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CURRENT CONCEPTS REVIEW

Glenoid Component Failure in Total Shoulder Arthroplasty

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- ▶ Glenoid component failure is the most common complication of total shoulder arthroplasty.
- ▶ Glenoid components fail as a result of their inability to replicate essential properties of the normal glenoid articular surface to achieve durable fixation to the underlying bone, to withstand repeated eccentric loads and glenohumeral translation, and to resist wear and deformation.
- ▶ The possibility of glenoid component failure should be considered whenever a total shoulder arthroplasty has an unsatisfactory result. High-quality radiographs made in the plane of the scapula and in the axillary projection are usually sufficient to evaluate the status of the glenoid component.
- ▶ Failures of prosthetic glenoid arthroplasty can be understood in terms of failure of the component itself, failure of seating, failure of fixation, failure of the glenoid bone, and failure to effectively manage eccentric loading.
- ▶ An understanding of these modes of failure leads to strategies to minimize complications related to prosthetic glenoid arthroplasty.

Failure of the polyethylene glenoid component is the most common complication of total shoulder arthroplasty and accounts for a majority of the unsatisfactory results after this procedure¹⁻⁹. Failure of the glenoid component is often manifested clinically by pain, loss of function, and the presence of a clunking noise and sensation^{10,11}. While many factors have been described as possible contributors to glenoid component failure, a systematic understanding of these factors is lacking. As a result, the incidence of glenoid component failure remains high. The purpose of this review is to synthesize the current peer-reviewed evidence in a way that clarifies the modes of failure and that suggests strategies for addressing each of these modes. This article does not review other causes of failure of total shoulder arthroplasty, treatment of failed shoulder arthroplasty, or failure of reverse total shoulder arthroplasty.

Modes of Failure

Failure of the Component Itself

Failures in this category are characterized by physical change in the glenoid prosthesis occurring after it is inserted, at the time of the operation.

Distortion of the Prosthetic Surface

All studies of retrieved polyethylene glenoid components have revealed changes to the joint surface¹²⁻¹⁷. These changes were particularly well analyzed in a laser scanning study by Braman et al.¹², which suggested that the pattern of loaded motion of the humeral head on the glenoid component surface in each patient's shoulder modulates the deformable polyethylene surface of the glenoid component by a combination of wear and cold flow. When the prosthetic humeral and glenoid ar-

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Fig. 1
Pitting and erosive wear of the posterosuperior aspect of a retrieved glenoid component that had been inserted in combination with a humeral head with a 6-mm-smaller diameter of curvature, as recommended by the manufacturer. The wear resulted in a secondary concavity of the posterosuperior articular surface with a diameter conforming to that of the humeral component. While not shown in this photograph, the keel of this prosthesis had fractured from fatigue.

articular surfaces are conforming (i.e., manufactured so that they have the same diameter of curvature), glenohumeral translation results in loading and flattening of the glenoid component rim. The result is a lessening of the intrinsic stability provided

by the glenoid component^{12,15}. When the surfaces are non-conforming (i.e., manufactured so that the diameter of curvature of the glenoid component surface is larger than that of the humerus), the humeral head tends to mold a more conforming concavity in the part of the glenoid component surface where glenohumeral contact is favored by the motion pattern of the shoulder^{12,13}. The result is an increase in the intrinsic stability provided by the glenoid component¹². Pitting, abrasion, or diffuse wear patterns of surface injury are also common among retrieved components¹²⁻¹⁴ (Fig. 1). Pitting could not be caused by contact with the smooth humeral head and, therefore, must arise from the interposition of particles of bone, polymethylmethacrylate bone cement, or polyethylene between the articular surfaces. Wear may be revealed by progressive thinning of the radiographic clear space normally occupied by polyethylene (Fig. 2). As reported by Conditt et al.¹⁸ for patellar components and by Silva et al.¹⁹ for tibial components, polyethylene wear is particularly severe in metal-backed components²⁰⁻²⁵ (Fig. 3). The increased wear rate of metal-backed glenoid components may be due to higher contact stresses in comparison with those seen with all-polyethylene components of the same thickness^{21,26,27}.

Fracture or Delamination of the Component

Glenoid components can fail as a result of fracture of the polyethylene body, fracture of the pegs or keel, delamination of the polyethylene, fracture of the metal back, or fracture of

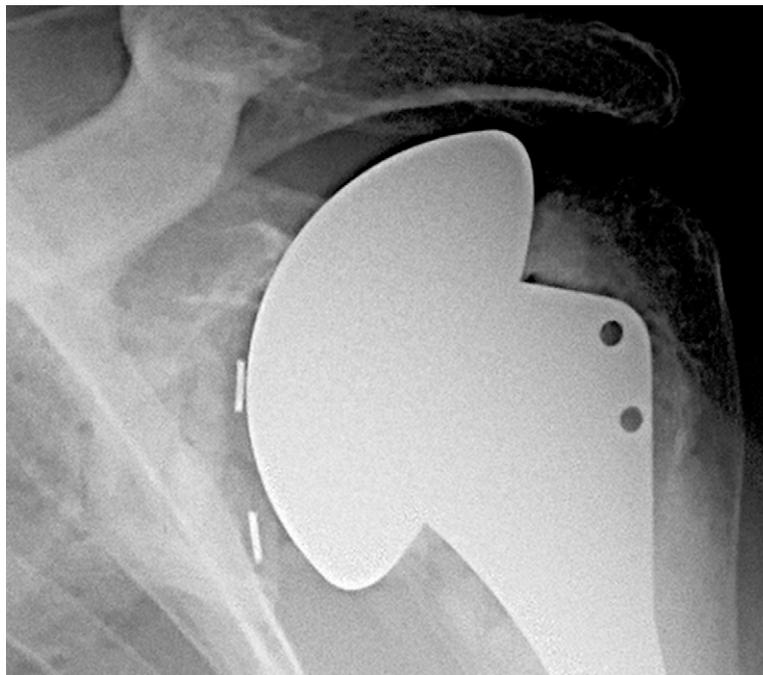


Fig. 2
Thinning of polyethylene at the superior aspect of the component as evidenced by narrowing of the distance between the humeral head and the upper metal marker in the glenoid component in comparison with the distance between the humeral head and the lower metal marker in the glenoid component. The loss of the concavity of the superior aspect of the glenoid component is accompanied by upward migration of the humeral prosthesis relative to the glenoid prosthesis.



Fig. 3

Complete wearing through of the upper polyethylene of a metal-backed component manifested by the absence of any radiographic clear space between the humeral prosthesis and the metal backing. The wear is accompanied by superior migration of the humeral component and so-called rocking-horse loosening of the glenoid component—i.e., loosening resulting from loading of one edge of the component causing lifting of the opposite edge of the component away from the bone. Note also the large amount of cement that had been used for fixation of the glenoid component and the radiolucent line surrounding the cement.

screws used for fixation^{16,25}. Catastrophic failure of polyethylene has been a particular problem when the polyethylene was sterilized by radiation in air, giving rise to free radicals that contributed to progressive oxidative deterioration of the components while they were on the storage shelf and after implantation²⁸. Fatigue failure of polyethylene or metal is a risk if the component is loaded with insufficient bone support¹⁶ (Fig. 4).

Separation of Polyethylene from the Metal Back of a Prosthesis

A particular problem with metal-backed glenoid components is the risk of dissociation of the polyethylene surface from its metal backing^{20,25,29,30}. Because it is difficult to chemically bond polyethylene and metal, the metal must achieve a mechanical purchase on the polyethylene. Dissociation results when eccentric loads exceed the strength of the fixation of the two components of the prosthesis to each other or when loading of the glenoid component deforms the polyethylene so that it is no longer captured by the metal portion of the component.

Failure of Component Seating

Failures in this category are characterized by inadequate support of the body of the glenoid component by the underlying bone. Poor seating predisposes the component to deformation, fatigue, and micromotion with a heightened risk of loosening.

Inadequate Preparation of the Bone Surface

Collins et al.³¹ demonstrated the importance of the preparation of the bone surface for minimizing wobble and warp of the glenoid component in response to eccentric loads. Wobble refers to movement of the component when it is challenged by off-center loads (Fig. 5). Warp refers to the bending of the polyethylene that occurs with off-center loads. Both wobble and warp challenge glenoid component fixation. Of the different methods of preparation, concentric reaming around a normalized glenoid centerline is the one that maximizes component stability when eccentric loads are applied. A flat bone surface provides less component stability than one that is concave³²⁻³⁴.

Prosthesis Not Fully Seated on the Prepared Bone

Glenoid component malpositioning is common among failed total shoulder arthroplasties⁷. Poor positioning can contribute to glenoid component loosening^{35,36}. Lazarus et al. described a system for the radiographic characterization of glenoid component seating and found that up to a third of the 328 glenoid components in their study population were poorly seated³⁶. Seating was worse for keeled components than for pegged components, at least in part because of the greater precision of the match between the geometry of the pegged component and that of the prepared glenoid bone. Keeled glenoid components provide less secure fixation than do pegged designs^{32,36}.

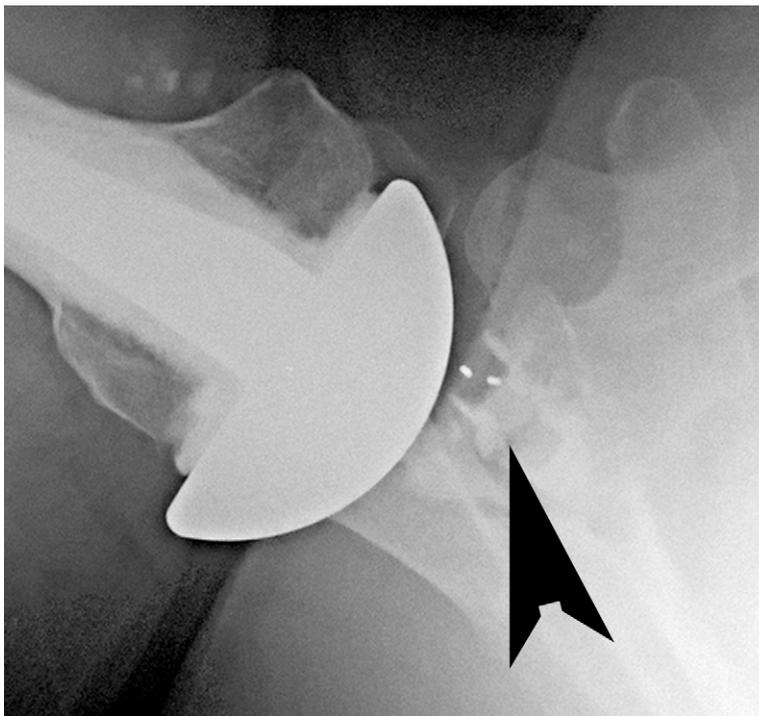


Fig. 4
Radiograph of a failed glenoid prosthesis, showing posterior subluxation of the humerus, eccentric glenoid loading, and posterior wear of the component rim. The keel of the glenoid component and the surrounding cement are fractured (arrow).

Loss of Cement Interposed Between the Body of the Component and the Glenoid Bone Surface

Opinions vary among surgeons regarding the advisability of placing cement between the body of the component and the prepared glenoid bone surface^{37,38}. On one hand, the grouting effect of cement can increase the quality of contact between the component and bone by filling in small voids. On the other hand, interposing cement between the back of the component and the bone presents a risk because a thin layer of cement is brittle and highly susceptible to fatigue, fracture, and displacement^{37,39-41}. The risk of cement fatigue may be increased by the admixture of antibiotics and by preparation methods that introduce porosity into the cement⁴². Failure of the cement interposed between the back of the component and the bone surface results in loss of seating and support for the component (Fig. 6).

Fracture or Bone Deficiency

Insufficient osseous support for the glenoid component may result from preoperative or intraoperative fracture, from glenoid bone erosion⁴³, from dislocation⁴⁴, or from dysplasia⁴⁵. It may also result from absorption of bone graft inserted at the time of the arthroplasty^{46,47}.

Resorption of Bone at the Prepared Surface

Reaming of the bone surface has been shown to create an optimal fit between the component body and the bone³¹. How-

ever, reaming may heat and disrupt the circulation to the surface of the glenoid bone, leading to a zone of necrosis, resorption, and loss of surface support of the prosthetic component (Fig. 7).

Failure of Initial Component Fixation

Inadequate fixation enables the glenoid component to move with respect to the glenoid bone⁴⁸. This motion may lead to a cycle of bone resorption around the implant, less stability, and increased motion of the prosthesis with a risk of complete failure of fixation. Metal-backed prostheses have been noted to have a higher rate of loosening than all-polyethylene components^{23,24,49}.

Suboptimal Cement Technique—Immediate Radiolucent Lines

Interposition of fluid or clot between the cement and the glenoid bone compromises the security of the fixation of the glenoid component, as does failure of cement to penetrate into the cancellous bone⁵⁰. Lack of secure cement purchase predisposes to motion of the glenoid component and to resorption of the glenoid bone. Most importantly, a lack of secure fixation reduces the ability of the component to resist lift-off in response to eccentric or rim loading. Poor cementing technique may or may not be revealed by postoperative radiographs. It is noteworthy, however, that radiographs made immediately after the operation frequently show a very high prevalence of periprosthetic radiolucent lines^{24,36,37,48,51-54}. Lazarus et al.³⁶ provided a classification of these lucent lines. The prev-



Fig. 5
Lifting up of the posterior aspect of a glenoid component (large arrow) associated with loading of the anterior aspect of the component. This rocking-horse wobbling is associated with resorption of bone around the component keel (small arrows).

absence of immediate postoperative radiographic lucency is greater with keeled glenoid components than it is with pegged glenoid components^{36,53,55}. The fact that these immediate postoperative lucent lines contain fluid or clot and not bone or cement suggests that radiolucent lines indicate suboptimal fixation of the component, predisposing it to motion and progressive loosening.

The ability to detect lucent lines is affected by the radiographic technique and positioning⁵⁶. Computed tomography is more sensitive than fluoroscopically controlled radiography for the detection of radiolucent lines³⁷. Postoperative lucent lines are associated with poorer clinical results⁵⁷ and have been shown to have a high probability of progressing^{3,24,52,58,59}.

Fixation in Bone of Limited Quantity and Poor Quality

The bone available for fixation of the glenoid component is limited by the geometry of the scapula⁶⁰⁻⁶². Glenoid bone stock can be compromised by age, disuse, inflammatory arthropathy^{63,64}, previous arthroplasty^{65,66}, and excessive reaming.

Failure of Bone

Loss of the quality and quantity of the bone into which the component was initially fixed leads to progressive instability of the component, which in turn accelerates bone resorption.

Progression of Radiolucent Lines and Development of Component Loosening

Because bone cement is not resorbed, any increase in the thickness or extent of radiolucent lines between cement and bone indicates loss of the periprosthetic glenoid bone necessary for glenoid component fixation^{67,68}. Such bone resorption may result from micromotion, from infection, or from bone death due to the heat produced by the drilling of holes or the curing of cement⁶⁹⁻⁷¹. The amount of heat from the exothermic reaction of cement curing is related to the volume of the cement that is used⁶⁹ and is a particular cause for concern because the thermal insulation properties of polyethylene do not allow dissipation of the heat.

Goodman et al.^{72,73} demonstrated that, while micromotion applied at a low frequency stimulates bone formation, a higher frequency of motion could have the opposite effect. Van der Vis et al.⁷⁴ attributed progressive micromotion to mechanical compression of the fibrous membrane that often forms between a prosthesis and bone, possibly leading to locally high fluid pressures that in turn may lead to osteocyte death and bone resorption. De Man et al.⁷⁵ demonstrated that compression of the fibrous membrane around a prosthesis leads to bone necrosis and cartilage formation, possibly because

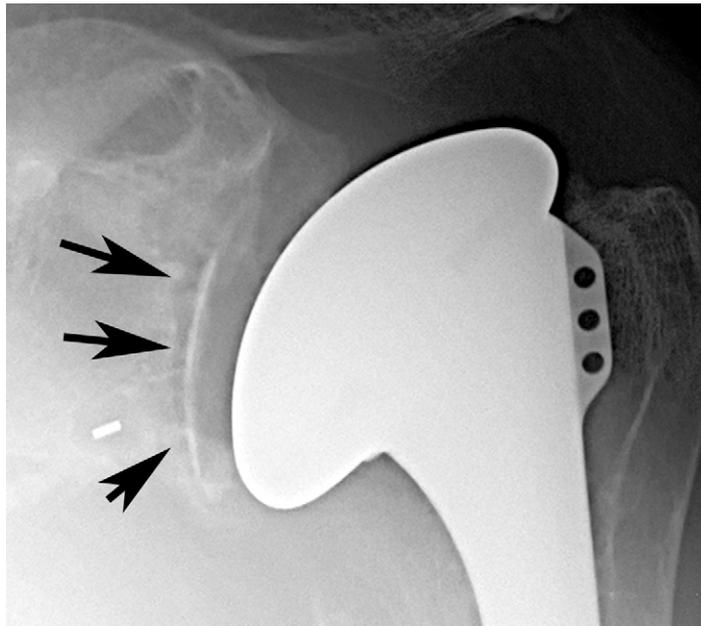


Fig. 6

A loose glenoid component with bone loss beneath a thin layer of cement underlying the glenoid component (arrows). At the time of operative revision, this thin layer of cement was seen to be cracked.

of fluid pressure or fluid flow. They concluded that compression of the fibrous membrane might play an important role in the early stages of loosening of a prosthetic joint replacement system.

Immunological Response to Polyethylene

In a study examining the immunological response to proteins that bind to ultra-high molecular weight polyethylene hip and knee components in patients who had aseptic loosening, Wooley

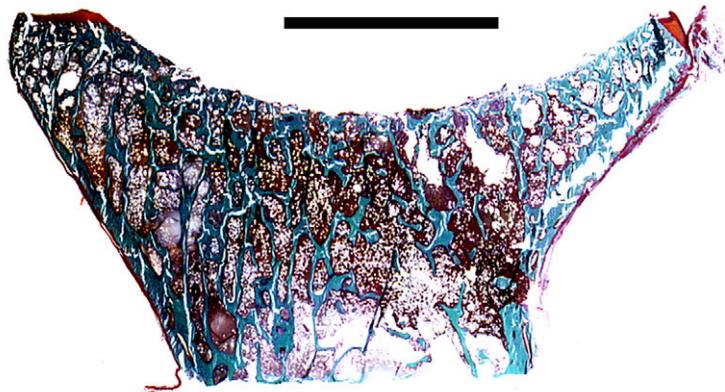


Fig. 7

Trabeculae exposed at the reamed surface of the glenoid bone may be damaged by the heat of reaming or by a lack of circulation to the surface. This freshly reamed canine glenoid was bisected through the shorter axis of its oval articular surface and in the plane normal to the surface and then was embedded in methylmethacrylate without decalcification. Ten-micrometer-thick sections were cut parallel to the sawn surface with use of a sledge microtome (model SM 2500; Leica, Wetzlar, Germany), thus providing a transverse cross section of the glenoid concavity and its underlying osseous architecture. The sections were stained with Goldner modified trichrome. Bone is stained teal blue while the marrow contents are stained dark red. The horizontal line indicates 1 cm.

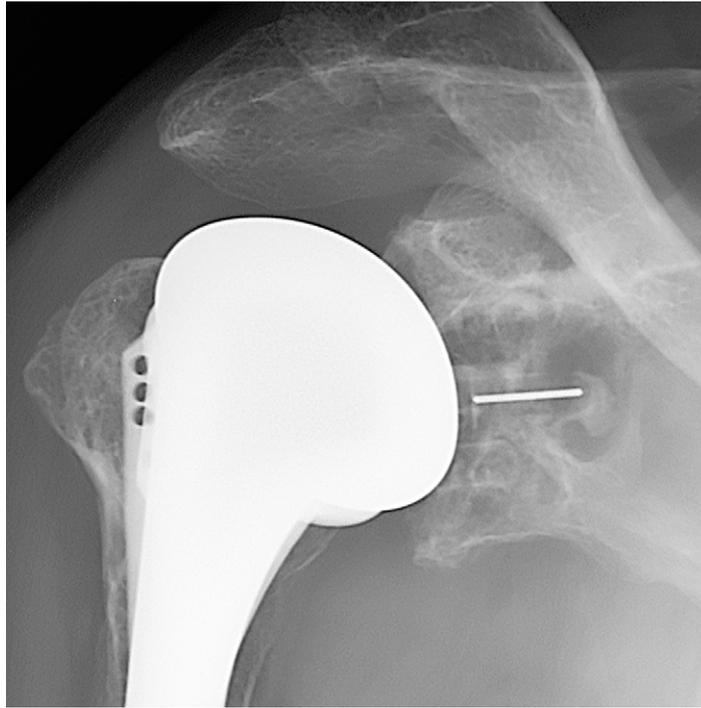


Fig. 8

The osteolytic bone resorption shown in this radiograph is much greater than the bone resorption seen with mechanical loosening alone. Pathologic and bacteriologic testing showed no evidence of infection but did reveal a massive chronic inflammatory reaction with small intracellular particles of polyethylene on polarized microscopy.

et al.⁷⁶ discovered a high prevalence of antibodies to these polyethylene-bound proteins. This immunological response may contribute to an inflammatory reaction in the periprosthetic tissue, ultimately leading to increased bone resorption around the prosthesis.

Osteolysis

Minute particles, especially those of polyethylene, can lead to progressive resorption of bone and consequently to prosthetic failure⁷⁷ (Fig. 8). Particles of $<1 \mu\text{m}$ in size are taken in by monocytes, macrophages, and osteoblasts, which then activate osteoclastic bone resorption by means of the receptor/activator of nuclear factor-kappa B (NF- κB) (RANK)/receptor/activator of NF- κB ligand (RANKL) mechanism as well as the prostaglandin E₂, tumor necrosis factor-alpha, interleukin-1, and interleukin-6 mechanisms^{73,78-84}. Fibroblasts may also respond to particulate debris and express proinflammatory cytokines and RANKL, stimulating osteoclastogenesis and bone resorption⁸⁵. These events are much more common in the hip, in which the risk of osteolysis is related to the rate of polyethylene wear^{86,87}. As a possible explanation of this difference in prevalence, Wirth et al.⁸⁸ demonstrated that the polyethylene debris particles seen after shoulder arthroplasty are larger and less spherical than those seen after total hip arthroplasty. These larger particles may be less ingestible and thus less provocative of osteoclast activation.

The observation of bone loss after arthroplasty should always raise concern regarding the possibility of infection⁸⁹. Because infections at the sites of shoulder arthroplasties are often caused by organisms of low virulence, such as *Propionibacter acnes* or *Staphylococcus epidermidis*, the radiographic appearance of an infected shoulder may be similar to that of a shoulder with aseptic loosening.

Prosthetic Loading

Polyethylene, cement, and bone are generally tolerant of loading in compression—i.e., concentric loading. However, eccentric loading challenges the integrity of all three of these materials^{40,90}.

Conforming Joint Surfaces

When the prosthetic humeral head is pressed into a glenoid component concavity with the same diameter of curvature, the position of the head is precisely defined by concavity compression^{1,91}. Some translation occurs with shoulder motion⁹². With conforming joint surfaces, the humeral head cannot translate on the glenoid component without separation of the joint surfaces and rim loading⁹³. As long as the joint surfaces remain in contact, all eccentric and translational forces are applied directly to the fixation of the glenoid component to bone^{32,33,94-98}. This mechanism helps us to understand the observation of Walch et al.⁹⁹ that the closer the match between the

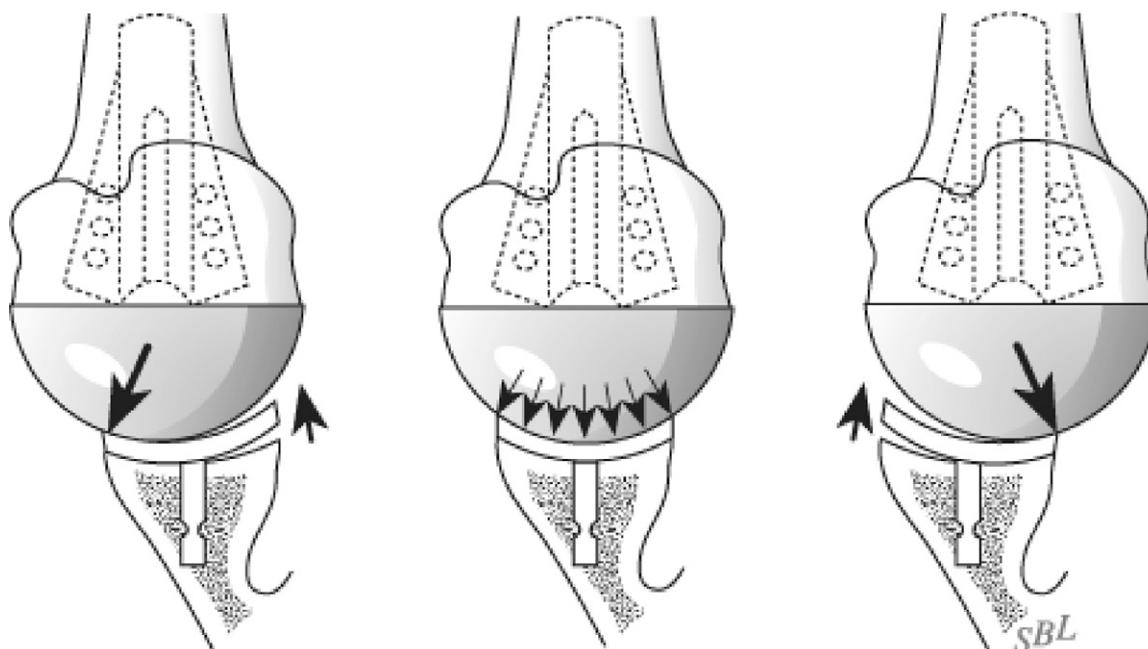


Fig. 9

Rocking-horse loosening. Although the glenoid component is stable when the load applied by the humeral head is centered (middle figure), anterior (left) or posterior (right) translation of the head of the glenoid causes eccentric loading and lifting up of the opposite, unloaded glenoid rim. (Reproduced, with modification, from: Matsen FA 3rd, Lippitt SB. *Shoulder surgery: principles and procedures*. Philadelphia: Saunders; 2004. Principles of glenoid arthroplasty; p 508. Reprinted with permission.)

humeral and glenoid component diameters of curvature, the higher the prevalence of periprosthetic radiolucency on follow-up radiographs.

Rim Loading

Component malposition can give rise to the rocking-horse loosening mechanism, in which loading of one edge of the glenoid component causes the opposite edge to lift off of the glenoid bone (Fig. 9)^{31,33,54}. Inferior placement of the glenoid component and/or superior placement of the humeral component are common causes for this phenomenon (Fig. 10).

Weight-Bearing Shoulder Prosthesis

Individuals who must use crutches, a cane, or a walker to walk place eccentric loads on the glenoid component that may contribute to prosthetic loosening¹⁰⁰.

Glenoid Component Version

If the glenoid component is abnormally retroverted, anteverted, or inclined superiorly or inferiorly, loads that would otherwise be concentric (aligned with the glenoid centerline) become eccentric^{26,101,102}, predisposing to displacement of the glenohumeral contact point and a substantial increase of stress within the cement mantle¹⁰³. Abnormal glenoid version can result from fracture, dysplasia, instability, or asymmetrical wear and has been associated with an increased rate of glenoid component failure¹⁰⁴⁻¹⁰⁸.

Glenohumeral Instability

Any tendency of the humeral head to assume an uncentered position on the glenoid component will result in eccentric loading^{109,110}. Conditions such as subscapularis deficiency, abnormal capsuloligamentous balance, and other causes of glenohumeral instability increase the risk of glenoid component loosening^{108,111,112}.

Rotator Cuff Insufficiency

As a special type of glenohumeral instability, the superior subluxation seen with massive rotator cuff deficiency is an important cause of eccentric loading¹¹³⁻¹¹⁵, creating the risk of rocking-horse loosening of the glenoid component^{31,33,54}.

Possible Strategies for Minimizing the Risk of Glenoid Component Failure

Patient Selection

Patients with poor-quality glenoid bone, glenoid bone deficiency, or major glenoid deformity are at increased risk for glenoid component failure. Patients whose shoulders are prone to eccentric loading, such as those with lower-extremity weakness and those with glenohumeral instability or rotator cuff deficiency, have higher rates of glenoid component failure.

Patient Counseling

Before and after total shoulder arthroplasty, patients should be advised that the glenoid component is at increased risk for



Fig. 10
Poor register of the humeral and glenoid components. The humeral component has been placed too high and the glenoid component, too low. The resulting eccentric loading has caused rocking-horse loosening of the glenoid component.

failure with heavy use and with activities that involve impact to the shoulder. Patients are also told that they should promptly report any loss of comfort or function or any new sensations of instability or clunking to their surgeon so that the shoulder can be assessed for glenoid component failure before major glenoid bone loss has occurred.

Component Design

Round-backed, all-polyethylene components with peg fixation perform better than do flat-backed, metal-backed, or keeled components^{16,20-27,29,30,32-36,49,53,55}. While many different polyethylenes with different amounts of cross-linking and different methods of component formation are available, there is no clear evidence supporting one over the other, although it is known that components sterilized with radiation in air should be avoided. Glenoid components with a diameter of curvature that is greater than that of the humeral head component are less subject to loosening^{32,33,94-99}.

Technique of Operative Implantation

It is desirable to restore normal glenoid version by reaming along a normalized glenoid centerline to the extent allowed by the available glenoid bone stock; posterior glenoid bone-

grafting is technically difficult and prone to failure. Reaming and drilling of the glenoid bone should be done with sharp tools that are cooled during use to minimize the risk of thermal damage to the bone. Seating is optimized by careful preparation of the glenoid bone so that there is a precise fit between the back of the glenoid component and the bone surface. All fluid and clot need to be removed from the fixation holes, and the bone should be dried before the insertion of cement to minimize the development of the immediate postoperative lucent lines that indicate suboptimal fixation. Minimizing the amount of cement used reduces the risk of heat damage to the bone. Placing the glenoid component directly on a carefully prepared congruently reamed joint surface avoids the need to insert cement between the back of the glenoid component and the glenoid bone surface, eliminating the risk of fatigue fracture of this thin brittle layer of cement and loss of component support.

Optimizing the Glenohumeral Relationship, Balance, and Stability

The humeral and glenoid components need to be positioned so that the humeral articular surface is centered on the glenoid articular surface in both the anteroposterior and the superior-inferior directions. This has been referred to as *ensuring proper*

register³⁸. Improper register with eccentric contact creates the risk of glenoid component loosening. At the conclusion of the operation, the shoulder should have an ample range of motion but should not allow the humeral head to be translated posteriorly by >50% of the width of the glenoid component surface.

Use of Pharmacological Agents

Although there is no evidence of the effectiveness of pharmacological agents in reducing the risk of glenoid component failure, we would like to call attention to this possibility, especially with regard to enhancing the stability of bone around prosthetic implants. Skripitz and Aspenberg¹¹⁶ reported that parathyroid hormone might increase the attachment of bone to polymethylmethacrylate. Clohisy et al.¹¹⁷ and Millett et al.¹¹⁸ explored the use of bisphosphonates in modulating osteolysis in animal models. Bhandari et al.¹¹⁹, Morris and Einhorn¹²⁰, and Hilding and Aspenberg¹²¹ reported that bisphosphonates might have a beneficial effect with regard to maintaining periprosthetic bone mineral density. Additional considerations regarding the use of bisphosphonates in the context of the fixation of cemented and press-fit prosthetic components were reviewed by Shanbhag¹²².

Overview

Glenoid component failure remains the most frequent complication of total shoulder arthroplasty. While new designs of humeral components appear each year, there has been little progress in developing strategies for minimizing the risk of glenoid component failure. It is clear that the mechanisms of glenoid component failure are different from those of tibial and acetabular component failure, in large part because the glenoid component is subject to eccentric loads, the glenoid component concavity is challenged to provide glenohumeral stability, and the bone available to support the glenoid component is limited. ■

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