Shoulder arthroplasty: The socket perspective

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Although much attention has been directed to the development of the humeral components used in shoulder arthroplasty, the major unsolved challenge lies on the glenoid side of the articulation. This challenge arises from difficulties resisting eccentric loading and providing adequate implant-bone fixation. Current glenoid component designs use polyethylene and polymethyl methacrylate and are prone to loosening, plastic deformation, particulate debris, and third-body wear. Metal-backed components present further challenges, and results have generally been disappointing. There is interest in biologic resurfacing procedures, including the interposition of fascia, capsule, or meniscal allograft and nonprosthetic glenoid arthroplasty, or what has become known as the "ream-and-run" procedure. Despite encouraging results, important questions remain unanswered about these procedures. However, each may warrant further exploration with a goal of providing an effective and durable approach to glenoid arthritis that avoids the risks associated with polymethyl methacrylate and polyethylene. (J Shoulder Elbow Surg 2007;16:241S-247S.)

Shoulder arthroplasty is a commonly applied and generally effective surgical treatment for debilitating arthritic conditions of the glenohumeral joint.[10] Although several generations of prosthetic approaches to the humeral side of the arthroplasty have proven effective,[3,9] the glenoid side presents unsolved challenges.[7] This article will attempt to assess why this may be and what alternatives may be considered for reconstruction of the glenoid articular surface.

The shoulder is unique in many regards, but one of the most intriguing aspects is the manner in which the glenoid manages its complex tasks of (1) distributing applied loads from the humerus uniformly to the subjacent bone and (2) providing the appropriately shaped and directed concavity to stabilize the glenohumeral joint through the concavity compression mechanism in the wide range of glenohumeral positions and functions. In marked contrast to the situation in the hip joint, the net humeral joint reaction force is not consistently applied to the center of the glenoid. Instead, the humeral force is applied to the posterior glenoid when the arm is forward, to the superior glenoid when the arm is adducted, and to the anterior glenoid when the arm is extended. These eccentric loads are accompanied by small degrees of translation of the humeral head away from the center of the glenoid. By virtue of the compliant cartilage and labrum at its periphery, the glenoid is well designed to accommodate eccentric loads and translations without excessive load concentration. The firm fixation of the joint surface complex to the subjacent bone resists the loosening effects of sheer and eccentric loading.

When cartilage loss occurs on the humeral side of the glenohumeral joint, its smooth spherical shape can be easily restored with a convex metal prosthesis solidly fixed to the humeral shaft without compromising stability, mobility, or load transfer. However, when the highly specialized mechanism of the glenoid socket is disrupted, secure, effective, and durable reconstruction is much more challenging. In fact, a large percentage of the failures of shoulder arthroplasty are related to problems in managing the glenoid socket.[1,12]

COMPLICATIONS OF TOTAL SHOULDER ARTHROPLASTY

Although the details of the pathogenesis and progression of glenoid arthritis have yet to be defined precisely, it is apparent that compromise of the structure or mechanical properties of the labrum and cartilage of the glenoid, the "soft side" of the articulation, will result in loss of the normal load-distributing and stabilizing mechanisms of the joint. With loss of the even distribution of the humeral force, local concentrations of load accelerate the deformation and deterioration of the cartilage. In degenerative joint disease, the cyclic process of load concentration and
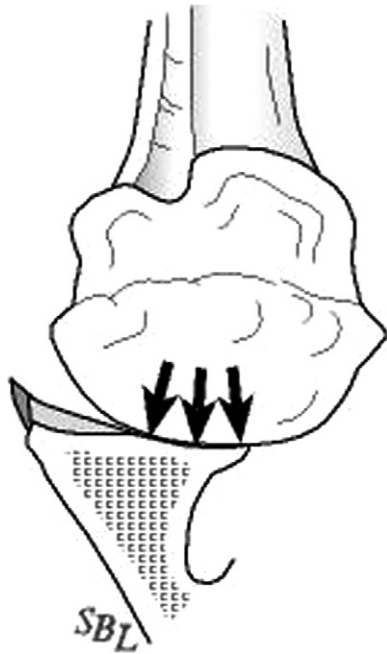
Figure 1 Thinning of the articular cartilage posteriorly gives rise to posterior load concentration, further wear of subjacent bone, and a biconcave glenoid. Because the contact area is diminished, the force per unit area, or local joint pressure, is increased (*arrows*). This predisposes the glenoid to additional wear and posterior instability. The problem cannot be solved on the humeral side of the arthroplasty.

joint surface deformation typically affects the posterior glenoid, resulting in a "biconcave" glenoid.

It appears that the posterior glenoid is particularly vulnerable to deformation because the posterior articular cartilage is thicker. Weldon et al[19] demonstrated in a cadaveric study that loss of the glenoid cartilage had a particularly marked effect on the stability provided by the posterior glenoid.

When distortion of glenoid anatomy occurs (Figure 1), normal load transfer and stability cannot be restored with hemiarthroplasty alone. The use of hemiarthroplasty alone in the presence of eccentric glenoid wear is associated with inferior outcomes.[13]

In total shoulder arthroplasty, a polyethylene prosthesis is inserted to improve the stability and load transfer offered by the glenoid. Although polyethylene is a useful bearing surface in many joint arthroplasties in which the loads are centered and evenly distributed over the joint surface, this material is at risk in the shoulder environment.[6,18,20] There are several reasons for the vulnerability of polyethylene in the shoulder.

1. Polyethylene undergoes plastic deformation when the force per unit area (local joint pressure) is high. When the humeral head is centered in the glenoid and when the prosthetic joint surfaces are con-

forming, the force is distributed over a broad area and the local joint pressure is low. High local joint pressures arise in two situations.

A. When the humeral head of a highly conforming system translates even slightly on the congruent glenoid face, the glenohumeral contact area is reduced to that of the round humeral head on the thin glenoid rim—a fraction of 1 mm². As a result, the force per unit area is very high and the rim is likely to deform permanently.

B. When the prosthetic joint surfaces have a high degree of mismatch (ie, the diameter of curvature of the glenoid surface is substantially greater than that of the humerus), the joint contact area is small and the joint pressure high. In both of these situations, the polyethylene component is prone to deform progressively from its original desired surface geometry.

2. Polyethylene generates small particles when it wears. These particles then facilitate additional destruction of the prosthetic joint surface by third-body wear.[4,5] Such wear progressively compromises the surface of the glenoid component and exposes it to accelerated wear and continued generation of abrasive particles. In addition, particulate debris instigates an osteolytic response, which may also affect glenoid fixation to underlying bone.

3. Although the humeral component can be durably fixed to the bone of the humerus via a press-fit,[2,11,17] it is difficult to fix the polyethylene joint surface permanently to the bone of the glenoid.[14]

A. In contrast to the acetabulum, the bony glenoid is relatively avascular. When polymethyl methacrylate (PMMA) is used to fix the glenoid component, the heat generated by the exothermic curing process is trapped beneath the insulating polyethylene and the bone, such that high temperatures can result at the bone-cement interface. Thermal injury to the bone at this critical interface contributes to component loosening.[8]

B. When a polyethylene component is cemented, the flexible polyethylene is supported by a brittle and thin layer of PMMA. When the component is loaded throughout the range of shoulder positions and activities, the bone cement is at risk for progressive cracking and fracture. The resulting change in PMMA configuration diminishes the support of the component, leading to progressive loosening. PMMA debris contributes to third-body wear and osteolysis.

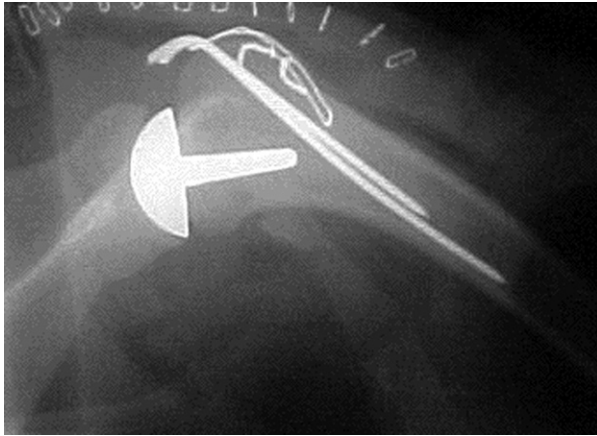C. A metal baseplate for the polyethylene glenoid component can be firmly fixed to the bone of

Figure 2 Completed canine ream-and-run procedure. The tuberosity was taken down for surgical exposure and reattached with a tension-band wire. The humeral component is press-fit in the proximal humerus. The glenoid has been reamed to a diameter 1 mm larger than that of the humeral head.
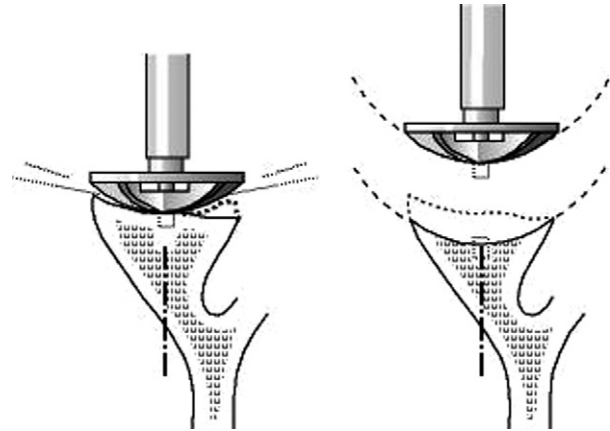

Figure 3 Spherical reaming to convert a biconcave glenoid to one with a single concavity with maximal load-bearing surface.

the glenoid without the use of cement. However, metal-backed components present three unique challenges. (i) By necessity, a metal-backed glenoid component is thicker than an all-polyethylene component. Raising the glenoid joint surface increases the risk of joint stiffness and instability. (ii) The fixation of the polyethylene surface to the metal baseplate is prone to failure. (iii) The interface between the metal and the polyethylene is subject to backside wear, with the generation of particulate debris and accelerated third-body wear and osteolysis.

  D. Although progress has been made with polyethylene anchoring systems, no system allows for the adequate bonding of the prosthetic joint surface to the surface of the underlying bone. Thus, the component is perpetually at risk for failure of fixation.

4. The tenuous fixation of the glenoid component makes it susceptible to loosening when eccentric loads are applied.

It is apparent from the foregoing that surgeons should continue to seek better options for dealing with the damaged or degenerated glenoid joint surface. There is some interest in biologic resurfacing procedures, such as the interposition of fascia, capsule, or meniscal allograft. The important questions that remain unanswered about these procedures concern the durability of the interposed material and whether the material becomes fixed to the bone of the glenoid.

There has also been interest in the possibility that an arthritic glenoid bone surface reamed to the desired concavity may regenerate and remodel a durable joint surface that is well fixed to the subjacent bone and capable of managing the range of loads

applied by a metal humeral prosthesis in an active individual. If such a biologic joint surface could be established and coupled with a press-fit humeral arthroplasty, the arthroplasty would be free of its two weakest links: polyethylene and PMMA.

In exploring this option, several questions needed to be answered.

1. Can the reamed glenoid match the stability provided by the normal glenoid? Weldon et al[19] demonstrated that the intrinsic stability lost by cartilage removal could be restored to the levels provided by a normal or a prosthetic glenoid.

2. Can the reamed mammalian glenoid heal and remodel to a biologic joint surface? Studies in a canine model demonstrate that a reamed glenoid in contact with a metal humeral surface regenerates a fibrocartilaginous surface that (A) is firmly bonded to subjacent bone, (B) distributes the humeral load evenly to the bone, and (C) re-establishes the stabilizing effect of the glenoid concavity (Figure 2).[16]

3. Can a technique for humeral hemiarthroplasty with this type of nonprosthetic glenoid arthroplasty be established for clinical use? Weldon et al[19] proposed a technique that has subsequently been tested clinically (Figures 3-6).

4. Can nonprosthetic glenoid arthroplasty manage the biconcave glenoid? Clinical experience to date suggests that a uniform concavity can be established via this technique (Figures 7 and 8).

5. Can patients with glenohumeral arthritis who wish to avoid the risks associated with polyethylene and PMMA benefit from humeral hemiarthroplasty with this type of nonprosthetic glenoid arthroplasty? Lynch et al[15] found that at 2 years after surgery, shoulder comfort and function were significantly improved after this procedure (Figures 9 and 10). Furthermore, patients with postoperative

Figure 4 Glenoid concavity reamed to a diameter 2 mm larger than that of the humeral head.
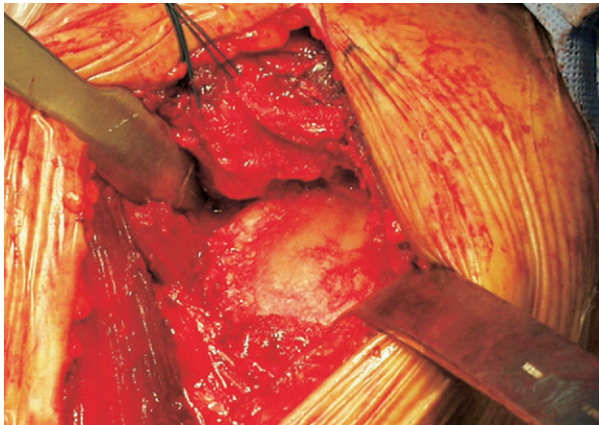

Figure 6 Intraoperative photograph of the glenoid from Figure 5 after concentric reaming around a drill hole in along the glenoid centerline. The healing of the fractured trabeculae is molded by contact with the humeral prosthesis as early postoperative mobilization is carried out.

Figure 5 Intraoperative photograph of a biconcave glenoid, showing residual cartilage (*upper left*) and bare bone (*lower right*).

Figure 7 Posterior glenoid erosion resulting in a characteristic biconcave glenoid.

films showing a regenerated joint space had better shoulder function than those without this finding. Subsequent follow-up of patients having what has become known as the "ream-and-run" procedure has shown substantial improvement for most but not all patients (Figure 11).

Over the time we have been using this procedure, certain technical elements have become incorporated into our protocol:

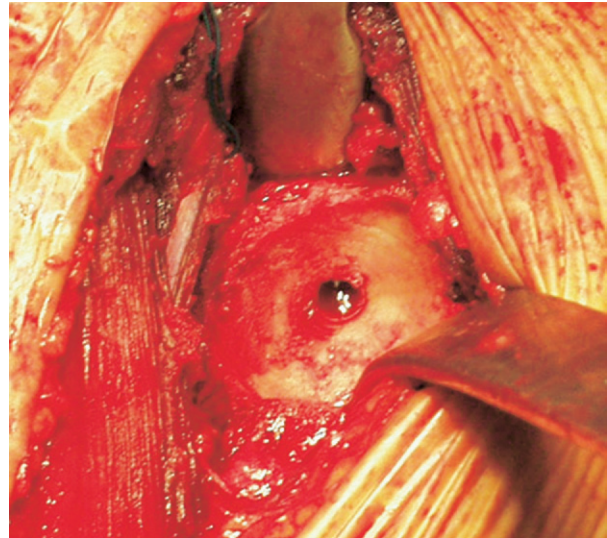1. The procedure is only offered to nonsmoking athletically-minded individuals not taking preoperative narcotics who are willing to commit to maintaining their motion during the critical first 3 months after the procedure.

Figure 8 Axillary radiograph of the same patient shown in Figure 7 one year after ream-and-run surgery. The centering of the humeral prosthesis in the glenoid, the elimination of the biconcavity, and the radiographic space between the humeral prosthesis and the glenoid bone should be noted.
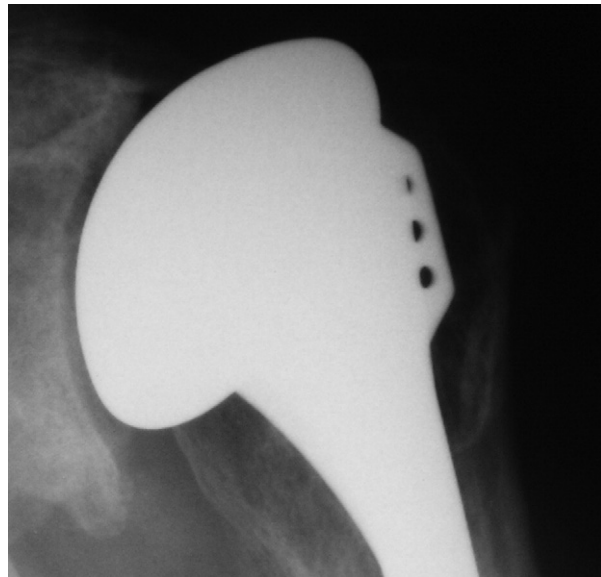

Figure 9 Anteroposterior radiograph suggesting soft-tissue formation between the humeral prosthesis and the glenoid bone 1 year after a ream-and-run procedure.

Figure 10 Axillary radiograph of the same shoulder shown in Figure 9 suggesting soft-tissue formation between the humeral prosthesis and the glenoid bone 1 year after a ream-and-run procedure.

2. A good preoperative axillary view is necessary to determine whether a biconcave glenoid or posterior humeral subluxation (or both) is present.
3. The subscapularis is released from its insertion to the lesser tuberosity along with the subjacent capsule. The capsule is released from the glenoid labrum, leaving the labrum attached to the glenoid. The subscapularis is released from the coracoid process.
4. In patients with posterior glenoid erosion and posterior humeral subluxation, the glenoid and humeral attachments of the inferior glenohumeral ligament are preserved.
5. The glenoid is reamed to a large diameter (usually 54 or 58 mm) with the center slightly above the superior-inferior midpoint of the glenoid. Rather than trying to correct glenoid retroversion, the goal of reaming is to ensure a single spherical glenoid cavity devoid of residual articular cartilage.
6. The humeral head diameter selected is 2 mm smaller than that of the reamed glenoid.

7. The humeral neck length is selected to allow 60° of internal rotation with the arm in 90° of abduction and no more than 50% posterior subluxation on the posterior drawer.
8. Range of motion is examined to ensure that the arm easily reaches 140° of elevation.
9. The stability of the shoulder is also examined with the arm in 90° of flexion. If the humeral
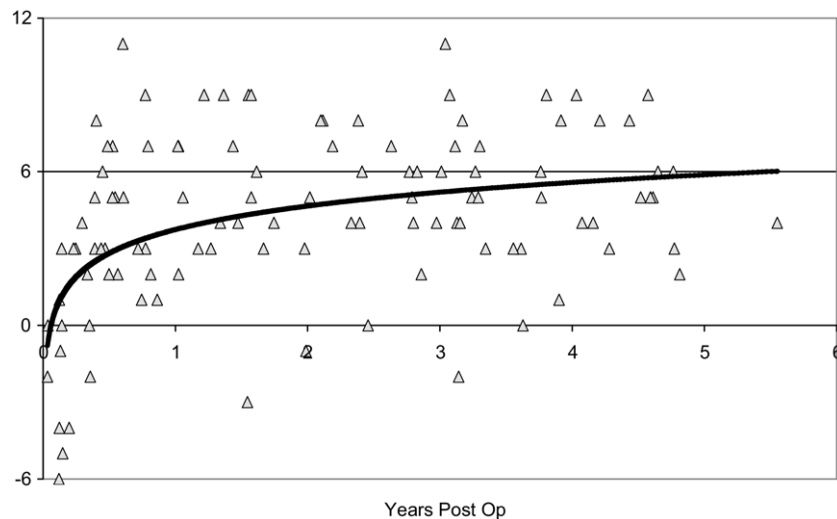
Figure 11 Change in self-assessed shoulder function as assessed by the Simple Shoulder Test in 110 patients having a ream-and-run procedure as a function of time after the procedure. The mean age at surgery was 57 ± 9 years. Of these patients, 71% had primary osteoarthritis and 17% had capsulorrhaphy arthropathy; the remaining 12% had other types of secondary arthritis.

head drops back more than 25% with the arm in this position, a rotator interval plication is performed.

10. The definitive humeral component is inserted after impaction autografting of the medullary canal and after drill holes are placed at the lesser tuberosity for attachment of the subscapularis.

11. Great care is taken to make sure that the humeral component is positioned so that its articular surface is centered in the reamed glenoid. It is particularly important to avoid a "too high" humeral position that would allow the humeral prosthesis to rest on the upper lip of the reamed glenoid.

12. After subscapularis repair and closure, the arm is placed in continuous passive motion for 36 hours.

13. Postoperative progress is carefully monitored to ensure that 140° of motion is maintained for the first 3 months after surgery.

14. Nonsteroidal medication is avoided for the first 6 weeks to prevent any potential inhibitory effect on healing of the reamed surface.

We continue to strive to optimize the results of this procedure through proper patient selection, attention to surgical detail, and carefully supervised postoperative care.

In conclusion, although much attention has been directed to the development of the humeral components used in shoulder arthroplasty, the major unsolved challenge lies on the glenoid side of the articulation. When the glenoid has been affected by arthritis, hemiarthroplasty and total shoulder arthroplasty both have their limitations. In view of the initial results, regenerative glenoid arthroplasty may warrant further exploration with a goal of providing an effective and durable approach to glenoid arthritis that avoids the risks associated with PMMA and polyethylene.

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