	21
Normal	3	3	50
Posterior	7	1	88
Superior	16	16	50
Total	44	35	—

* Deficiency of subscapularis, supraspinatus, or both.

Table III Comparison of radiographic and videographic evaluations of glenoid component loosening

	Videographic evaluation		Total
	Loose	Not loose	
Radiographic evaluation			
Loose	30	17	47
Not loose	6	26	32
Total	36	43	79

Objective 2: analysis of glenohumeral registry

When assessed intraoperatively, cases of posterior registry and anterior registry were more likely to have rotator cuff deficiency than cases of normal, medial, or superior registry (Table II). Radiographic glenoid loosening was associated mostly with superior (47%), anterior (20%), and medial (19%) registry ($P = .01$), whereas intraoperative glenoid loosening was more prevalent with superior (44%) and medial (28%) registry ($P = .037$, Table V).

Objective 3: explant analysis and failure pattern

Video evaluation (available for 34 of 60 cases) showed loosening in 8 cases of cemented glenoids (12 of 17 available [71%]). Furthermore, video evaluation showed loosening in 10 of 22 glenoid components (45%) without backside cement ($P = .282$).

Discussion

Preoperative planning for revision shoulder arthroplasty potentially leads to better outcomes.[3,13] Consequently, increased attention from many manufacturers has resulted in a variety of software programs to assist the surgeon in this preparation. These programs rely on preoperative computed tomography scans of sufficient quality to permit 3-dimensional reconstructions to be generated in the various software programs. Because of the artifact introduced by the metal implant, these methods are not feasible in the setting of patients with failed TSAs.

Table IV Relationship between videographic evaluation of synovitis and glenoid component loosening

	Videographic evaluation		Total
	Loose n (%)	Not loose n (%)	
Synovitis			
Mild	2 (6)	7 (16)	9
Moderate	11 (31)	23 (54)	34
Severe	23 (64)	13 (30)	36
Total	36 (100)	43 (100)	79

Table V Glenoid component loosening and radiographic and videographic evaluations of glenohumeral registry

	Radiographic evaluation		Videographic evaluation	
	Loose n (%)	Not loose n (%)	Loose n (%)	Not loose n (%)
Registry				
Superior	48 (47)	28 (44)	16 (44)	19 (44)
Anterior	20 (20)	21 (33)	6 (17)	11 (26)
Medial	19 (19)	1 (2)	10 (28)	2 (5)
Posterior	10 (10)	9 (14)	3 (8)	6 (14)
Normal	5 (5)	4 (6)	1 (3)	5 (12)
Total	102 (100)	63 (100)	36 (100)	43 (100)

In our study, we sought to improve the use of preoperative plain radiographs in predicting the pathology encountered intraoperatively. We compared our data from radiographic, intraoperative video, and explant analysis.

In our cohort, radiographic review resulted in a 40% false-positive rate of determination of glenoid component loosening with intraoperative confirmation in the context of existing parameters.[7] Conversely, our false-negative rate was 17%, confirming that radiographic examination is more likely to identify a fixed glenoid when it is, in fact, fixed. Whereas radiographic glenoid loosening was associated mostly with medial, anterior, and superior registry ($P = .01$), intraoperative glenoid loosening was more prevalent with superior and medial glenohumeral registry ($P = .037$). Intraoperative glenoid loosening was associated with a 53% chance of having severe or uncontained glenoid bone loss. However, if the glenoid is graded as well fixed, then 77% of patients will have mild or moderate rather than severe glenoid bone loss ($P = .008$).

We also found that radiographic evaluation of glenohumeral registry may be of use to surgeons during the preoperative planning process. In our cohort, although the most common registry was superior, rotator cuff deficiency was associated with posterior and anterior registry (88% and 79%, respectively). Conversely, rotator cuff deficiency was least common when medial registry existed (21%).

For example, if a patient has medial registry and a radiographically loose glenoid component, one can expect that the surgeon will encounter severe bone loss and severe synovitis, which will likely require more surgical time and effort to address the greater degree of surgical pathology. Conversely, a patient with a radiographically fixed glenoid component and anterior glenohumeral registry is more likely to have both less severe glenoid bone loss and less severe synovitis intraoperatively, thus likely representing a

less complicated surgical procedure, although this patient is more likely to have associated rotator cuff deficiencies that will need to be addressed.

In our explant analysis of both the humeral head and glenoid components, an eccentric wear pattern was predominant, occurring in 35 of 60 pairs (58%, $P < .001$), suggesting that 1 possible failure mechanisms of TSA is related to difficulty in achieving ideal soft-tissue balancing. In addition, it has been suggested that the use of backside cement results in increased rates of loosening of the glenoid component.[9] In our group of 34 patients with both explants and intraoperative videos available, we were unable to detect a difference in cases of glenoids with backside cement (67%) vs. those without (45%) that were found to be loose intraoperatively ($P = .282$).

Strengths and limitations

The strengths of this study are the use of intraoperative videos and explant analysis to validate the intraoperative findings in a large population of patients undergoing revision of failed TSAs. This provides a standard to assess the predictable intraoperative challenges that can be elucidated from plain radiographs. In addition, 3 observers each reviewed the preoperative radiographs, reviewed intraoperative videos, and performed the explant analysis independently, therefore reducing the potential for confirmation bias. The inter-rater reliability coefficient of each independent evaluation demonstrated that it is a reproducible methodology. In addition, cross-referencing of data decreases discrepancies when compared with a single data source.

A weakness of this study is that intraoperative videos were available for a smaller sample of our population compared with the preoperative radiographs, therefore potentially creating bias in our findings. However, this effect is mitigated by the random availability of the cases recorded (only some operating rooms were equipped with video recording equipment, but the room allocation was random). Nonetheless, the numbers recorded represent a large clinical experience. In addition, the explant analysis was performed on a reduced proportion of the population, potentially creating a bias. Some implants were lost because of inadvertent disposal and some were lost because of errors in explant cataloging and the storage protocol resulting from episodic staff turnover. We believe the available implants comprise a random selection and a true representation of the total population.

Conclusion

In patients who are undergoing revision of failed anatomic TSAs, preoperative radiographic evaluation of glenoid component loosening may often differ from intraoperative findings. Preoperative radiographic diagnosis of posterior and anterior glenohumeral registry can help anticipate intraoperative rotator cuff deficiency. Patients with a loose glenoid are more likely to have severe synovitis and more severe glenoid bone deficiencies. Failed TSAs are more likely to have asymmetrical wear of the glenoid component, suggesting altered pathomechanics that may have led to failure.

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