Reverse Total Shoulder Arthroplasty: Current Concepts, Results, and Component Wear Analysis


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Reverse Total Shoulder Arthroplasty: Current Concepts, Results, and Component Wear Analysis

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Introduction

After its introduction in the 1970s, reverse total shoulder arthroplasty had minimal clinical success, as its constrained design and lateralized glenohumeral center of rotation led to excessive shear forces and failure of the glenoid component . Modern implant design modifications have emphasized a larger radius of curvature of the glenoid component and movement of the center of shoulder rotation medially and distally, creating a more stable and efficient fulcrum and decreasing shear forces at the glenoid-bone interface . Since receiving U.S. Food and Drug Administration (FDA) approval in 2003, reverse total shoulder arthroplasty has become popular for use for more than rotator cuff-tear arthropathy; its uses include treatment of failed conventional total shoulder arthroplasties, rheumatoid arthritis in patients with an irreparable cuff tear, proximal humeral tumors, and proximal humeral fractures with anterosuperior escape . However, with major complication rates as high as 26%, limited implant longevity, and a lack of long-term functional outcome data, concerns have continued about its widespread use .

Source of Funding

There was no external funding source for this investigation.

Biomechanics of the Glenohumeral Joint

Without injury, the glenohumeral joint possesses remarkable mobility and is able to remain stable over the majority of an individual’s life span. While both static and dynamic restraints contribute to its stability, the glenohumeral joint lacks substantial intrinsic osseous constraints . Modern implant design modifications have emphasized a larger radius of curvature of the glenoid component and movement of the center of shoulder rotation medially and distally, creating a more stable and efficient fulcrum and decreasing shear forces at the glenoid-bone interface . Since receiving U.S. Food and Drug Administration (FDA) approval in 2003, reverse total shoulder arthroplasty has become popular for use for more than rotator cuff-tear arthropathy; its uses include treatment of failed conventional total shoulder arthroplasties, rheumatoid arthritis in patients with an irreparable cuff tear, proximal humeral tumors, and proximal humeral fractures with anterosuperior escape . However, with major complication rates as high as 26%, limited implant longevity, and a lack of long-term functional outcome data, concerns have continued about its widespread use .

Pathology of Rotator Cuff-Tear Arthropathy

Rotator cuff-tear arthropathy was originally described in 1983 by Neer et al., who described a massive rotator cuff tear as the initial event in the development of degenerative arthritis .

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lates the closed joint space, allowing synovial fluid to leak into the surrounding soft tissue. The negative fluid pressure that is key for shoulder stability is decreased, as is the quality and quantity of the synovial fluid, with resultant cartilage and osseous atrophy. In addition, reduced shoulder motion and function of the glenohumeral joint, recurrent bloody effusions, and loss of glycosaminoglycan content of the cartilage further accelerate the destruction of both articular and periarticular structures.

The term “rotator cuff-deficient arthritis” is used to describe arthritis in a shoulder with a massive rotator cuff tear, regardless of whether the cuff tear was the inciting event. Inflammatory causes of rotator cuff-deficient arthritis, emphasizing biomechanical factors rather than instability and deficient cartilage nutrition, have also been proposed. In 1981, Halverson et al. hypothesized that calcium phosphate crystals are formed in the diseased shoulder synovium and articular cartilage and are then released into the synovial fluid. Phagocytosis of these crystals precipitates an immunologic cascade, including the release of collagenase, leading to destruction of the rotator cuff tendon and articular cartilage, which then leads to further release of calcium phosphate crystals. Therefore, numerous pathologic causes have been proposed for the development of rotator cuff-deficient arthritis.

Evolution of Treatment Options for Rotator Cuff Tear Arthropathy

Rotator cuff-deficient arthritis of the shoulder has proved to be a difficult condition to treat successfully, and a surgical option that both relieves pain and improves shoulder function has been elusive. Treatment options have included, but are not limited to, nonoperative management, glenohumeral arthrodesis, resection arthroplasty, constrained or conventional total shoulder arthroplasty, and hemiarthroplasty. However, patient dissatisfaction with functional outcomes and high long-term complication rates with traditional management have revived interest in reverse total shoulder arthroplasty.
A trial of nonsurgical management, including activity modification, oral analgesics and anti-inflammatory medications, corticosteroid injections, fluid aspirations, and gentle range-of-motion exercises, should initially be considered for most patients. Patients may remain asymptomatic, or be able to cope with the pain, while maintaining an acceptable degree of function if the deltoid remains intact and can thus provide an adequately stable fulcrum of motion. Of note is the fact that repeated intra-articular injections have been shown to have diminishing utility in the treatment of rotator cuff-tear arthropathy, in addition to increasing the risk of iatrogenic infection; thus, repeated injections are not recommended.

Despite the use of nonoperative modalities, most patients continue to have unremitting shoulder pain in addition to worsening function, and thus surgical options must be considered.

The aim of glenohumeral arthrodesis is to provide pain relief by eliminating shoulder motion. Arntz et al. described the use of glenohumeral arthrodesis as a salvage procedure for patients who had had multiple prior surgical procedures and had rotator cuff-tear arthropathy, an irreparable cuff defect, and a deficient anterior part of the deltoid muscle (Fig. 3-A). However, poor bone quality often makes this procedure technically difficult, with a high risk of nonunion. In addition, a lack of motion of the glenohumeral joint, and a compensatory increase in scapulothoracic motion, may expose the acromioclavicular joint to excessive motion and cause pain.

Resection arthroplasty has been attempted in the past, but it is very rarely indicated as it produces a flail shoulder, with a high risk of inferior instability and brachial plexus traction neuritis. Shoulder arthroplasty should be considered for a patient for whom nonoperative management has failed and who has a functional deltoid muscle and preferably an intact coracoacromial arch. Numerous arthroplasty implant designs have been proposed for the treatment of rotator cuff-tear arthropathy, with constrained total shoulder arthroplasty being one of the earliest. In this design, the humeral component is allowed to move within the glenoid component, with the intent of providing a stable, fixed fulcrum through which the deltoid can move the humerus (Fig. 3-B). Initially considered a solution for rotator cuff-tear arthropathy, constrained total shoulder arthroplasty has been abandoned because of complication rates reportedly as high as 87.5%, as excessive interface stresses due to the constrained design cause rapid component loosening and failure.
Similarly, semiconstrained total shoulder arthroplasty implants have had little clinical success. The goal of this type of arthroplasty is to utilize an enlarged glenoid component that possesses a superior hood in order to resist superior humeral migration. However, Orr et al. demonstrated that these implant designs create increased tensile stresses at the inferior portion of the glenoid component-bone interface, and both Neer et al. and Amstutz et al. reported that the prevalence of radiolucency surrounding these hooded glenoid components is higher than that associated with standard total shoulder arthroplasty implants.

Neer et al. retrospectively reviewed the results of conventional total shoulder arthroplasty in the treatment of rotator cuff-tear arthropathy in sixteen patients, with all but one patient demonstrating a successful result with “limited goals” rehabilitation. In addition, other authors have demonstrated vastly improved results in patients with a repairable rotator cuff tear as compared with those with an irreparable tear. However, Franklin et al. retrospectively reviewed the results in fourteen patients with rotator cuff-tear arthropathy treated with conventional total shoulder arthroplasty and reported that 50% demonstrated glenoid component loosening. In those patients, superior displacement of the humeral head led to eccentric loading of the glenoid component, causing a “rocking horse” phenomenon of glenoid loosening (Fig. 4). Because of the high risks of edge loading and glenoid component failure, conventional total shoulder arthroplasty is no longer considered an option for the treatment of rotator cuff-tear arthropathy associated with an irreparable rotator cuff tear.

Hemiarthroplasty has proven to be an appropriate surgical procedure for rotator cuff-tear arthropathy, as it avoids the complications of glenoid loosening, in addition to providing pain relief and acceptable shoulder motion. Williams and Rockwood reported the use of hemiarthroplasty in twenty-two rotator cuff-deficient shoulders, with eighteen of the twenty-two patients demonstrating a satisfactory result according to the limited-goals criteria described by Neer et al. In addition, all patients had better pain scores. However, concerns regarding limited improvements in shoulder motion and risks of glenoid and acromion resorption have been raised. In addition, Sanchez-Sotelo et al. reported anterosuperior instability in seven of thirty patients treated with hemiarthroplasty, with only 67% of the procedures being graded as successful at an average of five years postoperatively. Also, Dines et al. noted that conventional total shoulder arthroplasty performed as a revision of a hemiarthroplasty in a patient with rotator cuff-tear arthropathy demonstrated uniformly poor results. Instability continues to be a long-term concern, especially in patients with a prior subacromial decompression, resected coracoacromial ligament, incompetent coracoacromial arch, or deltoid weakness.

Reverse total shoulder arthroplasty has been reintroduced to treat rotator cuff-tear arthropathy, as implant designs have been modified in an attempt to solve the dilemma of providing both glenohumeral stability and improved shoulder biomechanics. While modern prostheses are not fully constrained, the congruent joint surfaces of the reverse ball-and-socket design provide inherent stability, while moving the joint center of rotation medially and distally to increase deltoid function and the range of motion. However, a lack of long-term functional outcome data, questions regarding implant longevity, and reported major complication rates as high as 26% have continued to raise concerns about this procedure.

The Modern Reverse Total Shoulder Arthroplasty

The modern reverse total shoulder prosthesis is based on the design that Paul Grammont described in 1985 (Fig. 5).
Prior attempts to create a fixed fulcrum for shoulder motion, through the use of constrained implants, led to limited motion and early failure due to excessive torque on the glenoid implant and failure to optimize deltoid function. Earlier reverse ball-and-socket designs typically included a small glenoid component and a lateralized center of rotation within the prosthesis, rather than within the glenoid. This led to increased stresses at the glenosphere (glenoid component)-bone interface and thus early component failure. Whether the theoretical biomechanical benefits of the Grammont prosthesis will translate into successful long-term results has yet to be proven, but early results have been promising.

Biomechanical Descriptions of Reverse Total Shoulder Arthroplasty

Several investigations have provided insight into the functioning of this implant design. Harman et al. performed an in vitro assessment of glenosphere fixation and loosening utilizing a Sawbones model. Independent variables analyzed were the offset magnitude and the screw type and arrangement, while dependent variables were the shoulder range of motion and baseplate motion. They noted that, under increased loads, increasing the offset of the glenosphere resulted in greater micromotion at the baseplate, which may interfere with osseous ingrowth, thus supporting the advantage of a medialized center of rotation to decrease stress at the bone-implant interface. De Wilde et al. utilized computer modeling of the glenohumeral joint and deltoid function in the scapular plane to compare reverse total shoulder arthroplasty with the native shoulder and with conventional total shoulder arthroplasty, with regard to deltoid length and muscle tension with shoulder motion. They concluded that the reverse total shoulder arthroplasty design was superior to the conventional total shoulder arthroplasty in terms of abduction strength of a rotator cuff-deficient shoulder, as placing the center of rotation distally improved deltoid muscle tension.

Gutiérrez et al. evaluated the stability of the glenosphere on the basis of the implant abduction angle. They analyzed the forces and micromotion in glenoid components attached to polyurethane blocks placed in an apparatus simulating glenohumeral joint motion. They concluded that 15° of inferior tilt of the glenoid component provided the most uniform compressive forces and the least amount of micromotion when compared with baseplates implanted with 0° and 15° of superior tilt, suggesting that an implantation angle of 15° of inferior tilt may improve stability.

Chou et al. evaluated the effect of glenosphere geometry (concentric versus eccentric) and offset on glenohumeral motion in a Sawbones model. They noted that a larger glenosphere diameter increased both adduction and abduction of the shoulder, and the addition of an eccentric diameter further increased adduction while decreasing the amount of lateral positioning of the center of rotation. Therefore, they concluded that eccentric glenosphere geometry may minimize notching while also decreasing shear forces at the bone-implant interface.
Fig. 6-A and 6-B  Diagrams demonstrating an earlier reverse total shoulder prosthesis design, with a small glenosphere component and a lateralized center of rotation (Fig. 6-A), versus the modern design, with a large glenosphere, a nonanatomic valgus angle of the humeral implant, and medial and distal positioning of the center of rotation (Fig. 6-B). (Reprinted, with permission from Elsevier, from: Gartsman GM, Edwards TB, editors. Shoulder arthroplasty. Philadelphia: Saunders; 2008.)

<table>
<thead>
<tr>
<th>Study</th>
<th>No.</th>
<th>Duration of Follow-up (mo)</th>
<th>Subjective Outcomes</th>
<th>Functional Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molé and Favard⁴³, Rev Chir Orthop Reparatrice Appar Mot, 2007</td>
<td>484</td>
<td>52</td>
<td>90% satisfied or very satisfied</td>
<td>Constant, 62.0</td>
</tr>
<tr>
<td>Sirveaux et al.⁴⁴, J Bone Joint Surg Br, 2004</td>
<td>80</td>
<td>44</td>
<td>96% no or little pain</td>
<td>Constant, 65.6</td>
</tr>
<tr>
<td>Werner et al.⁴⁵, J Bone Joint Surg Am, 2005</td>
<td>58</td>
<td>38</td>
<td>Subjective shoulder value, 56%</td>
<td>Constant, 64</td>
</tr>
<tr>
<td>Boileau et al.⁵, J Shoulder Elbow Surg, 2006</td>
<td>45</td>
<td>40</td>
<td>82% satisfied or very satisfied</td>
<td>Constant, 58</td>
</tr>
<tr>
<td>Frankle et al.⁶, J Bone Joint Surg Am, 2006</td>
<td>60</td>
<td>33</td>
<td>68% good or excellent</td>
<td>ASES, 68.2</td>
</tr>
<tr>
<td>Walch et al.⁷, 2006</td>
<td>457</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall et al.⁷, J Bone Joint Surg Am, 2007</td>
<td>240</td>
<td>40</td>
<td>93% satisfied or very satisfied†</td>
<td>Constant, 60†</td>
</tr>
<tr>
<td>Young et al.⁸, J Shoulder Elbow Surg, 2009</td>
<td>49</td>
<td>38</td>
<td>89% good or excellent</td>
<td>ASES, 70</td>
</tr>
</tbody>
</table>

*ASES = American Shoulder and Elbow Surgeons. †The percentage is of the patients who retained the implants.
Reports of Clinical Outcomes after Reverse Total Shoulder Arthroplasty (Table I)

Reverse total shoulder arthroplasty has been shown to be effective in treating pseudoparalysis of shoulder elevation associated with a massive rotator cuff tear, with numerous studies demonstrating initial improvements in shoulder motion and patient satisfaction. However, most reports have presented only midterm follow-up results, and despite these encouraging midterm results, rates of complications and revisions have remained inordinately high. In one long-term analysis, Molé and Favard reported the radiographic appearance of deterioration after approximately five to six years, with clinical deterioration appearing after approximately eight years. Thus, additional long-term studies are required to assess the duration for which these implants can be expected to last.

In a study of 484 patients followed for a mean of fifty-two months, Molé and Favard reported improvements in the Constant score from 24 points preoperatively to 62 points postoperatively, with 96% of the reported an increase in the mean Constant score from 22.6 points preoperatively to 65.6 points postoperatively, with 96% of the patients having little or no pain and an increase in mean active shoulder elevation from 71° to 130°. However, the total complication rate was noted to be 55%, with a revision rate of 33%. Seventeen of the procedures were the primary treatment, while forty-one were revisions. On average, the subjective shoulder value (an estimation by the patient of the value of his or her shoulder as a percentage of an entirely normal shoulder) increased from 18% preoperatively to 56% postoperatively, the Constant score increased from 29% to 64%, the Constant score for pain increased from 5.2 points to 10.5 points (15 points indicating pain-free), active anterior elevation increased from 42° to 100°, and active abduction increased from 43° to 90°. However, the total complication rate was noted to be 55%, with a revision rate of 33%. Nine percent of the patients experienced dislocation, and 7% demonstrated glenoid or humeral stem loosening. In addition, it was noted that the reoperation rate was lower and the final Constant scores and postoperative pain scores were significantly improved in patients for whom the reverse total shoulder arthroplasty was the primary procedure.

Frankle et al. reported the results of treatment with the reverse shoulder prosthesis (RSP; Encore Medical, Austin, TX) of 209 patients followed for a mean of seven years. In a retrospective review of eighty reverse total shoulder arthroplasties, with a mean duration of follow-up of forty-four months and a mean patient age of 72.8 years, Sirveaux et al. reported improvements in the Constant score for pain and postoperative shoulder motion. However, their findings were significantly worse results were noted.

### TABLE I (continued)

<table>
<thead>
<tr>
<th>Revision Rate</th>
<th>Component Failure Rate</th>
<th>Complication Rate</th>
<th>Infection Rate</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>11% at 10 years</td>
<td>6% loosening; 9% dissec.</td>
<td>25.6% intraop. or postop.</td>
<td>Forward flex., 71° → 130°</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>12% at 5 years; 71% at 7 years</td>
<td>6% loosening; 9% dissec.</td>
<td>16% grade-3 or 4 notching</td>
<td></td>
</tr>
<tr>
<td>33%</td>
<td>7% loosening; 9% dislocation; 2% dissec.</td>
<td>50%</td>
<td>Revision reverse total shoulder arthroplasty had significantly worse results</td>
<td></td>
</tr>
<tr>
<td>22%</td>
<td>0% loosening</td>
<td>24%</td>
<td>11% grade-3 or 4 notching</td>
<td></td>
</tr>
<tr>
<td>12%</td>
<td>17%</td>
<td>3%</td>
<td>Forward flex., 55° → 105°; abduct. 41° → 102°</td>
<td></td>
</tr>
<tr>
<td>3% primary; 31% revision; 26% overall</td>
<td>12% primary; 33% revision</td>
<td>8% dislocation †</td>
<td>3%*</td>
<td></td>
</tr>
<tr>
<td>20% had removal or revision</td>
<td>8% dislocation †</td>
<td>0%</td>
<td>Forward flex., 124°; 24% notching</td>
<td></td>
</tr>
</tbody>
</table>
Texas) in sixty patients, who had an average age of seventy-one years and were followed for an average of thirty-three months. They noted significant improvements in the mean American Shoulder and Elbow Surgeons (ASES) score, from 34.3 to 68.2 points; the mean function score, from 16.1 to 29.4 points; and the mean pain score, from 18.2 to 38.7 points. Forward flexion increased from 55.0° to 105.1°, and abduction increased from 41.4° to 101.8°. However, after only thirty-three months of follow-up, there was a 17% complication rate and 12% revision rate. Other reported results of reverse total shoulder arthroplasty are presented in Table I.

Thus, while the results of reverse total shoulder arthroplasty are encouraging with regard to the postoperative range of motion, pain relief, and improvements in clinical outcome measures, the high complication rates and necessity for revision procedures, especially in patients who have had multiple operations, are justifiably troubling. Complications include, but are not limited to, aseptic loosening, instability, glenosphere dissociation, humeral disassembly, infection, humeral fracture,
neurapraxia, and scapular notching\textsuperscript{5,34,49}, with overall complication rates as high as 71\% and revision rates as high as 33\% in mid-to-long-term follow-up studies\textsuperscript{44,45}.

Key Aspects of Surgical Technique in Reverse Total Shoulder Arthroplasty

Proper implantation of a reverse total shoulder arthroplasty prosthesis is technically demanding, and high complication rates have led to the suggestion that only the most experienced shoulder surgeons should utilize these prostheses\textsuperscript{3}. While it is impossible to review all of the technical aspects of this complex procedure, certain key aspects will be emphasized.

Most surgeons employ a standard deltopectoral approach, through which the subscapularis is incised. After implantation, the subscapularis is repaired with the hope of both improving humeral internal rotation and creating an anterior envelope to...

<table>
<thead>
<tr>
<th>GRADE</th>
<th>PERCENT OF DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Damage</td>
</tr>
<tr>
<td>1</td>
<td>1%-10% Damage</td>
</tr>
<tr>
<td>2</td>
<td>11%-50% Damage</td>
</tr>
<tr>
<td>3</td>
<td>51%-100% Damage</td>
</tr>
</tbody>
</table>

help prevent instability. In contrast, some authors have advocated the use of a superolateral approach, which obviates the need for a subscapularis tenotomy and passes through the deltoid, and these authors have reported lower rates of dislocation with this approach. However, reported drawbacks of the superolateral approach are limited visualization leading to improper component positioning and decreased external rotation postoperatively compared with that associated with the deltopectoral approach.²,³⁶

Regarding humeral preparation, the humeral head is typically osteotomized in neutral version, although there has been a recent trend toward cutting the humerus in increased retroversion with the intent of improving postoperative external rotation. Molé and Favard⁴⁰ reported improved results with regard to the Constant score, radiographic evidence of loosening, and glenoid complications when the humeral cup was implanted in neutral version. The humerus is reamed and broached in a manner similar to that used for conventional total shoulder arthroplasty. Most systems currently allow the same humeral stem to be utilized for a hemiarthroplasty, conventional total shoulder arthroplasty, or reverse total shoulder arthroplasty, thus leaving options available for intraoperative decision-making.

Glenoid preparation requires careful attention to the amount of bone removed, and preoperative planning with regard to the patient’s available bone stock is crucial. Central guidewire placement is also critical, and factors that must be considered include the best bone available for baseplate screw fixation and placement of the baseplate as inferiorly as possible, with an inferior tilt, as this has been shown to decrease the rate of implant loosening and scapular notching.³³–³⁵ The most critical screw for fixation is the central screw, which should obtain fixation in the far cortex and is commonly 30 to 40 mm in length. The most common length of the superior and inferior screws is 30 to 35 mm, while the most common length of the anterior and posterior screws is 15 mm. Typically, locking screws are utilized in the superior and inferior holes, while nonlocking screws are utilized in the anterior and posterior holes (Figs. 8-A and 8-B).

Scapular notching remains a substantial concern in reverse total shoulder arthroplasty, with rates reported to be as high as 98%, although the long-term clinical relevance remains unclear.⁶ To minimize notching, the baseplate should be placed flush with the inferior margin of the native glenoid, and the glenosphere should be implanted with an inferior tilt of 10° to 15° to increase inferior clearance. Some surgeons prefer inferior overhang of the glenosphere component, to further reduce the risk of scapular notching. While the long-term effect of scapular notching remains disputed, the presence of an abduction deficit due to decreased clearance is consistent with the recent finding of increased inferior quadrant damage in reverse total shoulder arthroplasty humeral polyethylene components.

Retrieved Reverse Total Shoulder Arthroplasty Humeral Polyethylene Components

Analyses of polyethylene components retrieved at revisions of total knee, hip, and shoulder replacements have been used to study the impact of design, patient, and surgical factors on implant performance. Recently, damage modes observed in retrieved reverse total shoulder arthroplasty humeral polyethylene components have been reported.⁴¹ Fourteen consecutive reverse total shoulder arthroplasty humeral polyethylene components retrieved at the time of revision surgery in eleven patients were analyzed for nine damage modes (abrasion, burnishing, scratching, pitting, wear through, third-body wear, delamination, surface deformation, and fracture) in each of four quadrants on the bearing surface (Fig. 9). Scratching and abrasion were found in fourteen and thirteen components, respectively, followed by third-body debris and pitting (Fig. 10, Table II). All modes of damage were found to be the greatest in the inferior quadrant.

The authors concluded that impingement of the humeral polyethylene at the lateral edge of the scapula, consistent with an adduction deficit, leads to inferior-quadrant wear and associated polyethylene damage. In addition, the finding of third-body debris was consistent with impingement leading to separation between the bearing surfaces, allowing ingress of metallic debris. Therefore, the results of analyses of reverse total shoulder arthroplasty polyethylene components point to the importance of appropriate glenosphere positioning to improve component stability and reduce polyethylene wear and damage.

Discussion

Reverse total shoulder arthroplasty has been shown to provide pain relief and improve function. Movement of the glenohumeral center of rotation distally and medially improves deltoid function and decreases glenoid implant-bone interface stresses and loosening. Promising results of reverse total shoulder arthroplasty for the treatment of rotator cuff-tear arthropathy have led to its expanded use, and it has now become a surgical option for failed conventional total shoulder arthroplasties, patients with rheumatoid arthritis and an irreparable rotator cuff.

### Table II Frequency and Severity of Nine Damage Modes*

<table>
<thead>
<tr>
<th>Damage Mode</th>
<th>Humeral Polyethylene Components with Damage (no. [%])</th>
<th>Average Wear Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scratching</td>
<td>14 (100%)</td>
<td>8.79</td>
</tr>
<tr>
<td>Abrasion</td>
<td>13 (93%)</td>
<td>4.00</td>
</tr>
<tr>
<td>Embedded third-body debris</td>
<td>8 (57%)</td>
<td>2.25</td>
</tr>
<tr>
<td>Pitting</td>
<td>6 (43%)</td>
<td>2.50</td>
</tr>
<tr>
<td>Burnishing</td>
<td>4 (29%)</td>
<td>2.00</td>
</tr>
<tr>
<td>Surface deformation</td>
<td>3 (21%)</td>
<td>1.67</td>
</tr>
<tr>
<td>Fracture</td>
<td>1 (7%)</td>
<td>3.00</td>
</tr>
<tr>
<td>Wear through</td>
<td>1 (7%)</td>
<td>3.00</td>
</tr>
<tr>
<td>Delamination</td>
<td>0 (0%)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

tenth, proximal humeral tumors, and proximal humeral fractures with anterosuperior escape. However, rates of instability, implant loosening, infection, fracture, and other complications remain high, demonstrating the importance of strict patient selection, operative experience, close patient follow-up for several years, and future design modifications.

D. Nam, MD
C.K. Kepler, MD

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