# Managing Glenoid Bone Loss in Revision Total Shoulder Arthroplasty: A Review

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Revision of the glenoid component in total shoulder arthroplasty (TSA) remains an unresolved problem. Even with meticulous surgical technique, available bone stock may preclude the implantation of a new glenoid component. Multiple studies have demonstrated that patients in whom a new glenoid can be placed have improved pain scores and satisfaction when compared to patients who lack sufficient bone to accommodate a glenoid component. Glenoid bone grafting has become a common method of recreating bone stock in hopes of preventing later fractures, maintaining joint kinematics, and allowing for glenoid reimplantation in a single or dual stage manner. Based on the limited available data, cases of revision TSA that do not allow for glenoid reimplantation are most reliably treated with glenoid bone grafting followed by glenoid reimplantation at a secondary surgery if deemed necessary. This review serves to discuss aseptic loosening of the glenoid as well as to describe the surgical options for management of glenoid bone loss in revision TSA.

## Introduction

The number of total shoulder arthroplasty (TSA) cases continues to grow each year. With the increasing number of procedures being performed, there, in turn, will exist a greater need for revision procedures. Failure of a shoulder arthroplasty can result from soft-tissue problems, bony deficiencies, infection, and component wear or loosening[1]. Component loosening and osseous deficiencies may occur on the humeral and/or glenoid side. Multiple studies have identified glenoid component loosening as one of the more common etiologies necessitating revision after total shoulder arthroplasty[2-4]. Glenohumeral joint instability in the setting of rotator cuff deficiency is also a common cause of glenoid loosening. Eccentric loading of the glenoid from a proximally migrated humerus leads to increased stress at the bone-cement or bone-implant interface, commonly referred to as the "rocking horse phenomenon"[5]. Eccentric loading and glenoid loosening may also result from incomplete glenoid seating, glenoid or humeral malposition, or tuberosity malunion. The importance of glenoid implantation becomes evident when one considers outcomes in patients who undergo revision surgery for failed glenoid components. Multiple studies have underscored the importance of glenoid component reimplantation in determining functional outcome. Consideration of glenoid component design followed by literature suggesting poor results in revision settings will be discussed in this review. This will be followed by treatment options for this problem. The concepts and techniques discussed assume an intact rotator cuff and the absence of infection, as these topics are beyond the scope of this paper.

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## Glenoid Component Design

Loosening of the glenoid component remains the most likely cause of implant failure in total shoulder arthroplasty. This is almost always multifactorial in its etiology. Such factors may include mechanical failure of the fixation in response to high tensile stress or osteolysis of the surrounding bone stock in response to particulate wear debris. Design changes and improved techniques to diminish the rate of radiolucent lines in the immediate postoperative period and to improve long-term glenoid stability have included preservation of the subchondral plate, concentric glenoid reaming, improved cement pressurization methods, and optimal biomaterial selection and design. More recent studies have suggested that improved glenoid component design, cement techniques (pressurization rather than manual packing), and more precise instrumentation all play a vital role in enhancing initial fixation, which may reduce the incidence of early loosening of non-metal-backed glenoid components[6]. Studies indicate that the low strength and small volume of bone in the glenoid vault are limiting factors for securing fixation of a glenoid component[7,8]. Current research efforts have been geared towards identifying the optimal locations of fixation, the optimal types of fixation, and the effect of glenoid deformity and shoulder pathology on achieving fixation with a focus on identifying and understanding the glenoid failure modes in different implant designs[9].

As most cases of aseptic failure of primary TSAs result from failed fixation of the glenoid, obtaining optimal fixation has been a focus of research. Component loosening is largely related to wear of products and osteolysis[10]. Though noncemented, metal-backed glenoids offer the theoretic advantage of long-term bone in-growth/on-growth, these designs have demonstrated higher complication rates due to increased ultra-high molecular-weight polyethylene wear and joint overstuffing[11]. Failure has been associated with polyethylene wear, metal wear, instability, fracture, and back-side wear in snap-fit metal-polyethylene designs[11-15]. As a result, cemented glenoids are most commonly used. Finite

element analysis has demonstrated increased stresses in the polyethylene of a metal-backed glenoid component[14]. Fox et al in their review of 1542 total shoulder arthroplasties using 6 different glenoid designs found that metal-backed bone-ingrowth components failed much more frequently than all-polyethylene designs, and metal-backed cemented components offered no advantage for improved survival[12]. Despite the trend away from metal-backed designs, Clement et al described their outcomes using a metal-backed glenoid component in rheumatoid patients at 8 to 14 year follow-up, noting 89% survivorship at 10 years[16]. They assert that the key design features in the survivorship of the metal-backed glenoid are: a low-profile tray with a fully-coated bone in-growth substance at the plate-bone interface, a conical stem, and secure screw fixation. Sperling et al showed an estimated glenoid survival of 97% at ten years using the Neer II all-polyethylene prosthesis[17]. However, Stewart and Kelly[18] had a revision rate of 8.1% with the same prosthesis and Søjbjerg et al[19] showed loosening in 40% of their patients at 7.7 years. More recent studies have demonstrated encouraging survivorship (89-94% at 15 years) for glenoid components with cemented all-polyethylene designs[12]. Newer third generation designs have demonstrated reliable durability of the glenoid component with 92% survival at 10 years in one study[20].

Several studies have investigated loosening rates comparing pegged and keeled glenoid component designs. Three-dimensional finite element analysis by Lacroix et al demonstrated that bone stresses are not much affected by the prosthesis design, except at the tip of the central peg or keel[21]. They concluded that a "pegged" anchorage system is superior for normal bone, whereas a "keeled" anchorage system is superior for rheumatoid bone. Several clinical studies have shown less evidence of radiographic lines of lucency in pegged compared to keeled glenoid designs and have concluded superior technical outcomes with pegged glenoids[22-24]. However, recent studies have challenged the superiority of pegged designs. Finite elemental analysis by Mansat et al investigating the effect of eccentric loading on a keel glenoid and a peg glenoid implant indicates that eccentric loading greatly increases stresses in the cement mantle at the bone-cement interface, and no significant difference exists between keel and peg implants[25]. Roche et al, in a biomechanical study, showed that, regardless of the axes tested, no discernable difference in edge displacement (distraction and compression) occurs before or after cyclic, eccentric loading for either the keeled or pegged glenoid designs[26].

Biomechanically, it is believed that in order to optimize glenoid component design against abrasive wear, surgeons must rely on high conformity designs. Glenohumeral mismatch has been identified as an important factor in total shoulder arthroplasty and is defined as the difference in the curvature between the glenoid component and the humeral head. No mismatch results in a congruent articulation in which the radii of curvature of the glenoid and humeral head are the same. The degree of mismatch results in varying levels of noncongruent articulation. While a congruent articulation allows for optimal surface contact, minimizes the risk of surface wear of the glenoid component, and contributes to joint stability, these advantages come with a lack of obligate translation (translation between the articular surfaces that occurs with active and passive shoulder mobility and is absorbed by elastic deformation of the articular cartilage and the glenoid labrum in the normal shoulder)[27]. A lack of this translation after total shoulder arthroplasty may lead to loosening of the glenoid component because of increased stresses at the implant fixation site[27, 28]. Karduna et al in a cadaveric study determined that normal glenohumeral joint translation is best reproduced by a glenohumeral radial mismatch of approximately 4 mm, anterior-posterior translation is greater than superior-inferior translation (1.5 mm compared with 1.1 mm), and variations of 0 to 5 mm of radial mismatch do not alter prosthetic joint stability[29]. Walch et al conducted a multicenter investigation utilizing a single type of prosthesis (Aequalis; Tornier, Montbonnot, France) that included a cemented, all-polyethylene glenoid component and specifically evaluated the influence of glenohumeral mismatch on the appearance of glenoid radiolucent lines[27]. In their study, glenohumeral prosthetic mismatch ranged from 0 to 10 mm. Glenohumeral mismatch had a significant influence on the scores for the glenoid radiolucent lines, which were best when the radial mismatch was between 6 and 10 mm[27]. Importantly, despite the relationship between glenohumeral mismatch and the formation of radiolucent lines, the mismatch had minimal effect on clinical results or complication rates[27]. With multiple prosthetic designs available, the "ideal" mismatch between a prosthetic humeral head and a glenoïd component remains undetermined and warrants further investigation.

Finite element analyses of glenoid component position demonstrate the centrally-aligned implant is least likely to fail. Glenoid malposition has been noted as a cause of loosening. Nyffeler et al have demonstrated in a cadaveric study that an increase in anteversion results in anterior translation of the humeral head and in eccentric loading of the anterior part of the glenoid, whereas retroversion is associated with posterior displacement and posterior loading of the glenoid[30]. These results suggest that both instability and glenoid component loosening may be related to the version of the glenoid component. Similarly, Favre et al noted that component positioning may lead to impingement, eccentric loading, and potential loosening[31]. In their biomechanical study, they identified the inclination of the glenoid component, the inferior–superior position of the humeral component along the resection line, and the prominence of the humeral calcar as the most sensitive parameters affecting impingement.

Most importantly, the quality of the supporting bone stock has been found to be particularly significant to cement survivability, more so than the occurrence of eccentric loading of the joint[32]. Cadaveric study of bone mineral density in different regions of the glenoid demonstrates that posteriorly and superiorly the glenoid bone stock provides stronger support for any kind of fixation on the bony surface[33]. Unfortunately, in revision cases, bone loss can be unpredictable, and the patterns of glenoid bone stock that have been described in the native glenoid may no longer exist.

## Glenoid Revision

The possibility of glenoid resurfacing during revision for aseptic loosening depends largely on the available glenoid bone stock. Because of the small anatomic size of the bony glenoid, glenoid bony deficiencies frequently compromise component fixation, pose considerable reconstructive challenges, and sometimes precludes placement of a glenoid component[34]. The decision to reimplant a new glenoid is often determined by the type and severity of the deficiency that results after removal of a loose or otherwise unsalvageable component. Other considerations include the integrity of the rotator cuff and absence of infection.

### *Glenoid Lucency After Primary TSA*

A critical evaluation of radiographs must be undertaken prior to revision shoulder arthroplasty. Attention must be directed at the presence or progression of glenoid radiolucent lines, osteolysis, glenoid component migration, glenoid bone loss, and humeral component migration. It is worth noting that lucency surrounding the glenoid component does not imply glenoid loosening. Nagels et al define radiological loosening as a progressive translucency around the glenoid component of 2 mm or more, spanning the whole cement-bone interface, or an apparent shift of the component[35]. Deutsch et al modified the Souter's system[36] and graded glenoid lucency as grade 0 for no radiolucent line, grade 1 for less than 1 mm wide and incomplete, grade 2 for 1 mm wide and complete, grade 3 for 1.5 mm wide and incomplete, grade 4 for 1.5 mm wide and complete, and grade 5 for 2 mm wide and complete[37]. They define glenoid loosening as 1) a circumferential radiolucent line of at least 2 mm around the glenoid component, 2) progression of radiolucent lines on serial radiographs, 3) presence of cement fragmentation, and 4) gross component migration.

### *Glenoid Bone Loss During Revision TSA*

Several methods of classifying glenoid bone loss have been proposed. Glenoid bone deficiency is commonly classified according to Atuna et al[38]. In this classification system, glenoid bone loss is categorized intraoperatively on the basis of location and severity. Based on the location, defects are categorized as peripheral (anterior or posterior), central, or combined (central and peripheral). Based on severity, deficiencies are classified as mild if they involve less than one-third of the glenoid rim or surface, moderate if they involve between one third and two thirds, and severe if they involve more than two thirds. Classification is important because mild and moderate deficiencies are often suitable for component reimplantation with or without bone grafting of the glenoid while severe central or combined deficiencies often preclude implantation of new component.

## Surgical Treatment and Review of Literature

Revision surgery begins with a vigilant regard for preservation of existing glenoid bone stock. The surgeon must exercise meticulous care when removing the glenoid component and, if it exists, the cement mantle from the native glenoid. The surgical procedure consists of removal of the loose glenoid component and thorough debridement of all of the devitalized tissues and detritus from the glenoid perimeter and from within the remaining glenoid vault cavity[39]. Defects are classified as contained or uncontained/segmental. In many situations, with proper surgical technique, mild defects that are contained within the glenoid vault still allow for placement of a glenoid component without the need for complex reconstruction measures.

In contrast, segmental defects and severe cavitary defects cannot allow for reliable fixation and reinsertion of a glenoid component. The glenoid must contain enough volume to support a trial component. Once the degree of glenoid bone loss is assessed intraoperatively, the surgeon must determine whether reimplantation of a glenoid component is feasible. If glenoid bone loss is insufficient for reimplantation of a glenoid component, alternative surgical options must be considered. Again, the concepts and techniques discussed assume an intact rotator cuff and the absence of infection as these topics are beyond the scope of this paper.The following are options for management:

*1. Removal of glenoid component without bone grafting or reimplantation of a new component*

No study has specifically examined removal of the glenoid component without bone grafting or reimplantation of a new component. Several investigations have included these patients in their study cohort but have not specifically evaluated their outcomes. It is thought that glenoid component removal in cases of aseptic loosening offers satisfactory pain relief on most occasions, although it remains inferior to replacement with regard to pain relief and function[1,40]. Dines et al evaluated outcomes of revision TSA and included 12 patients who underwent glenoid resection, 7 of whom did not undergo any additional bone grafting or interpositional arthroplasty[41]. They compared this group to 10 patients who underwent glenoid reimplantation and did not note any significant differences in outcome at mean 76 months follow-up.

*2. Single stage allogenic or autogenous bone grafting of the glenoid without glenoid reimplantation*

More commonly, the glenoid is managed with bone grafting without glenoid reimplantation during revision surgery when single-stage glenoid reimpantation is not possible. Grafting is thought to be important for several reasons including prevention of later insufficiency fractures, restoration of the joint line for improved joint kinematics, and the potential for later glenoid component placement[42]. No standard method of bone grafting has been established as the gold standard, and authors report different indications for each approach[37, 38, 43]. It is often necessary to use corticocancellous bone allograft in cases of peripheral or combined severe defects and impaction cancellous bone grafting in those cases with contained central defects.

Neyton et al reported nine patients who underwent removal of loose glenoid components and reconstruction of the glenoid with corticocancellous bone grafting in a single-stage

procedure. They noted that, in cases of an isolated central deficiency, a bicortical bone graft was impacted into the central defect with the cortical surface positioned laterally[43]. Cancellous bone was then packed around and behind the bicortical graft. In cases with anterior glenoid wall insufficiency, a bicortical bone graft was secured via two cortical screws and cancellous bone packed into the residual defect. At a minimum followup of 24 months, five patients had satisfactory and four patients had unsatisfactory results according to Neer's criteria. Radiographs revealed central graft resorption with an average medialization of the humeral head within the glenoid of 4.1 mm. Antuna et al reported on 48 shoulders that underwent glenoid component revision surgery[38]. Eighteen shoulders underwent removal of the component and bone grafting for bone deficiencies, and 30 shoulders underwent implantation of a new glenoid component. At a minimum follow-up of 2 years, there was considerable pain relief (86%) and improvement in range of motion in the group of patients who underwent revision of the glenoid component. The group of patients without a glenoid component was less satisfied than the group with glenoid reimplantation, and pain relief was achieved in only 66%. Deutsch et al included 17 patients who underwent glenoid component removal, bone grafting, and revision to a hemiarthroplasty in their evaluation of 32 patients who underwent revision shoulder arthroplasty for glenoid component loosening[37]. They determined that while both glenoid reimplantation and revision to a hemiarthroplasty with glenoid bone grafting improved function, satisfaction, and level of pain at mean 4-year follow-up, reimplantation of a new glenoid afforded greater improvements in pain and range of motion. Similarly, Cheung et al compared 35 shoulders that had removal and bone grafting without glenoid reimplantation with 33 shoulders that underwent placement of a new glenoid component. They determined that reimplantation of a glenoid component leads to pain relief and patient satisfaction and a slight clinical benefit compared to bone grafting[42].

Though bone grafting may be the most viable option when reinsertion of a glenoid component is not possible, concern remains regarding the fate of grafts. Scalise and Iannotti reviewed 11 patients with severe glenoid deficiencies from aseptic loosening of a glenoid component who underwent conversion of a TSA to a humeral head arthroplasty and glenoid bone grafting[39]. They grafted cavitary lesions with either allograft cancellous bone chips or bulk structural allograft, depending on the presence or absence of glenoid vault wall defects. They noted substantial graft subsidence in all patients and determined greater subsidence with structural than cancellous chip allografts. Importantly, graft subsidence did not correlate with clinical outcome scores in their small sample. It remains to be determined whether graft subsidence influences the ability to reimplant a glenoid at a latter stage if necessary.

*3. Single stage allogenic or autogenous bone grafting of the glenoid with biologic resurfacing*

Glenoid biological resurfacing with hemiarthroplasty has been well-described in the management of primary glenohumeral arthritis. Cadaveric study has demonstrated decreased stress on the underlying glenoid and avoidance of central glenoid contact[44]. Clinical studies have demonstrated successful patient-derived outcomes at early follow-up; however, a significant risk of reoperation has also been noted[45-47]. While these studies make glenoid resurfacing a potential option in revision shoulder arthroplasty, its utility for this specific indication is relatively unknown. No study has specifically evaluated this patient population. Tissue options include joint capsule, fascia lata, meniscal allograft, Achilles tendon allograft, and synthetic materials[45]. The technique generally involves reaming the glenoid to provide a base of bleeding bone and to correct version followed by graft interposition. Elhassan et al reviewed 21 patients who underwent glenoid bone grafting for glenoid bone loss during revision shoulder arthroplasty[34]. Their series included 10 patients who underwent biological resurfacing (7 Achilles tendon allografts, 3 fascia lata autograft) of the glenoid in addition to bone grafting and hemiarthroplasty. They observed that patients who underwent revision TSA with placement of glenoid component had improvements in forward flexion and external rotation. However, improvement in range of motion, in particular shoulder external rotation, was more considerable in patients who underwent revision hemiarthroplasty with glenoid reconstruction without biologic resurfacing compared with the patients who underwent biologic resurfacing. The utility of glenoid resurfacing for primary glenohumeral arthritis is debated, and it is questionable whether an interposition graft acts as a durable bearing surface. Similarly, glenoid resurfacing in revision shoulder arthroplasty has not been identified as a necessary addition to bone grafting.

*4. Single stage allogenic or autogenous bone grafting of the glenoid with glenoid reimplantation*

Severe central bone deficiencies often contraindicate the use of the glenoid component; however, less severe glenoid bone deficiencies are sometimes treated with bone graft or concentric glenoid reaming and glenoid component insertion[1]. Elhassan et al included 3 patients who underwent revision total shoulder arthroplasty with glenoid bone grafting in a single-stage procedure in their evaluate of 21 revision shoulder arthroplasties[34]. All patients had central glenoid bone defects. At mean 45 month follow-up, Constant-Murley score improved from 32.3 to 68.6 with no evidence of glenoid loosening and no additional secondary surgical procedures. Studies specifically evaluating single-stage bone grafting of the glenoid with reimplantation of a component during revision shoulder arthroplasty are lacking. As graft resorption and lack of adequate graft incorporation are concerns, there is a theoretical risk of glenoid loosening with a single-stage approach.

*5. Dual stage allogenic or autogenous bone grafting of the glenoid followed by glenoid reimplantation*

Some patients who undergo glenoid component removal and bone grafting have persistent pain and limitation in range of motion. In these situations, the surgeon can consider reimplantation of a glenoid component. Cheung et al reported on seven patients who underwent reimplantation of a new glenoid component following removal of the previous glenoid

component and placement of an allograft[48]. Eliminating two patients who underwent repeat revision for infection, they noted that at average 79 months follow-up pain was significantly improved; however, range of motion was not. Phipatanakul and Norris reviewed 24 patients who underwent allograft cancellous bone grafting for glenoid defects during revision TSA[49]. Incorporation of the allograft bone allowed for revision to a total shoulder replacement in 4 cases with residual pain at a mean of 11 months postoperatively, which resulted in satisfactory pain relief. Cheung et al, as part of their investigation of patients who underwent revision TSA for glenoid loosening, examined 35 patients who underwent glenoid removal and bone grafting [42]. They noted that 6 patients had reimplantation of a new glenoid at a mean of 3.5 years postoperatively for persistent pain, noting that bone grafting of a large glenoid deficiency was critical in providing the bone stock necessary for later reimplantation.

## Conclusion

With the increasing number of TSA cases performed each year, revision of the glenoid, although uncommon, remains unresolved. Meticulous surgical technique during index implant insertion may continue to decrease the need for glenoid revision. In the setting where revision is necessary, careful cement removal with preservation of bone stock is critical. Multiple studies have demonstrated that patients in whom a new glenoid can be placed have improved pain scores and satisfaction when compared to patients who lack sufficient bone to accommodate a glenoid component. As a result, glenoid bone grafting has become a common method of recreating bone stock in hope of preventing later fractures, maintaining joint kinematics, and allowing for glenoid reimplantation in a single or dual stage manner. Based on the limited available data, cases of revision TSA that do not allow for glenoid reimplantation are most reliably treated with glenoid bone grafting followed by glenoid reimplantation at a secondary surgery, if deemed necessary. This review serves to demonstrate the paucity of studies that specifically evaluate the long-term outcomes of the management of glenoid bone loss in revision TSA and underscores a need for high-quality research in this area.

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