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Observations on retrieved glenoid components from total shoulder arthroplasty

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Hypothesis: Polyethylene components retrieved at revision of total knee and hip replacements have been analyzed to study the effect of design, patient, and surgical factors on initial implant performance, but few studies have reported similar types of findings in retrieved glenoids.
Materials and methods: From 1979 to 2006, 78 glenoid components were retrieved from revision surgery in 73 patients at a single institution. Each glenoid component was analyzed for 9 modes of damage in each of 4 quadrants into which the bearing surface was divided. For each glenoid, the most recent radiographs before removal were scored using an adapted radiolucency score.
Results: Scratching, pitting, and burnishing were the most common and most severe types of polyethylene wear. In addition, the modes of damage observed were not uniformly distributed across the bearing surface, but commonly focused in the inferior quadrant of the glenoid, suggesting a propensity for a humeral impingement mechanism leading to glenoid loosening. The radiographic analysis performed was found to severely underestimate the presence of clinical glenoid loosening.
Conclusion: Impingement of the glenoid with bone at the edge of the humeral component and edge deformation secondary to eccentric forces of the humeral head on the glenoid rim are highly associated with glenoid loosening. Analysis of retrieved glenoid components, along with patient, design, and surgical factors, provide important information on the causes of component failure.
Level of evidence: Basic science study.

Keywords: Polyethylene wear; glenoid loosening; glenoid component failure; total shoulder arthroplasty revision

Analysis of polyethylene components retrieved at revision of total knee and total hip arthroplasties has been effective for defining the effect of design, patient, and surgical factors on implant performance, but few such studies have reported similar findings in retrieved total shoulder arthroplasty (TSA) glenoid components.[10,11,23,25] Scarlat and Matsen[23] reported 39 glenoid components retrieved after a mean implantation length of 2.5 years. The most frequent finding was erosion of the rim of polyethylene glenoid components, which occurred in 28 cases, followed by surface irregularities in 27, fractured glenoid components in 11, and central wear in 9. Hertel and

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Ballmer[10] also noted the presence of central wear in their report of 7 components. In all of the glenoids, a new conforming articular facet had been worn, with a radius of curvature matching that of the humeral head. Gunther et al[9] described the wear mechanisms in 10 all-polyethylene glenoid components, adopting a previously described classification system[11] for total knee arthroplasty tibial polyethylene inserts. Scratching, abrasion, pitting, and delamination were the most common damage modes, implying that these components sustained a combination of abrasive and fatigue wear similar to that observed in total knee arthroplasty.

These studies demonstrated the potential for wear and surface damage in glenoid components but were limited by the numbers of retrieved components, the different designs, and the lack of complete radiographic and clinical data from which to explore relationships between implant performance and clinical, surgical, and design factors. The purpose of the present study, therefore, was to determine the wear damage and examine these relations using a large collection of retrieved components with multiple designs.

Materials and methods

From 1979 to 2006, 78 retrieved TSA glenoid components were collected from removal and revision surgeries of 73 patients as part of an ongoing, Investigational Review Board-approved implant retrieval system at a single hospital. The implants were from 4 manufacturers: 52 Biomet (Warsaw, IN), 17 Smith and Nephew (Memphis, TN), 6 Custom HSS (Hospital for Special Surgery, New York, NY), and 2 DePuy (Warsaw, IN); the manufacturer of 1 glenoid implant could not be determined. Polymethylmethacrylate cement was used to implant 74 glenoids, and adjuvant screw fixation was used for the remaining 4. Backings were keeled in 43 glenoids and pegged in 35. The articulation of the glenoid implants was nonconforming in 54% and conforming in 46%. A conforming surface was one in which the glenoid radius matched the radius of the humeral head component vs the presence of a greater radius mismatch in nonconforming surfaces. In 55 of the 73 patients, the glenoid was removed and the TSA was converted to a hemiarthroplasty.

Retrospective review of the medical records and radiographs were available for 71 of the 73 patients. The clinical information included patient demographics, medical comorbidities, shoulder history, clinical assessment (pain and range of motion), intraoperative findings, implant information, and postoperative complications. The primary arthroplasty in 57 patients occurred at our institution, from 17 orthopedic surgeons, and 14 patients received their initial surgeries at other hospitals. The revision surgeries were performed by 15 different orthopedic surgeons at our institution. Glenoid components were removed from both shoulders in 3 patients, and 2 patients underwent revision of a glenoid component that was subsequently removed at a second surgery. Average patient age was 60.8 ± 11.7 years at the time of revision surgery. The mean length of implantation was 4.0 ± 4.4 years (range, 0.1-19.2 years). The primary diagnosis was osteoarthritis in 54 patients, rheumatoid arthritis in 12, avascular necrosis in 3, fracture in 1, and systemic lupus erythematosus in 1. The revision diagnosis was aseptic glenoid loosening in 60 patients, septic loosening in 6, and instability in 5. Additional pathology determined intraoperatively at revision surgery included glenoid osseous defects after component removal in 61%, adhesions in 55%, rotator cuff tendinopathy in 52%, humeral head subluxation or dislocation in 37%, and deltoid atrophy in 20%. The average forward elevation was 56° (range, 0° to 170°), and external rotation was 18° (range, −40° to 80°) for patients just before revision surgery (Table I).

The polyethylene-bearing surfaces of the components were examined microscopically using ×31 magnification in a light stereomicroscope. For each surface, 9 modes of damage were subjectively scored: burnishing, abrasion, scratching, pitting, delamination, focal wear, surface deformation, embedded third body debris, and fracture, based on previously developed scoring systems for polyethylene joint replacement components.[10,11] The surface was divided into anterior, posterior, superior, and inferior quadrants and given a subjective damage score of 0 to 3 for each damage mode in each quadrant[10] (Figure 1).

The most recent plain anteroposterior (AP) and axillary shoulder radiographs before removal of the glenoid were examined. The extent and amount of radiolucency in the AP view was measured with digital calipers according to the system described by Molé,[19] in which the area surrounding the glenoid fixation keel is separated into 6 zones. Radiolucent lines were assigned a numeric value by the thickness of the radiolucency for all 6 zones, and the values were summed to give the radiolucency score. A score between 0 and 6 points corresponded to no loosening, between 7 and 12 points represented possible loosening, and between 13 and 18 points represented definite loosening.[19] The same method was adapted to the axillary radiographs, with radiolucencies measured in 3 zones corresponding to the anterior rim (zone 1), around the fixation keel or pegs (zone 2), and the posterior rim (zone 3) of the glenoid. The amounts of subluxation in the coronal (AP view) and sagittal (axillary view) planes were measured as the percentage of translation and graded as mild (<25%), moderate (25% to 50%), or severe (>50%).[23] The glenoid wear measurements and radiographic analysis were performed by a senior orthopedic resident experienced with wear analysis from prior total knee arthroplasty retrievals.

Results

Glenoid component wear analysis

Scratching was the most common damage mode, involving all 78 glenoids that were retrieved, closely followed by pitting in 73 glenoids (Figure 2, *A* and *B*). Both modes were most prevalent on the inferior aspect of the retrieved components. Next were burnishing in 54 glenoids and abrasion in 53 (Figure 2, *A* and *C*). Specifically, abrasion on the edge of the component, consistent with glenoid impingement with the humerus, was evident in 29 of 78 glenoid components (Figure 2, *C*). In two-thirds of these cases, the abraded area occurred on the anterior and inferior quadrants. Surface deformation occurred in 48 of the retrieved glenoids, with edge deformation evident in 18

Table I Clinical information

Variable[a]	All	Conforming	Nonconforming
Patients, No.	71	33	38
Glenoids, No.	78	36	42
Age at revision, y	60.8 ± 11.7	61.2 ± 11.7	60.6 ± 11.8
Time since primary surgery, y	4.1 ± 4.4	5.1 ± 5.4	3.1 ± 3.1[b]
Gender, No.			
Male	30	11	19
Female	41	22	19
Affected extremity, No.			
Right	32	13	19
Left	39	20	19
Forward elevation	64.8 ± 36.2	64.3 ± 37.1	65.2 ± 35.9
External rotation	19.4 ± 24.0	29.5 ± 25.0	11.5 ± 20.6[b]
Primary diagnosis, No.[c]			
Osteoarthritis	54	22	32
Rheumatoid arthritis	12	8	4
Avascular necrosis	3	3	0
Fracture	1	0	1
SLE	1	0	1
Revision diagnosis, No.[c]			
Glenoid Loosening	57	25	32
Infection	9	6	3
Instability	5	2	3
Revision procedure, No.[c]			
Conversion hemiarthroplasty	55	28	27
Revision glenoid	16	5	11
Intraoperative findings, %[c]			
Glenoid loose	91.50	95.20	90.30
Glenoid osseous defect	60.50	61.90	61.30
Rotator cuff tendinopathy	52.10	57.10	48.40
Humeral head subluxation	36.60	23.80	48.40
Adhesions	54.90	57.10	51.60
Deltoid atrophy	19.70	23.80	16.10

SLE, Systemic lupus erythematosus.
[a] Continuous data are presented as the mean ± standard deviation.
[b] Denotes statistically significant difference between conforming and nonconforming groups.
[c] Number of patients.

(Figure 2, *D*). In 63% of the glenoids with deformed edges, the deformation occurred on the posterior quadrant.

Wear-through occurred in 32 glenoids, with a focal wear damage pattern in 7 of these components, all with nonconforming designs, in which a new bearing surface similar to the radius of curvature of the opposing humeral component was worn into the original surface (Figure 2, *E*). Delamination was noted in 10 of the 78 glenoids, consistent with a fatigue wear mechanism (Figure 2, *F*). Seven components had fractured, including all 3 Hylamer glenoids (Figure 2, *G*).

Whether cemented or fixed with screws, metal-backed glenoid components provided a source of metallic debris that served as third-body debris, having become embedded into the polyethylene bearing surface. The 4 glenoids with metal backing fixed with screws all had embedded third-body metallic debris (Figure 2, *H*). All of the metal backed glenoid components had conforming surfaces.

Scratching was not only the most common damage mode, but it was also the most severe, with an average wear score of 8.44 out of 12. Again, pitting was second with an average score of 6.51, followed by burnishing with 4.38 and abrasion with 3.40. The average wear score was calculated by determining the cumulative amount of wear for a specific damage mode (ie, scratching) measured in all 78 glenoids in this study, divided by 78. Thus, the average wear score takes into account even those glenoids that did not exhibit that particular mechanism of damage. However, scratching and pitting were again the most severe when the average wear score was corrected for the number of glenoids actually affected by each respective mechanism. Fracture was third, followed by abrasion, burnishing, delamination, and embedded third-body debris (Table II).

Irrespective of damage mode, the inferior glenoid sustained the greatest wear, with a mean total score of 7.5, and

Grade	Percent of Damage
0	No Damage
1	1%-10% Damage
2	11%-50% Damage
3	51-100% Damage

*Severe damage in a small area increases score by one point.

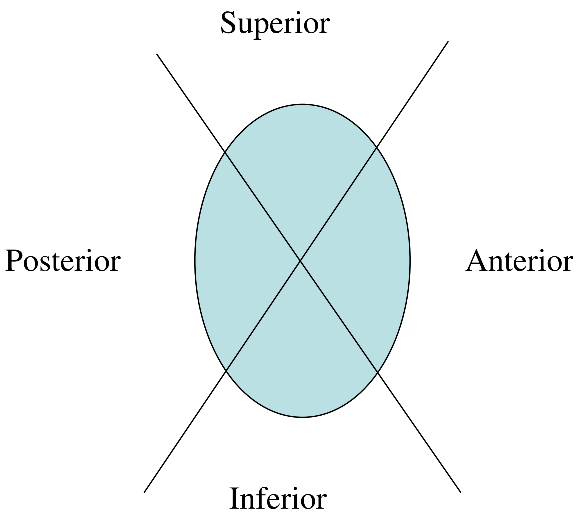

Figure 1 Damage map and score[a] for glenoid components.

the posterior region also had marked wear, with a score of 6.8 (Figure 3). The difference between inferior and posterior wear was statistically significant ($P = .026$). The pattern of wear did not differ between conforming and nonconforming designs. When glenoid components with edge deformation were compared with those with impingement, edge deformation components had the greatest amount of wear posteriorly (mean score, 6.3), whereas components with impingement were most damaged inferiorly (mean score, 8.0). No correlation was found between patient age at the time of revision, length of implantation, or prerevision range of motion with overall glenoid wear.

Radiographic data

Radiolucent lines in the preoperative AP view were greatest in zones 1, 2, and 4, corresponding to loosening in the 2 superior zones and at the inferior neck of the glenoid (Figure 4, *A*). In the axillary view, zone 2 (around the fixation keel) had the greatest amount of radiolucency (Figure 4, *B*). The mean radiolucency score on the AP view was 7.1 ± 4.2, representing possible loosening, whereas the radiolucency score on the axillary view was 4.0 ± 2.1. Of note, 11 glenoid components had dislocated from the bone and were free within the glenohumeral joint, of which 6 were conforming designs and 5 were nonconforming designs.

Discussion

TSA has become the accepted method to treat end-stage glenohumeral osteoarthritis, rheumatoid arthritis, and osteonecrosis, as well as displaced fracture dislocations of the proximal humerus. A total of 13,000 TSA procedures were performed in the United States in 2004, the most recent year for which the National Hospital Discharge information is available, and year-on-year percentage increases in TSA rival those of total hip and knee arthroplasty.[20] Long-term survival of the implant is a concern, however, because TSA can be associated with serious complications, including prosthetic loosening, glenohumeral instability, periprosthetic fracture, rotator cuff tears, infection, neural injury, and deltoid muscle dysfunction.[3,12,17,29] In patients dissatisfied after TSA, failure attributed to glenoid loosening accounted for 59%.[2,3,22,28]

This study measured implant performance based on retrieval and radiographic analysis to determine patterns of failure and the factors that contributed to them. Scratching, pitting, and burnishing were the most common types of wear damage, described in nearly all reports of wear of polyethylene joint replacement-bearing surfaces, regardless of the conformity between the articulating surfaces.[9-11,23,30] Although scratching, most probably caused by abrasive wear from asperities on the metallic humeral bearing surface was seen in all 78 retrieved glenoids, abrasion and surface deformation were more rare. This generally occurred at the edges of the components, consistent with abrasion of the polyethylene against bone and deformation of the polyethylene as a result of subluxation or dislocation of the opposing metallic component.[21] Our data also demonstrated that glenoid wear was not uniformly distributed across the bearing surface, because regardless of the mode of damage, the inferior region sustained the greatest amount of wear. The propensity for wear to occur at the inferior aspect and edges of the glenoid emphasizes the importance of proper component positioning, because factors such as an inferiorly placed glenoid or superiorly placed humeral component can predispose to edge loading and component failure.[7]

With 37% of the glenoid components demonstrating signs of impingement with associated abrasion, loosening related to impingement of the glenoid with bone at the edge of the humeral component appears to be a common occurrence in TSA. Impingement was found in the inferior and anterior quadrants, consistent with the metaphyseal bone surrounding the humeral head impinging on the inferior and anterior walls of the polyethylene glenoid when a patient performs adduction and internal rotation, which are common occurrences in connection with daily activities.[13] As the humerus impinges on the glenoid, a shear force results in a direction closely aligned with major fixation interfaces, causing increased stress at the

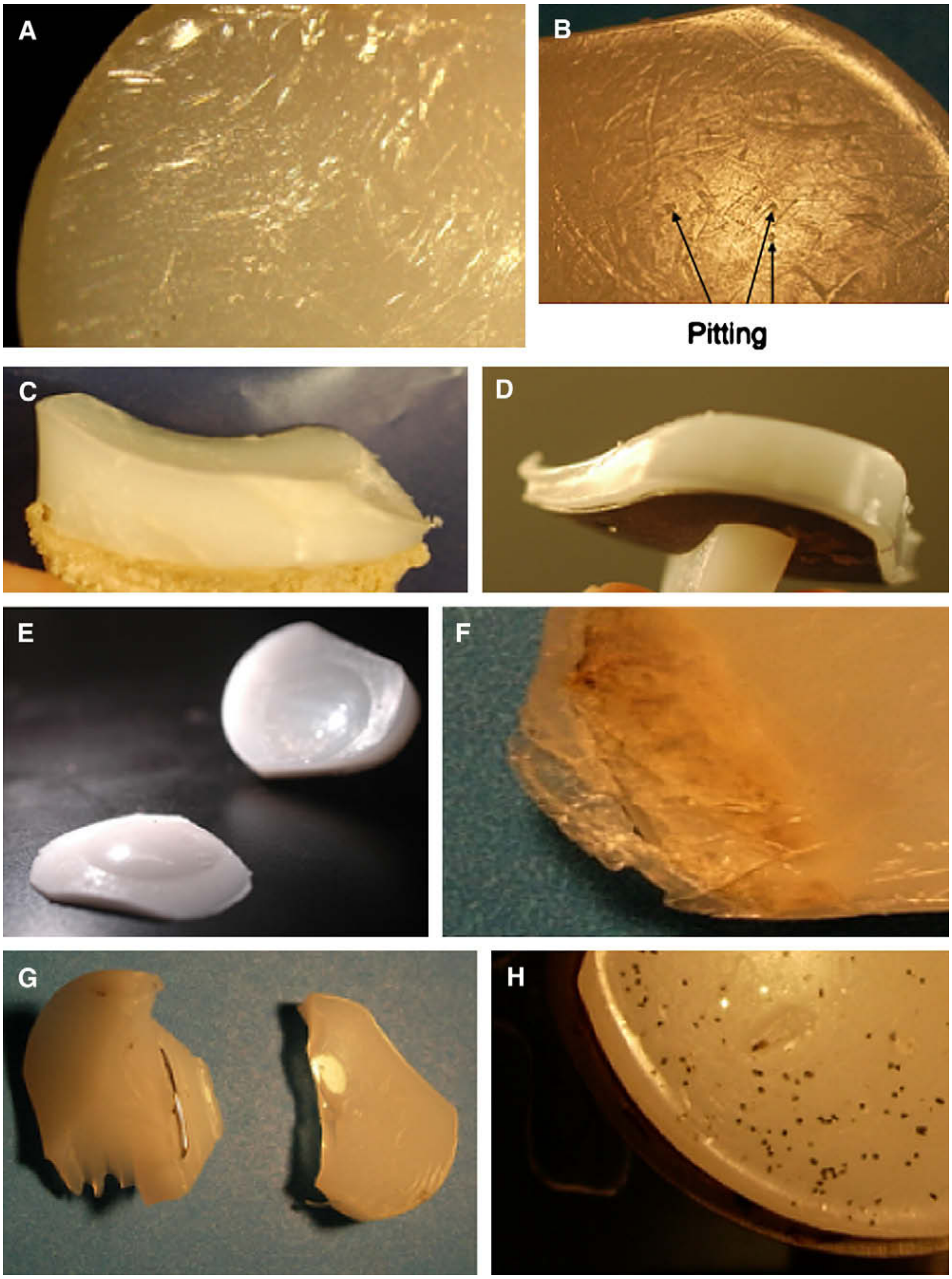

Figure 2 **(A)** Scratching was present in 78 glenoids retrieved. **(B)** Pitting was present in 73. **(C)** Abrasion on the edge of the component, consistent with glenoid impingement with the humerus, was evident in 29 components. **(D)** Edge deformation evident in 18. **(E)** A focal wear damage pattern was present in 7 components with nonconforming designs. **(F)** Delamination was noted in 10 glenoids, consistent with a fatigue wear mechanism. **(G)** Fractures were present in 7 components. **(H)** Third body metallic debris was found in the 4 glenoids with metal backing fixed with screws.

bone—implant interface (Figure 5). These inferior wear patterns were consistent with increased radiolucent lines in the superior and posterior aspects of the cement—bone interface of the conforming glenoid, because inferior compressive forces would create a distractive force at the superior margin of the glenoid. Of the 29 glenoid components with impingement, more than two-thirds were conforming designs, and 25 were revised for glenoid loosening (3 for infection, 1 for posterior dislocation).

The detrimental effects of humeral impingement raise the importance of appropriate implant positioning and soft-tissue tensioning intraoperatively. Any positioning of the components that decreases the distance between the most inferior—lateral portion of the glenoid and the most medial portion of the humerus has been shown to minimize the angle of glenohumeral elevation that could occur before impingement.[9] Factors such as rotator cuff deficiency, abnormal capsuloligamentous balance, and the use of

Table II Glenoid wear mode: frequency and severity of damage

	Glenoids involved	Average glenoid wear score	
Damage mode	No. (%)	For all 78	Per glenoid affected
Scratching	78 (100)	8.44	8.44
Pitting	73 (94)	6.51	6.96
Burnishing	54 (69)	4.38	4.68
Abrasion	53 (68)	3.40	5.00
Surface deformation	48 (62)	1.55	2.52
Wear-through	32 (41)	1.56	3.80
Delamination	10 (13)	0.53	4.13
Fracture	7 (9)	0.54	5.99
Embedded third body	5 (6)	0.26	4.06

humeral components with improper head thickness or neck offset can all decrease this distance.[5,8,16] Risk factors for impingement must be accounted for to ensure positioning of the humeral articular surface on the center of the glenoid articular surface in both the superior—inferior and anterior—posterior directions.[15]

In addition, adherence to these principles will decrease the risk of eccentric loading and subsequent edge deformation, which also has an important effect in glenoid loosening. Of the 18 components showing edge deformation, 16 were revised for loosening and 1 for anterior—superior subluxation of the humeral head. The mechanism by which edge loading leads to component loosening has been described as the rocking horse phenomenon and has been considered the primary cause of glenoid loosening.[13] As the prosthetic humeral head translates inferiorly and superiorly during motion, eccentric forces are produced on the glenoid rim, ultimately causing rim deformation and component loosening (Figure 6). However, of the 18 glenoid components with edge deformation, 83% were nonconforming glenoids with deformation occurring in the inferior and posterior quadrants vs the inferior—superior direction typical of conforming glenoid designs.

The glenoid components with edge deformation were implanted in retroversion, consistent with the humeral head loading the posterior and inferior polyethylene edge, and causing increased anterior radiolucent lines on imaging. Instead of the superior—inferior rocking horse seen in rotator cuff deficiency,[3] a glenoid component see-saw pattern may occur from posterior to anterior rocking in cases with glenoid retroversion. Glenoid retroversion leads to decreased glenohumeral contact areas, increased contact pressures, and posterior eccentric loading, all of which increase stresses on the cement mantle and increase the risk of edge deformation and component loosening.[6,15,24] Thus, it is essential that components are positioned and soft tissue is tensioned appropriately so that loads across the glenohumeral interface are concentric and aligned along the glenoid centerline.[16]

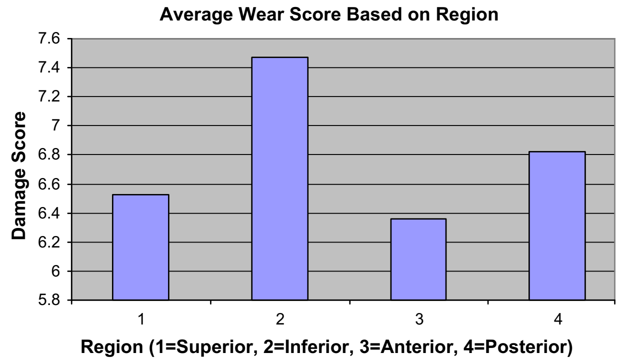

Figure 3 Regional damage score regardless of mechanism.

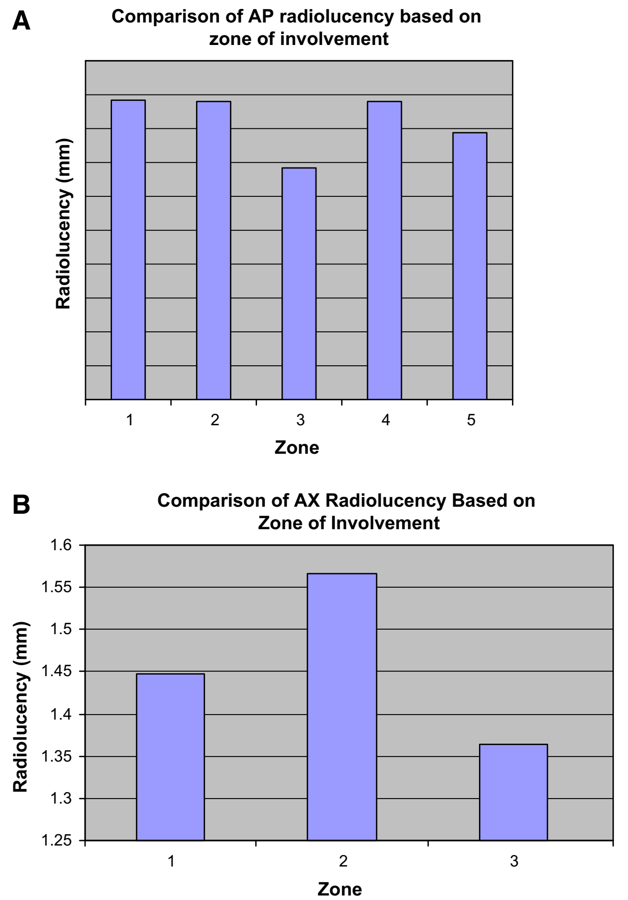

Figure 4 **(A)** Comparison of anteroposterior radiolucency based on zone of involvement. **(B)** Comparison of axillary radiolucency based on zone of involvement.

Glenoid components with articular surfaces that conform to the radius of curvature of the head of the humeral component have increased surface area for contact but do not allow obligate glenohumeral translation, whereas nonconforming glenoids have decreased contact areas and increase contact loads but enable obligate translation. One

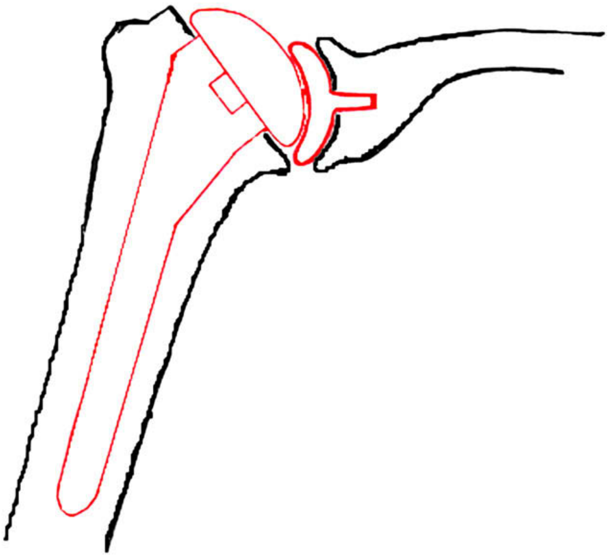

Figure 5 Mechanism of glenohumeral impingement.

Figure 6 Mechanism of rim deformation and eccentric loading.

could hypothesize that over time, a nonconforming glenoid will creep and wear to become conforming to the radius of the prosthetic humeral head, in essence, decreasing the obligate translation originally present and increasing the surface area for contact as in a conforming surface. Although this does not necessarily imply that a nonconforming glenoid will become a conforming glenoid, the characteristics of the glenohumeral interface are altered by the presence of focal wear. We observed wear-through in 32 of the glenoid components, and 7 components in particular (all nonconforming designs) had a focused wear pattern similar to the radius of curvature of the humeral head component. In these cases the increased contact loads of the nonconforming design apparently exceeded the stress thresholds of the polyethylene, thus causing focal wear through.[13]

Seven of the retrieved components had fractured, including the 3 Hylamer glenoids. The high rate of wear of Hylamer inserts, which are sterilized by gamma irradiation in air, is thought to be secondary to the increased effect of oxidative degradation of the polyethylene.[26] To our knowledge, this material is no longer used in glenoid components. Keels, pegs, and screws are the most commonly used methods for adjuvant glenoid fixation; however, glenoids with screws seem particularly susceptible to the generation of metallic wear particles, presumably from fretting motion and corrosion between the screw and the metal backing. The 4 components with metallic debris embedded in the polyethylene surface had been fixed with screws. Although it is unclear which polyethylene construct, in terms of cross-linking and component manufacturing, is the strongest at resisting wear, evidence suggests that round-backed, all-polyethylene components with peg fixation perform better than flat-backed, metal-backed, or keeled components because the pegs may distribute load more effectively.[4,14,15] Intraoperatively, overstuffing of the joint must be avoided because it can lead to increased, often eccentric loading and, subsequently, increased wear of the glenoid component.[13]

Our radiographic analysis found a mean radiolucency classification score for all glenoid components examined of 7.1 ± 4.2 in the AP view, representing a possibly loose component. However, 92% of the glenoids were grossly loose intraoperatively, thus suggesting that the radiolucency score severely underestimates the presence of clinical loosening. Published reports about the incidence of radiolucent lines vary greatly, with rates ranging from 30%[21] to 84%.[27] In addition, the predictive capability and significance of radiolucent lines with regards to future glenoid loosening has not been elucidated. Torchia[27] found that 93% of shoulders that went on to glenoid loosening had radiolucencies on the initial postoperative images compared with 44% which did not; however, Miletti et al[18] found no correlation between radiographic criteria and clinical loosening. A case−control study to evaluate the predictive capabilities of radiolucent lines might provide additional information regarding the significance of radiographic glenoid lucency as it relates to glenoid component failure.

A study design that allowed comprehensive analysis of a large number of retrieved components was thought to be crucial to understanding glenoid failure; however, these types of studies have inherent limitations. Retrieval studies represent between 0% and 12.5% of individuals with symptomatic glenoid loosening who require revision surgery[18,29] but do not represent the 30% to 90% of individuals with asymptomatic radiolucencies around the glenoid components.[1,4] In addition, further studies are warranted as highly cross-linked polyethylene components are introduced into TSA. These materials have increased wear resistance properties, possibly allowing a better compromise between nonconformity and wear, but because of their reduced toughness and resistance to crack propagation may also be at increased risk of fracture. The patients in the current study represent failed glenoid components, so analysis of patient, design, and surgical factors provided important information on the causes of component failure.

Acknowledgments

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