Comparison of conforming and nonconforming retrieved glenoid components

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The purpose of this study was to compare differences in wear performance of conforming and nonconforming glenoid designs, using clinical, radiographic, and retrieved polyethylene glenoid component outcome Sixty-three glenoids met the study criteria, and each glenoid was assigned to the conforming group (if the radii of curvature of the humeral and glenoid components were identical) or the nonconforming group (if a mismatch existed between the radii of curvature). The mean length of implantation was 5.6 ± 5.5 years in the conforming group and 3.1 ± 3.1 years for the nonconforming group (P < .05). The loosening score was 3.2 ± 2.0 in the conforming group and 2.4 ± 1.2 in the nonconforming one (P < .05). The nonconforming group had a significantly greater burnishing score (P < .01), while the conforming group had greater abrasion and delamination scores (P < .05). Articular conformity contributes to differences observed from retrieved polyethylene glenoid components, which are consistent with differences in performance that may influence loosening. (J Shoulder Elbow Surg 2008;17:914-920.)

The prevalence of glenoid component loosening can be as high as 12.5% after total shoulder arthroplasty (TSA). Symptomatic glenoid loosening is the most common complication and comprises one-third of all complications.[2,3,13,19] In patients dissatisfied after TSA, failure was attributed to glenoid loosening in 59% of cases. The wear patterns after TSA have not been extensively studied and may provide additional information about factors that contribute to glenoid component failure.

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The appropriate amount of articular congruity of the glenoid component is an area of intense debate. The advantages of a conforming glenoid component include an increased surface area with concentric loading, thus leading to decreased polyethylene wear and improved joint stability. The disadvantage, however, is the inability to allow coupled translation of the shoulder, potentially causing increased stress at the implant-bone interface.[14,18] Nonconforming glenoid components possess a greater radius of curvature relative to the opposing humeral head, thereby facilitating coupled translation but at the expense of increased contact stresses and a less stable glenohumeral joint.[14,18]

Because *in vivo* wear patterns have been reported for only a few retrieved polyethylene glenoid components, only limited conclusions have been drawn about how design and clinical factors affect wear performance and relate to failure. The purpose of this study was to compare differences of conforming and nonconforming glenoid designs on the basis of clinical, radiographic, and damage modes of retrieved polyethylene glenoid components.

MATERIALS AND METHODS

From 1979 to 2006, total shoulder arthroplasty components were retrieved during revision surgery at a single hospital. The components were assigned an anonymous number and stored in the laboratory until analysis. Seventy-eight retrieved glenoid components from 73 patients were available from 4 identifiable manufacturers (52: Biomet, Warsaw, IN; 17: Neer II [Smith & Nephew, Inc. - Orthopedics, Memphis State, TN]; 6: Custom HSS [Hospital for Special Surgery, New York, NY]; and 2: Depuy Orthopaedics, Inc., Warsaw, IN). The manufacturer of 1 glenoid implant could not be determined. The articulation of the glenoid implants was nonconforming in 54% and conforming in 46%. To examine the effect of conformity, only all-polyethylene, cemented, keel fixation glenoids components were included. Glenoids were excluded if they were made from highly crystalline polyethylene (Hylamer; DePuy DuPont, Warsaw, IN), peg fixation, a metal backing, or screw fixation, in an effort to eliminate these confounding variables from the comparison of conformities. Fifteen of the 78 glenoids were excluded from the conformity analysis because 6 were metal-backed, 4 had screw fixation, 3 were made from Hylamer, and 2 had peg fixation. A glenoid component was assigned to the conforming group (if the radii of curvature of the humeral head and glenoid components were the same) and to the non-conforming group (if a mismatch existed between the radii of curvature) (Table I).

Retrospective review of the medical records and radiographs was conducted for all patients. The clinical information was obtained from medical records, including patient demographics, medical comorbidities, shoulder history, clinical assessment (pain, range of motion), intra-operative findings, implant information, and postoperative complications.

The most recent plain shoulder radiographs (anteroposterior [AP] and axillary [AX] views) prior to removal of the glenoid were examined. The extent and amount of radiolucency in the AP view was measured with digital calipers by using the system described by Molé.[11] The radiolucent lines were assigned a numeric value based on the thickness for all 6 zones, and the values were summed to give the radiolucency score. A score of 0-6 points corresponds to no loosening, 7-12 points to possible loosening, and 13-18 points to definite loosening.[11] The same method was adapted to the AX radiographs, with radiolucencies measured in 3 zones corresponding to the anterior rim (zone 1), around the fixation keel (zone 2), and the posterior rim (zone 3) of the glenoid (Figure 1). The glenoid loosening[17] and lucency[6] classifications were determined for each glenoid (Tables II and III) based on the AP and AX views. The amounts of subluxation in the coronal (AP view) and sagittal (AX view) planes were measured as the percent of translation and graded as mild ($<$ 25%), moderate (25-50%), or severe ($>$ 50%).[17] The glenoid version was also calculated by measuring the angle formed by a line perpendicular to the scapular axis and a line along the maximum AP diameter of the glenoid cavity.[12]

The polyethylene bearing surfaces of the components were examined microscopically with 4x<typist: insert multiplications symbol> magnification loupes and in a light stereomicroscope at magnifications up to 31x<typist: insert multiplications symbol>. Nine modes of damage were scored for each glenoid: burnishing, abrasion, scratching, pitting, delamination, focal wear, surface deformation, embedded 3rd body debris, and fracture.[7-9] The surface was divided into anterior, posterior, superior, and inferior quadrants, and given a subjective damage score of 0-3 for each damage mode in each quadrant (Figure 2).[8] Thus, the total possible score was 108 (3 points for each of the 4 quadrants of the glenoid component for all 9 damage modes).

Statistical analyses were used to compare patient characteristics, radiographic measurements, and damage modes between the conforming and nonconforming groups, using Student's *t* test for continuous variables and Chi-square test for categorical variables (SPSS 14.0, Chicago, IL). *P* values of less than .05 were considered significant.

RESULTS

Of the 63 glenoids that met the study criteria, clinical information was available for 56 (from 54 patients). For the conforming group, 27 glenoids were examined for wear damage, with clinical information available on 24. For the nononforming group, 36 were examined for damage, with clinical information available on 32.

The mean patient age was similar between the 2 groups, but the length of implantation was significantly greater in the conforming group at 5.6 $\pm$ 5.5 years, compared to only 3.1 $\pm$ 3.1 years in the nonconforming group (Table IV). The conforming group had greater forward elevation than the nonconforming ($69.3° \pm 36.9°$ vs. $65.5° \pm 37.4°$), but only external rotation reached statistical significance ($33.0° \pm 26.2°$ vs. $12.9° \pm 21.0°$; $P < .05$). Sixty-seven percent of patients in the conforming group had osteoarthritis compared to 87.5% in the nonconforming, but the difference was not significant. The glenoid component was removed in 87.5% of the conforming group and 71.9% of the nonconforming, and the glenoid was revised in the remainder in each group. The glenoid was found to be macroscopically loose in the overwhelming majority of cases, with 95.8% in the conforming and 90.6% in the nonconforming group. No significant differences were found in intraoperative findings between groups, including glenoid osseous defects in 62.5% of cases in each group ($P > .05$), rotator cuff tears in 58.3% in the conforming group and 46.9% in the nonconforming ($P > .05$), and glenohumeral instability in 33.3% of conforming and 46.9% of nonconforming cases ($P > .05$). There were no differences between the proportion of cases with infection in both groups, and no significant differences in terms of damage mapping data occurred between the groups ($P > .05$).

Radiolucent lines in the AP view of conforming glenoids were greater in zones 1, 2, and 4 compared to the nonconforming glenoids; however, no significant difference was found between the groups (Figure 3, *A*). In the AX view, the conforming group had greater radiolucent lines in all 3 zones (Figure 3, *B*). The mean radiolucency score was 9.2 for both groups, which represents possible loosening. The conforming

Table I Implant information

	Conforming	Nonconforming	P value
Manufacturers			.0001
Biomet designs	33.3%	96.9%	
NEER II designs	58.4%	0.0%	
HSS custom	8.4%	0.0%	
DePuy	0.0%	0.0%	
Unknown	0.0%	3.1%	
Articulation			
Conforming	100%		
Nonconforming	—	100%	
Fixation			1.000
Cemented	100%	100%	
Screw	—	—	

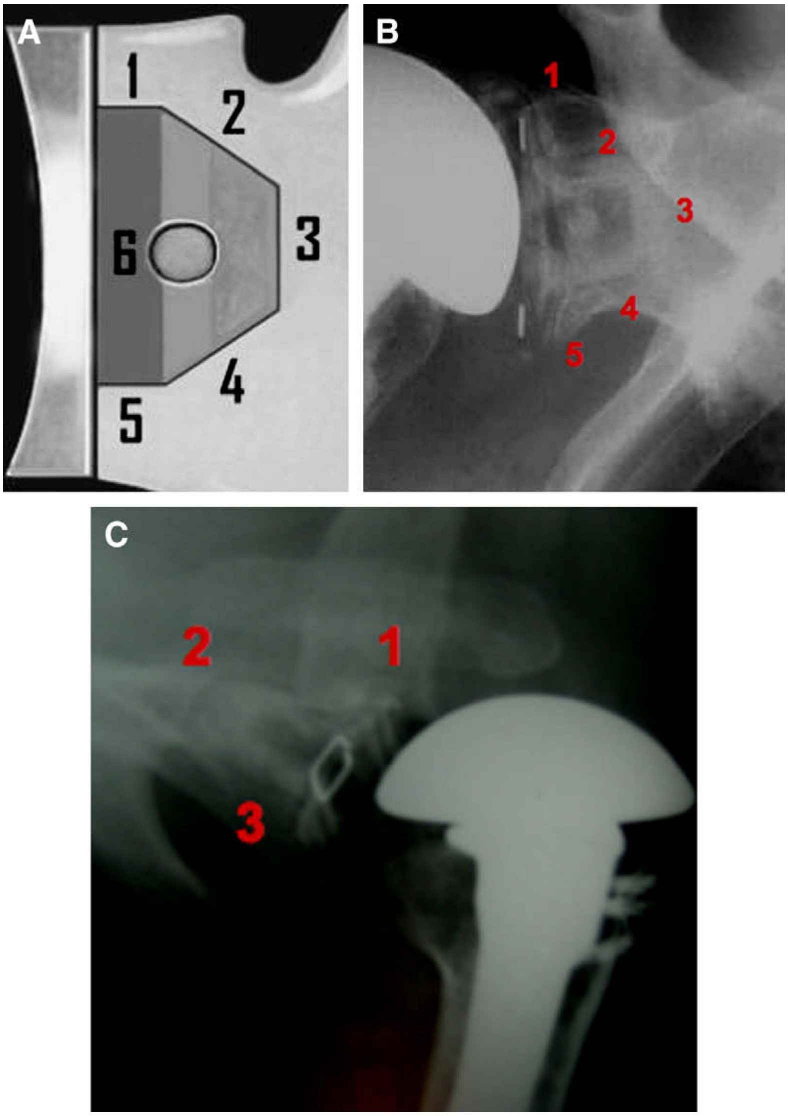

Figure 1 Modified Molé System for the measurement of radiolucency. **A,** Schematic of the Molé System. **B,** Anteroposterior view of the glenohumeral joint with six zones. **C,** Axillary view of the glenohumeral joint with three zones. **A** and **B** modified and reprinted with permission from Szabo et al.[22]

glenoids had greater loosening and lucency scores in both radiographic views (Table V). Both the loosening and lucency scores were significantly different between groups in the AX plane, while only the loosening score was significantly different in the AP plane. No significant difference was found for version or subluxation.

The damage score for burnishing was significantly greater for nonconforming glenoids (Table VI). Conforming glenoids had significantly greater abrasion and delamination scores. Damage to the glenoid rim was common in both groups, although the wear patterns differed significantly between groups. Impingement, abrasion at the glenoid edge, was observed in 29 polyethylene glenoid components, with 69% (20/29) in the conforming group and 31% (9/29) in the non-conforming ($P < .05$) (Figure 4, *A*). Surface deformation, on the other hand, was present in 18 retrieved glenoids, with 16.7% (3/18) in the conforming and 83.3% (15/18) in the nonconforming group ($P < .05$) (Figure 4, *B*). The distribution of damage also differed with 56% of nonconforming glenoids having involvement of the posterior quadrant and 68% of conforming glenoids having involvement of the anterior and inferior quadrants. The mean version was 13.2° retroversion (range, 32° retroversion to

Table II Torchia classification for glenoid loosening

Classification	Description
Not loose	No radiolucent lines or radiolucent lines limited to the flange; no change in position
Minimal risk of loosening	Incomplete line < 2 mm and involving < 1/3 of the keel
Possibly loose	Incomplete line < 2 mm that involves > 1/3 of the keel
Probably loose	Complete radiolucent line < 1.5mm or incomplete line ≥ 2 mm in diameter involving > 1/3 of the keel
Definitely loose	Complete line > 1.5 mm in diameter or shift in position

Table III Franklin classification for glenoid lucency

Grade	Description
Grade 0	None
Grade 1	< 1 mm and incomplete
Grade 2	1 mm and complete
Grade 3	1.5 mm and incomplete
Grade 4	1.5 mm and complete
Grade 5	≥ 2 mm and complete

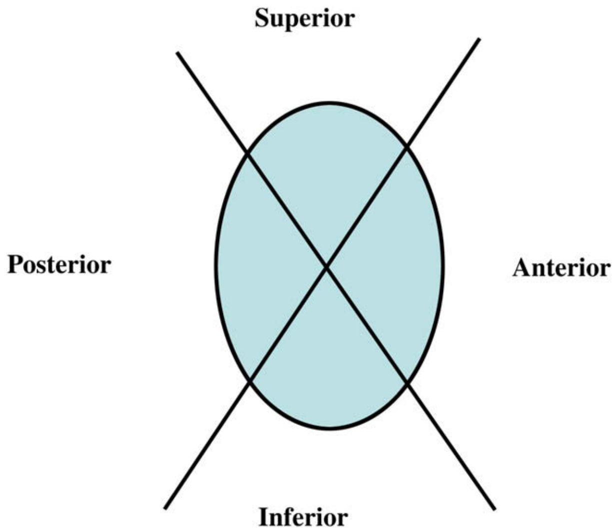

Figure 2 Damage mapping and scoring for glenoid components. Each quadrant was graded: 0 = no damage; 1 = 1-10% of the surface had evidence of the damage mode; 2 = 11-50% of the surface; and 3 = 51-100% of the surface. The score for a quadrant with severe damage in a small area was increased by one point. For each damage mode, the total score was calculated as the sum of all four quadrants with a maximum score of 12.

15° anteversion) for cases with surface deformation, 4.4° retroversion (range, 37° retroversion to 26° anteversion) for those with impingement, and 3° anteversion (range, 19° retroversion to 27° anteversion) for those without damage to the glenoid rim; however, these differences did not reach significance ($P > .05$).

DISCUSSION

The glenohumeral joint is an enarthrodial articulation with a hemispherical humeral head and a shallow glenoid that allows multiplanar range of motion but relies on the surrounding soft tissues to provide stability. The goal of total shoulder arthroplasty is to replicate natural motion and stability, while limiting wear and maintaining fixation of the prosthesis to the host bone.[21] In the native shoulder, the humeral head may translate 1.5 mm from anterior to posterior and 1.1 mm superior to inferior on the glenoid.[10] The prosthetic joint articulation can account for the complexity of this head movement through the use of nonconforming articular surfaces, although articular conformity has a direct relationship with stresses on and within the polyethylene glenoid, and also influences shear loads at the interface between the glenoid component and the surrounding bone or bone cement.[21]

The conforming group demonstrated greater loosening and lucency scores compared to the nonconforming group, suggesting that plain radiographs provided a better indication of glenoid loosening for conforming glenoids. Radiolucent lines were more evident in the axillary view, as demonstrated by a greater difference in loosening and lucency scores between groups. Furthermore, about 70% of the conforming group had grade 5 lucency scores and definitely loose loosening scores on the axillary view. Although prior classification systems have focused on the anteroposterior view, the axillary view provides additional information and greater insight into the mechanism of failure.

The mean radiolucency classification score for the conforming and nonconforming glenoid components was 9.2, representing a possibly loose component; although more than 90% of the glenoids were grossly loose intraoperatively. Although the overwhelming majority of glenoids were found to be grossly loose in both groups, conforming glenoids had a greater proportion of radiographic parameters suggestive of a loose glenoid. From these results, the radiographic classification systems appear limited in their ability to diagnose glenoid loosening. The orthopaedic surgeon should have a high suspicion of glenoid loosening in any patient with shoulder pain and any evidence of radiolucency around the glenoid component. A case-control study to evaluate the predictive capabilities of each system might be able to provide additional information regarding the significance of radiographic glenoid radiolucency, as it relates to glenoid component failure.

Table IV Clinical information

	Conforming	Nonconforming
No. patients	24	30
No. glenoids	24	32
Age at revision (± SD)	59.2 ± 12.7	59.8 ± 12.3
Length of implant (± SD)	5.6 ± 5.5	3.1 ± 3.1†
Gender		
Male	9 (37.5%)	12 (40.0%)
Female	15 (62.5%)	18 (60.0%)
Affected extremity		
Right	11 (45.8%)	16 (53.3%)
Left	13 (54.2%)	14 (46.7%)
Forward elevation (± SD)	69.3° ± 36.9°	65.5° ± 37.4°
External rotation (± SD)	33.0° ± 26.2°	12.9° ± 21.0°†
Primary diagnosis		
Osteoarthritis	16 (66.7%)	28 (87.5%)
Rheumatoid arthritis	6 (33.3%)	4 (12.5%)
Revision diagnosis		
Glenoid loosening	19 (79.2%)	25 (78.1%)
Infection	5 (20.8%)	4 (12.5%)
Instability	—	3 (9.4%)
Revision procedure		
Conversion hemiarthroplasty	21 (87.5%)	23 (71.9%)
Revision glenoid	3 (12.5%)	9 (28.1%)
Intraoperative findings		
Glenoid loose	23 (95.8%)	29 (90.6%)
Glenoid osseous defect	15 (62.5%)	20 (62.5%)
Rotator cuff tears	14 (58.3%)	15 (46.9%)
Instability	6 (33.3%)	15 (46.9%)
Adhesions	14 (58.3%)	17 (53.1%)
Deltoid atrophy	6 (33.3%)	5 (15.6%)

†Denotes statistically significant difference between conforming and nonconforming groups.

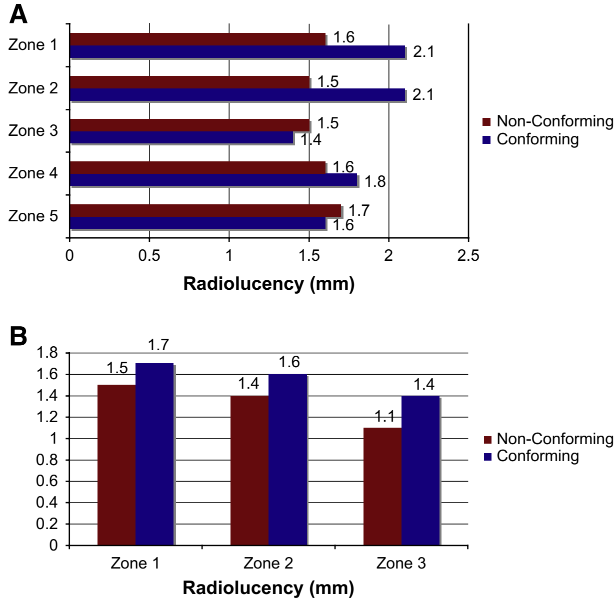

Figure 3 A, Comparison of antero-posterior radiolucency between conforming and nonconforming glenoids. **B**, Comparison of axillary radiolucency between conforming and nonconforming glenoids.

Our findings suggest different failure mechanisms for conforming and nonconforming glenoid components. Conforming glenoids had higher scores in 7 of 9 damage modes, with scratching, pitting, and abrasion prevalent in the inferior quadrant. Of the glenoids with impingement, 69% were conforming, involving the inferior and anterior quadrants. Our experience in analyzing retrieved polyethylene components from total hip and total knee arthroplasty has shown that abrasion, which is an easily identifiable damage mode, is the result of the opposing osseous surfaces rubbing against the polyethylene component.[9] In the case of the prosthetic glenohumeral joint, the opposing surface that would cause abrasion is most likely the bony surface surrounding the head of the humeral component, due to a combination of the glenoid position and repetitive shoulder internal rotation and adduction. Specifically, the metaphyseal bone surrounding the humeral head impinges on the inferior and anterior walls of the conforming glenoid component, causing excessive polyethylene debris and increased stress at the opposing bone-implant interface. The wear patterns are consistent with increased radiolucent lines in the superior and posterior aspects of the cement-bone interface of the conforming glenoid. The edge abrasion of the conforming glenoid rims grossly appears to have a greater amount of volumetric loss of polyethylene (Figure 4, *A*). Additional studies to quantify the amount of polyethylene debris would provide support for increased radiolucency around conforming glenoid components.

Scratching and pitting were localized in the inferior quadrant and burnishing at the anterior quadrant for nonconforming glenoids. Of the glenoids with surface deformation, 83% were nonconforming, with deformation occurring in the inferior and posterior quadrants. Glenoids with surface deformation were generally implanted in retroversion, and the humeral head edge loaded the posterior and inferior polyethylene edge, thus causing the observed deformation.[5,15] The eccentric posterior contact loads explain the increased anterior radiolucent lines, and instead of the superior-inferior rocking horse seen in rotator cuff deficiency,[6,16] a glenoid see-saw pattern may occur from posterior to anterior in cases with glenoid retroversion.

Nonconforming component designs had less radiolucency and less damage to the polyethylene surface. Walch et al[18] conducted a multicenter study to determine the effect of glenohumeral prosthetic conformity on radiolucent lines in patients treated with an all-polyethylene glenoid component for osteoarthritis. At a mean of 53.5 months, no significant differences

Table V Radiographic analysis of conforming and nonconforming glenoids

	Conforming (± SD)	Nonconforming (± SD)
Radiolucency score	9.2 ± 3.9	9.2 ± 4.1
Loosening score AP	3.2 ± 1.0	2.4 ± 1.2[†]
Not loose	0.0%	0.0%
Minimal risk	6.7%	33.3%
Possibly loose	20.0%	14.3%
Probably loose	20.0%	28.6%
Definitely loose	53.3%	23.8%
Lucency score AP	4.3 ± 1.2	3.3 ± 1.9
Grade 0	0.0%	14.3%
Grade 1	6.7%	4.8%
Grade 2	0.0%	14.3%
Grade 3	13.3%	9.5%
Grade 4	13.3%	14.3%
Grade 5	66.7%	42.9%
Loosening score AX	3.6 ± 0.7	2.2 ± 1.2[†]
Not loose	0.0%	0.0%
Minimal risk	0.0%	35.3%
Possibly loose	10.0%	23.5%
Probably loose	20.0%	23.5%
Definitely loose	70.0%	17.6%
Lucency score AX	4.5 ± 1.0	2.9 ± 1.9[†]
Grade 0	0.0%	11.8%
Grade 1	0.0%	17.6%
Grade 2	10.0%	17.6%
Grade 3	0.0%	5.9%
Grade 4	20.0%	11.8%
Grade 5	70.0%	35.3%
Coronal subluxation	19.4% ± 16.1%	24.5% ± 19.9%
Sagittal subluxation	18.3% ± 6.7%	30.5% ± 28.0%

[†]Denotes statistically significant difference between conforming and nonconforming groups.

Table VI Glenoid component wear analysis

	Conforming (± SD)	Nonconforming (± SD)	P value
Burnishing	2.0 ± 3.4	6.6 ± 3.6	.0001
Abrasion	4.1 ± 3.8	2.2 ± 2.8	.032
Delamination	1.0 ± 2.6	0.1 ± 0.5	.017
Wear Through	1.6 ± 2.7	1.0 ± 1.6	.463
Surface Deformation	1.8 ± 2.6	1.5 ± 1.6	.945
Pitting	7.5 ± 3.0	6.3 ± 3.2	.131
Scratching	8.3 ± 3.2	8.8 ± 3.2	.773
Fracture	0.5 ± 2.4	0.2 ± 1.1	.766
Embedded 3rd Body	0.0 ± 0.2	0.0 ± 0.0	.248

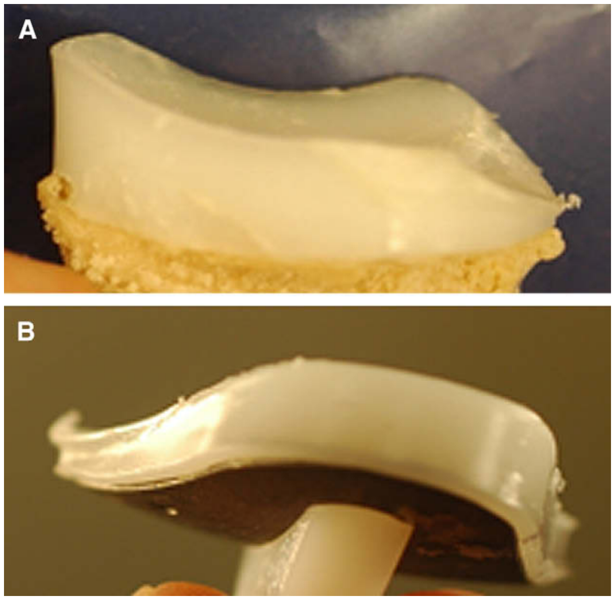

Figure 4 Observed damage modes. A. Abrasion of the glenoid rim. B. Surface deformation of the glenoid rim.

were found in clinical outcomes or complications between groups; however, there was a significant linear relationship between mismatch and glenoid radiolucency score. Greater prosthetic mismatch was associated with decreased radiolucency scores.[18]

Retrieval studies provide valuable information about polyethylene wear patterns after total shoulder arthroplasty; however, there are limitations inherent in these types of studies. Component retrieval studies represent between 0% and 12.5%[4,13,20] of symptomatic glenoid loosening cases that require revision surgery. They do not represent the 30-90%[1,4] of cases with asymptomatic radiolucencies around the glenoid components. The cases in the current study represent failed glenoid components, so analysis of patient, design, and surgical factors can provide critical information on the causes of component failure.

There are a number of limitations inherent in the study. The study design is a retrospective cohort study comparing 2 different glenoid articulations. Damage mapping as an outcome can only be conducted in a retrospective study design, and would not be practical in a randomized, controlled trial, or prospective study. Only glenoid component characteristics were used as inclusion and exclusion criteria to allow the maximum possible sample size. The humeral component was not directly analyzed, and, therefore, factors such as overstuffed joint, concentric, eccentric, head size, collar size, and neck shaft angle could possibly affect the results. A notable bias is the difference in length of implantation between groups. The conforming group had greater than 3 years of before revision surgery compared to the nonconforming group, which might, in part, explain the difference in radiolucent lines, classification scores, and damage mapping scores. However, matching the groups for length of implantation would have decreased the sample size and might not have affected the results. Of note, many other potential confounding factors were not statistically different between groups, including primary diagnosis, rotator cuff tear, instability, and glenoid bone stock. A study design that allowed comprehensive analysis of the largest number of possible specimens was thought to be crucial to further understanding glenoid failure and improvement in component design. The amount of impingement observed on the conforming glenoid components led to greater volumetric polyethylene loss and likely has a role in the radiographic and damage mapping results. Therefore, surface conformity plays a considerable role in the differences that are observed. There are confounding factors that exist, however, which could play a lesser role in the analysis. In conclusion, the present study is the largest series of retrieved glenoid prostheses to date for revision total shoulder replacement from a single institution. The damage modes of the glenoid occur most commonly by scratching, pitting, burnishing, and abrasion, although wear patterns and distributions differ with articular conformity. Conforming glenoids demonstrate impingement of the anterior and inferior rim, whereas nonconforming glenoids demonstrate edge deformation of the posterior quadrant and can cause antero-posterior see-saw when placed in retroversion. Eccentric contact loading of the glenoid component may occur from impingement, as in the case of the conforming group; excessive retroversion, as in the case of the non-conforming group,[5] or rotator cuff deficiency,[6,16] resulting in increased polyethylene debris and ultimately symptomatic glenoid loosening.

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