# Stemmed Humeral Replacement

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## Introduction

Although the first stemmed humeral replacement, constructed out of platinum and rubber and performed for an indication of tuberculosis, was performed by Péan in 1893, the procedure did not begin to be widely performed until Neer described his results in 1955 [1, 2]. Recently, both humeral hemiarthroplasty and total shoulder arthroplasty have increased remarkably in frequency. Between 1993 and 2008, the number of humeral components placed in the United States increased from 13,837 to 46,951 per year [3]. Given the frequency of placement of a humeral component, a thorough understanding of the surgical indications and goals, design features, techniques, and outcomes associated with the humeral component is critical not only for a shoulder surgeon but also for the general orthopedic surgeon.

## Goals of Humeral Component Design

There are four primary goals in humeral component design. The first is to replicate, as faithfully as possible, pre-injury/pre-deformity anatomy. Numerous biomechanical studies have demonstrated that this provides the highest likelihood for restoration of native kinematics and that differences as small as 4 mm can have marked biomechanical consequences [4–6]. The anatomy and biomechanics of the proximal humerus is covered in detail in Chap. 2. The second is to achieve initial implant stability [7, 8], which allows immediate range of motion, prevents implant subsidence that could lead to malalignment, and is a prerequisite for biologic ingrowth and implant incorporation in cementless designs [9]. The third goal is to achieve long-term implant fixation, thus avoiding aseptic loosening and the consequences of humeral revision [10–13]. These goals are ideally attained while avoiding proximal humeral bone loss via osteolysis and [14, 15] stress shielding [14–16] as these can complicate revision options and potentially lead to periprosthetic fracture [17–19]. The fourth goal relates to ease of extraction in cases of unanticipated need for revision such as infection or loss of rotator cuff function. Ideally, the humeral stem can be extracted with minimal loss of metaphyseal bone to maximize revision options. This final goal highlights the importance of achieving a balance between long-term fixation and ease of potential extraction. A variety of design- and technique-driven strategies are employed to achieve these goals.

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## Humeral Stem Design Evolution

Most strategies implemented to restore humeral anatomy have focused on implant design. Neer's initial humeral component design of a straight stem with fins was based upon his measurements of 50 cadaveric humeri [5]. However, subsequent detailed radiographic and anatomic research has demonstrated that humeral head inclination varies widely [6, 20–22]. Newer designs have thus introduced modularity, primarily at the head/body junction, to increase the options available to the surgeon [4]. Another advance is the introduction of variable head-shaft angles (Fig. 3.1) [20, 21, 23–25]. Components are also available to offer similar variability in version to match the wide variability in proximal humeral version [19, 26–29]. However, it should be recognized that humeral version is primarily determined by surgical technique rather than component design. The center of rotation of the humeral head is offset posteriorly, medially, and superiorly in relation to the humeral shaft and varies from patient to patient. Thus, most modern designs provide a humeral head with an eccentrically placed receptacle for the Morse taper [6, 20, 21, 24, 30], and modern designs also provide variability in humeral head thickness to accommodate individual anatomy [20, 21]. Many early systems were designed without variable inclination, which tends to lead to displacement of the center of rotation superiorly and laterally, resulting in a relative "overstuffing" of the joint [20, 31, 32]. This issue was worsened by the early introduction of modularity combined with overly thick humeral heads, as many designs did not account for the thickness of the collar and the gap between the humeral head

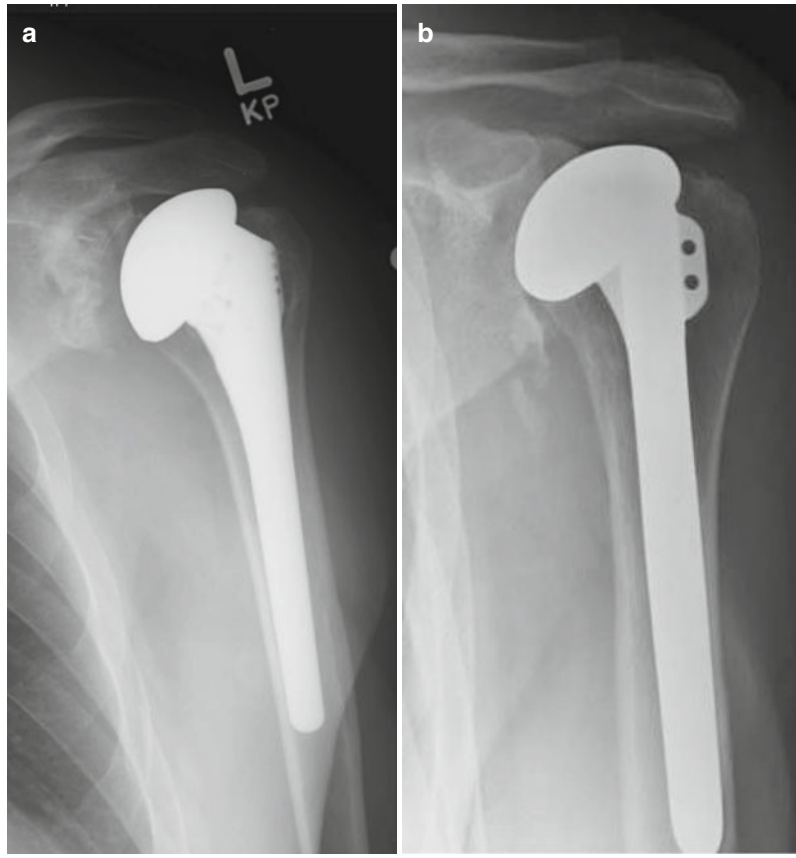


**Fig. 3.1** These anteroposterior radiographs demonstrate two components, (**a**) one with variable offset and inclination and (**b**) one with fixed offset and inclination. As can be seen, the implant with fixed inclination has been placed in varus to attempt to replicate anatomic inclination

and collar [6, 21]. Subsequent biomechanical studies have demonstrated that "overstuffing" decreases range of motion and translation [31, 32] and thus may place more stress through the glenoid component and may lead to increased rates of glenoid loosening [33, 34]. Subsequent designs have accounted for these findings [6]. Finally, degenerative conditions of the glenohumeral joint are associated with contracture and imbalance of the capsule, musculature, and other periarticular tissues. Perfect recreation of pre-deformity anatomy acts only as a supplement to soft tissue balancing. Indeed, in the setting of significant deformity, soft tissue balancing may become even more important to reduce stress placed on the implant, recenter the humeral head, and maximize range of motion [4].

Recently, "platform" stems have been released that provide modularity at both the diaphyseal/metaphyseal junction and the head/body junction, achieving fixation within the diaphyseal region. This potentially allows for revision from a hemiarthroplasty or anatomic total shoulder to a reverse total shoulder arthroplasty without revision of the fixated portion of the humeral component [13]. While these advances offer the surgeon the ability to best replicate the patient's anatomy, each additional modular junction also serves as an additional potential location for component dissociation and component fracture [4]. Increased modularity also serves as a potential location for fretting wear and metallosis, as has been experienced in total hip arthroplasty [35]. Furthermore, the desired version and depth of stem seating may vary between anatomic and reverse total shoulder arthroplasty. Therefore, for accurate and optimal humeral prosthetic positioning using platform stems, the additional modularity should enable the surgeon to adapt to the fundamental differences between ideal implant placements in different arthroplasty designs.

## Indications for a Stemmed Humeral Replacement

A stemmed implant remains the gold standard. A stemmed humeral component is indicated for anatomic total shoulder arthroplasty performed for glenohumeral osteoarthritis [15, 23, 28, 34, 36–41], avascular necrosis [42, 43], inflammatory arthritis [17, 36, 37, 44, 45], and various traumatic conditions [17, 36, 46–48]. Particular indications for a stemmed over a stemless implant include proximal humeral bone loss preventing adequate stemless fixation, poor vascularity of the proximal humeral bone that might compromise long-term fixation, poor biology of proximal humeral bone such as prior radiation that might compromise long-term fixation, and proximal humeral deformity that would prevent anatomic placement of a stemless implant. Particular scenarios where a stemless or resurfacing-style implant may be relatively indicated are the presence of prior proximal humeral hardware that precludes placement of a stemmed humeral component, such as a humeral nail, hardware extending toward the proximal humerus, or a long-stemmed distal humeral component of a total elbow arthroplasty.

## Humeral Fixation Options

Most of the strategies used for initial implant stability have been technique driven. Given that humeral component aseptic loosing is relatively uncommon, it is important to recognize that adequate initial and long-term stability can be achieved with a variety of techniques. In North America, stemmed humeral prostheses remain the gold standard at this point. First method of fixation is to cement the stem, using either a proximal or diaphyseal technique [7, 8, 11, 15, 37, 38, 40, 49–52]. The second is to machine the proximal humerus to be slightly undersized relative to the dimensions of the component, which allows a press fit that provides implant stability via hoop stresses [20, 39]. Within the humerus press-fit fixation may be insufficient – in one retrospective comparative study 49 % of press-fit stems shifted during early follow-up, while no cemented stems shifted [53]. For all modern prostheses, press-fit fixation is combined with osseous ingrowth and on-growth surfaces on the humeral component that provide friction for a "scratch fit" [39, 41, 45, 54–56]. Following Neer's initial designs, many prostheses also

incorporate fins that provide additional initial torsional stability [4, 5]. Finally, many authors have used cancellous bone graft from the humeral head for impaction grafting to improve initial stability and to fill voids that could impede component incorporation [57, 58]. Biomechanical studies have demonstrated that while there is no difference in axial [8] micromotion between cemented and cementless initial fixation, rotational [7] micromotion is decreased in cemented as compared to press-fit stems.

Both implant design- and technique-based strategies have been utilized to maximize long-term humeral fixation. With cementless implants, initial designs led to a 55 % rate of radiographic loosening [52], mirroring the prosthetic design experience in total hip arthroplasty [9]. This problem led to the adoption of biologic on-growth and ingrowth surfaces developed for total hip arthroplasty [9] into humeral component design [45]. Subsequent studies using components of a similar design but with an incorporated ingrowth surface reduced rates of radiographic loosening over fivefold from 55 % to 10 % [55]. These results were achieved despite retrieval studies demonstrating that only 11 % of the ingrowth surface incorporates, with 95 % of the ingrowth occurring at the medial and lateral bone-to-implant interfaces [54].

Another major change in long-term fixation has been a shift in emphasis from diaphyseal to metaphyseal fixation [14, 39], again paralleling the development of taper-wedge stems in total hip arthroplasty [59]. The humeral endosteal diaphysis has an ellipsoid [60], highly variable shape [22] with a proximal to distal torsion [22, 39]. Thus, even with reaming, the diaphyseal portion of the implant has a relatively poor fit and more implant/bone voids in comparison to the metaphyseal region of the component [39]. Comparative studies have demonstrated lower rates of radiographic loosening with metaphyseal compared to diaphyseal fixation for cementless components, which has led to the suggestion that if diaphyseal fixation is required, the component should be cemented [39]. Metaphyseal bone may also be more well vascularized and may thus allow more rapid ingrowth than diaphyseal bone [61].

The use of metaphyseal fixation may also ease humeral stem removal during revision [10–13]. Bone preservation is enhanced as metaphyseal fixation minimizes proximal humeral bone loss from stress shielding [14–16]. Furthermore, access to diaphyseal bone is not needed during revision, which is bone preserving [17]. Metaphyseal fixation may also reduce the incidence and complications associated with periprosthetic fracture while paradoxically increasing the likelihood for intraoperative periprosthetic fractures during implantation [17–19]. A large, diaphyseally fixated stem acts to stress shield the proximal humerus while also acting as a large lever arm and concentrating stress at the tip of the stem [17]. Diaphyseal periprosthetic fractures likely have a lower healing potential than metaphyseal periprosthetic fractures (Fig. 3.2) [61]. Concern for diaphyseal periprosthetic fractures is one reason for the development of stemless implants, which will be covered in more detail in Chap. 5.

The use of cemented versus cementless implants continues to be a source of significant controversy, with each having relative advantages and disadvantages (Table 3.1). Cemented implants can achieve immediate and lasting fixation, overcoming voids, irregularities, and other sources of mismatch between the component and the endosteal surface that could compromise cementless fixation [22, 39]. Cemented components are generally smaller than uncemented stems, which may prevent stress shielding and intraoperative periprosthetic fractures, which can occur with bulkier cementless implants [14]. In cases with significant proximal humeral osseous deficiencies or poor bone quality and ingrowth potential, cement fixation has distinct advantages over cementless techniques [41].

Cemented fixation has several distinct disadvantages. At the time of implantation, cementation is more time-consuming, and it can be technically challenging to achieve good cement technique. Prior cementation substantially complicates subsequent humeral revision [13]. In particular, diaphyseal cementation can make stem removal difficult. In infection cases all prior cement must be removed or it can serve as a reservoir of biofilm-protected bacteria. Attempts at stem or

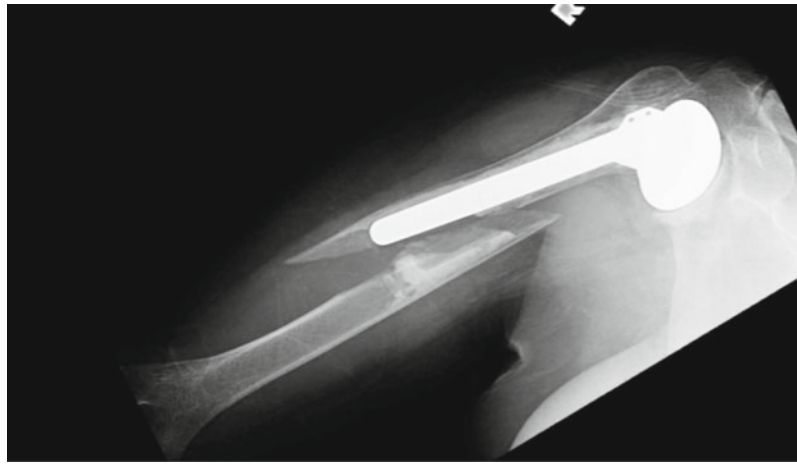

**Fig. 3.2** This anteroposterior radiograph of the right humerus demonstrates a diaphyseal humeral periprosthetic fracture around a cemented, diaphyseally fixated component where stress concentrates at the distal aspect of the component

**Table 3.1** Advantages and disadvantages of cemented and cementless fixation

| Cemented | | Cementless | |
|---|---|---|---|
| Advantages | Disadvantages | Advantages | Disadvantages |
| Strong initial fixation | Time-consuming | Rapid | Stress shielding, radiolucent line formation |
| Can be used in the presence of prior radiation or osteonecrosis | Technically demanding | May ease revision and facilitates component removal | Relies upon a closer match between the component and the humerus, increasing the likelihood for intraoperative periprosthetic fracture |
| Antibiotic-laden cement may provide additional sepsis prevention in cases with prior infection | Complicates revision and may predispose toward iatrogenic humeral fracture | No concern for extrusion in cases with humeral perforation | Possibly decreased strength of initial fixation |
| Supported by randomized clinical trial data | Can extrude through perforations and compromise neurovascular structures | Technically simple | May not incorporate with bone with compromised blood supply or viability |

cement removal can frequently lead to iatrogenic humeral fracture or perforation, especially in osteoporotic bone. Indeed, in one series of 80 cases, removal of cemented humeral stems was the most common cause of intraoperative complications during revision shoulder arthroplasty [11, 13]. In revision settings, in which there may be cortical bone perforation in the humeral canal, cement pressurization can lead to extrusion [11] potentially compromising neurovascular structures, in particular the radial nerve. The introduction of variable inclination components may reduce the need for cementation. With nonvariable designs, surgeons often fill voids created by the mismatch between the optimal prosthetic head location and the optimal stem location with cement as these may differ widely with anatomic variability [6].

## Clinical Outcomes

Overall excellent outcomes have been described for modern humeral components, with low rates of radiographic loosening, symptomatic loosening,

or need for revision (Table 3.2) [14, 15, 34, 36, 37, 40, 44, 49–52, 62]. Indeed, clinical outcomes on the humeral side have been excellent since initial implant designs. For instance, in a 1987 prospective cohort study of 50 anatomy total shoulder arthroplasties with cemented Neer II components followed for a mean of 3.5 years, while 10 % of humeral components had at least one radiolucent line, only one component (2 %) had to be revised for a subsequent humeral fracture [36]. Although humeral component designs have changed substantially in the over 25 years since this report was published, these results are difficult to improve upon. However, although rare, humeral loosening does occur, and revisions for humeral loosening are fraught with complications and should thus be avoided if possible [10, 13]. For instance, when the Mayo Clinic described their experience with 35 revisions performed for loosening of the humeral component in anatomic

**Table 3.2** Outcomes regarding the humeral component in primary anatomic total shoulder arthroplasty from the largest available series with rates of radiographic and clinical humeral loosening

| Study characteristics | | | Implant characteristics | | | Clinical outcomes (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Author (year) | *N* | Mean f/u (years) | M/D | C/U | PF/PC | Radiographic loosening | Symp. loosening | Revision for loosening | Humeral revision |
| Barrett (1987) [36] | 50 | 3.5 | D | 72 % C | PF | 0 | 0 | 0 | 4.0 |
| Sperling (2000) [55] | 62 | 4.6 | D | U | PC | 9.7 | 1.6 | 1.6 | NA |
| Sanchez-Sotelo (2001) [51] | 43 | 6.6 | D | C | NA | 2 | 0 | 0 | 0 |
| Sanchez-Sotelo (2001) [52] | 72 | 4.1 | D | U | PC | 56 | 1.3 | 1.3 | 4.2 |
| Godenéche (2002) [34] | 268 | 2.5 | M | 99 % C | PC | 8 | 0.4 | 0.4 | 2.2 |
| Matsen (2003) [39] | 131 | 2.0 | M | U | PF | 0 | 0 | 0 | 0 |
| Verborgt (2007) [56] | 37 | 9.2 | D | U | PF | 19 | 0 | 0 | 2.7 |
| Khan (2009) [37] | 25 | 10.6 | M | C | NA | 0 | 0 | 0 | 0 |
| Cil (2010) [62] | 1,112 | 8.1 | D | 15 % C | 86 % PC | NA | NA | 1.1 | 9.4 |
| Throckmorton (2010) [41] | 76 | 4.3 | D | U | PC | 0 | 0 | 0 | 0 |
| Litchfield (2011) [38] | 80 | 2.0 | D | C | NA | NA | 0 | 0 | 0 |
| Litchfield (2011) [38] | 81 | 2.0 | D | U | PF | NA | 0 | 0 | 0 |
| Raiss (2012) [40] | 39 | 11.0 | M | C | NA | 0 | 0 | 0 | 0 |
| Owens (2014) [64] | 35 | 6.5 | D | 29 % C | PC | 0 | 0 | 0 | 2.9 |
| Raiss (2014) [15] | 262 | 8.2 | M | 74 % C | PC | 1 | 1 | 0 | 3.8 |
| Cemented weighted mean | | | | | | 2.4 | 0.4 | 0.4 | 4.0 |
| Uncemented weighted mean | | | | | | 3.3 | 0.2 | 0.9 | 6.8 |

Comparative studies have been broken into their comparative groups when possible
*N* number of shoulders, *f/u* follow-up, *M* metaphyseal, *D* diaphyseal, *C* cemented, *U* uncemented, *NA* not applicable/not available, *PF* press fit, *PC* proximal on-growth or ingrowth coating, *Loose* loosening, *Symp* symptomatic

total shoulder arthroplasty, only 71 % satisfactory or excellent results were achieved using Neer's criteria, 23 % of patients had cement extrusions, 17 % of patients had iatrogenic intraoperative humeral fractures, and 11 % of patients required reoperation [10].

The most common reasons for revision of the humeral component are problems on the glenoid side [63] and within the rotator cuff [13], with isolated aseptic loosening accounting for the vast minority of humeral revisions. In a large retrospective series with 1,112 anatomic total shoulder arthroplasties, of the 104 humeral revisions, only 12 (11.5 % of all humeral revisions, 1.1 % of all total shoulder arthroplasties) were performed for humeral loosening, and of these 9 (75 %) were in association with either glenoid polyethylene wear or instability. Therefore, isolated humeral loosening thus only occurred in 0.3 % of cases and accounted for only 2.9 % of humeral revisions [62]. Rates of humeral loosening requiring revision have been similarly low in other series, ranging from 0 % to 1.6 % [15, 34, 36–41, 51, 52, 55, 56, 62, 64]. When data from these series was pooled, the weighted mean rates of humeral loosening requiring revision was 0.4 % for cemented and 0.9 % for uncemented components. The overall humeral revision rates were 4.0 % for cemented components and 6.8 % for uncemented components in these weighted mean averages, again suggesting that issues independent of the humeral component such as instability, glenoid loosening, rotator cuff dysfunction, and infection play the largest role in humeral component revision [15, 34, 36–41, 51, 52, 55, 56, 62, 64]. Of note, given the technical difficulty and high complication rate associated with revision of a cemented stem [13], the improved "survival" of cemented components may reflect the resistance of the surgeon to revise a cemented components [62].

The debate between the use of cemented and cementless fixation of humeral components continues with no clear distinction in outcomes or performance between designs in routine shoulder arthroplasty. A prospective, double-blind, randomized clinical trial comparing cemented and cementless fixation in anatomic total shoulder arthroplasty performed for primary osteoarthritis demonstrated better Western Ontario Osteoarthritis Scores in the cemented group [38]. However, this study was conducted with a fixed inclination, diaphyseally fixated stem instead of a variable inclination, and metaphyseally fixated stem. In addition, there were no differences in other validated measures of shoulder function, shoulder range of motion, or the complication rates or rates of loosening or revision between groups in the short term [38]. As a result, this study remains difficult to interpret given the implants currently available. Many studies suggest that with modern metaphyseal on-growth and ingrowth stems, functional outcomes and survival rates to loosening or revision are equivalent between cemented and cementless fixation [14, 39, 49, 62]. In the largest series to date with 395 anatomic total shoulder arthroplasties with a mean follow-up of 8 years and a minimum follow-up of 4 years with a metaphyseal, on-growth fixation design, no difference could be found between cemented and uncemented stems [15]. The best available evidence for modern stems thus suggests that unless a specific indication exists for one method of fixation, both cemented and uncemented stems can be recommended.

Beyond measuring component survival to revision for symptomatic aseptic loosening, many authors have also described humeral radiographic outcomes with respect to radiolucent lines, stress shielding, and osteolysis. Radiolucent lines are variably described and their clinical significance remains a subject of debate. Generally, radiolucent lines have been classified using Gruen zones translated from total hip arthroplasty, with three medial zones, three lateral zones, one zone at the tip of the component, and one zone for the undersurface of the humeral head with each numbered beginning at the proximolateral aspect of the component [65]. Lines can then be described based upon their thickness and by which zones they involve [41, 51, 52, 55]. While subsidence or change in component position on serial radiographic is almost universally agreed to be a sign of a loose component, whether a threshold degree of severity of radiolucent line formation is also a portent of progressive radiolucencies or aseptic

loosening remains controversial. In cementless components, these lines are most commonly described at or near the tip of the component in zones 3–5, although in diaphyseal fixation designs, they are also common within the more proximal aspects of the component [39, 52]. In cemented designs radiolucent lines are most common in the mid-body and proximal aspects of the component in zones 1–2 and 6–7 [51].

Radiolucent line formation is common, especially in cementless components [50]. In a series of 39 cemented, metaphyseally fixated components followed for a minimum of 10 years, 50 % of components had at least one radiolucent line 2 mm wide, but none were symptomatically loose and none had required revision [37]. Similarly, in a series of 43 cemented, diaphyseally fixated components followed for a mean of 6.6 years, 37 % of components had at least one radiolucent line of at least 1 mm, but no revisions were required. In another series of 131 uncemented, metaphyseally fixated, press-fit components followed for a minimum of 2 years, 57 % of components had a radiolucent line of at least 1 mm in some portion of the component, but none had shifted or subsided and none required revision [39]. In another recent series of 67 uncemented, metaphyseally fixated total shoulder arthroplasties with an on-growth coating followed for a mean of 5.5 years, condensation lines were described around the tip of the stem in 85 % of cases, although no cases of revision for humeral loosening were described [15].

In components with metaphyseal fixation, whether due to isolated proximal cementation or as a result of cementless metaphyseal fixation, distal radiolucent lines likely represent signs of stress shielding, which is of unknown clinical relevance (Fig. 3.3). Other studies have reported stress shielding with cementless components. In one series spot-welds were described in 82 %, and other signs of osseous remodeling were described in 63 % [15]. This phenomenon appears to be more frequent in cementless than cemented designs [14, 15]. Given that the proximal humerus is largely non-weight bearing and that forces are transmitted to most proximal aspect of proximal humerus through the rotator cuff, some authors have theorized that stress shielding may be a consequence of biological abnormalities within the underlying bone and abnormalities within the rotator cuff instead of implant designs [14], which has been supported by a computer modeling analysis [16].

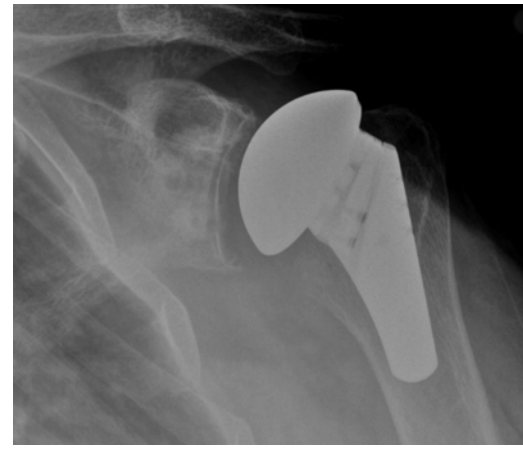

**Fig. 3.3** This anteroposterior radiograph of the *left* shoulder in a patient status-post placement of an uncemented, metaphyseally fixated humeral component demonstrates signs of stress shielding including osteopenia of the calcar, a condensation line at the distolateral aspect of the component, and internal remodeling with trabecular streaming toward the taper of the component

Finally, proximal humerus osteolysis can occur [14, 15] which may predispose patients to periprosthetic fracture [17–19] and complicate revision surgery [10–12]. In the largest series to comment on osteolysis, of the 262 total shoulder arthroplasties followed for a mean of 8.2 years, osteolysis was encountered in 54 % of patients [15]. However, this process appears to be associated with glenoid loosening [15, 62] and thus may be a consequence of an inflammatory response to particulate wear, analogous to osteolysis seen with hip and knee arthroplasty, and not a consequence of humeral component design or implantation technique (Fig. 3.4) [66–68]. Perhaps the strongest argument in favor of the association between osteolysis and polyethylene glenoid wear is the observation that osteolysis does not occur with hemiarthroplasties [15]. One aspect of component design that may, however, play a role in this regard is whether the porous coating is circumferential, as this may “seal” the

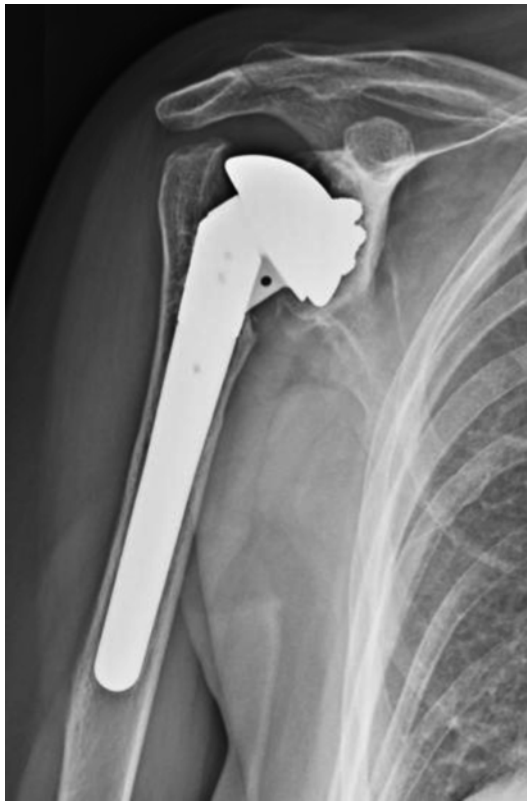

**Fig. 3.4** This anteroposterior radiograph of the *right* shoulder demonstrates a patient with osteolysis and humeral component loosening due to loosening of a metal-backed glenoid component

distal aspect of the component from wear debris and may thus reduce distal osteolysis [69]. Some authors have theorized that the inflammatory response to wear debris may explain almost all cases of "isolated" humeral loosening – in one report a case of "isolated" humeral loosening retrieval analysis demonstrated a giant cell foreign body reaction to wear debris at the bone-component interface [63].

## Technical Tips and Pearls

Based upon the current best available evidence, several technical tips and pearls can be provided. Recreation of the pre-injury/pre-deformity humeral articular anatomy provides the best chance for normal glenohumeral kinematics. Even small deviations from normal anatomy can significantly alter glenohumeral kinematics. The anatomy of the proximal humerus is highly variable, and the primary goal is to implant the humeral component in a position allowing for humeral head positioning that recreates the articular anatomy. Thus, whenever possible, the surgeon should avoid a "one-size-fits-all" approach.

Preoperative planning is important, and failure to do so may result in both intraoperative and postoperative complications. Several factors must be considered in choosing a humeral stem system that can both recreate the anatomy and provide durable fixation, including individual variation in proximal humeral anatomy, bone quality/bone loss, posttraumatic deformity, previous surgery, and potential for future rotator cuff dysfunction, as occurs in the setting of inflammatory arthritides. Preoperative templating helps to judge the size and position of components in relation to the patients' size and anatomy and to determine if a given system can achieve the operative goals. When templating, magnification must be accounted for when using standard plain films. If a diaphyseally fixated component is chosen, it is important to realize that the diaphysis humeral endosteum is, on average, 20% smaller from anterior to posterior than it is from medial to lateral, and thus templating solely on the anteroposterior view will cause the surgeon to systematically overestimate the component size [60].

For uncomplicated glenohumeral arthritis, both cemented and cementless designs provide both reliable and durable results. In general, cementless designs are ideally indicated in younger patients, those with good metaphyseal bone quality and in primary surgery. Cemented implants are ideal in cases with poorer bone quality, a very large endosteal diaphyseal canal, revision surgeries with bone loss, and when aberrant proximal humeral anatomy is encountered. Platform systems may be idea in cases with higher risk of future cuff dysfunction such as inflammatory arthritis. In cases with either mismatch between humeral anatomy and the prosthetic humeral component, consider cemented fixation or impaction grafting. Components with greater modularity, variability, and metaphyseal fixation can also assist in achieving this goal, while monoblock, diaphyseally fixated components make this

goal harder to achieve. Consider the use of a long-stemmed prosthesis in cases with an exceptionally large canal or with significant metaphyseal/diaphyseal bone loss. A recent series of long-stemmed primary total shoulder arthroplasties demonstrated excellent outcomes and no humeral loosening, suggesting that when necessary use of a long-stem does not negatively impact the patients outcome [64].

The surgical approach to humeral preparation will vary depending on the chosen system and the experience of the surgeon. If a cementless humeral component is preferred a smaller lesser tuberosity osteotomy should be considered to avoid compromise of the anterior metaphyseal bone. The frequently encountered anatomic neck osteophytes should be removed to define the anatomic neck prior to making the humeral head osteotomy. Systems with fixed inclination angles often provide cutting guides based on an endosteal diaphyseal reamer to recreate the inclination angle, while systems with variable angles of inclination allow a freehand cut to replicate the patients' anatomy. The version of the humeral osteotomy should be angled to recreate the patient native retroversion angle, except in cases of humeral head subluxation where a correction may be preferred. For cemented implants, over-reaming slightly compared to the chosen diameter of the implant improves the cement mantle, although the optimal mantle thickness in the humerus is unknown. For cementless implants, careful broaching of the metaphysis can prevent intraoperative fracture. If soft metaphyseal bone or gaps are encountered, impacting grafting or conversion to a cemented implant should be considered. Consider leaving a trial in place when performing glenoid preparation to avoid retractor damage to the metaphyseal bone. Finally, a trial of humeral component stability should be considered after glenoid placement but prior to final humeral component placement if there are concerns for instability or subluxation.

Regardless of the implant selection or technique, the surgeon must be aware that long-term complications related to the humeral component are rare, and often those issues that do arise are usually related to the glenoid component, and thus in those cases where "isolated" humeral loosening is suspected as the cause of failure, the surgeon must search for other potential causes of failure and should be prepared for a full revision.

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