The glenoid in total shoulder arthroplasty

Mark Schrumpf · Travis Maak · Sommer Hammoud ·
Edward V. Craig

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Abstract Management of glenohumeral arthrosis with a total shoulder prosthesis is becoming increasingly common. However, failure of the glenoid component remains one of the most common causes for failure. Our understanding of this problem has evolved greatly since the first implants were placed in the 1970's. However glenoid failure remains a challenging problem to address and manage. This article reviews the current knowledge regarding the glenoid in total shoulder arthroplasty touching on anatomy, component design, implant fixation, causes of implant failure, management of glenoid failure and alternatives to glenoid replacement.

Keywords Total shoulder arthroplasty · Glenoid component · Hybrid glenoid · Radiolucent lines · Glenoid loosening · Glenoid component failure

Introduction

Shoulder arthroplasty dates back to 1893 when Jules-Émile Péan, a French surgeon, implanted a platinum and rubber prosthesis to replace a glenohumeral joint that had been

destroyed by tuberculosis [1]. Very little progress was made in design and function until 1951 when Charles Neer developed an unconstrained Vitallium prosthesis for the treatment of proximal humerus fractures [2, 3]. Over time Neer sought to develop a shoulder prosthesis that would also afford patients with glenohumeral arthritis pain relief and introduced a glenoid resurfacing component.

Influenced by the success of total hip arthroplasty, Neer developed the first modern total shoulder prosthesis, the Neer II (Smith & Nephew, Memphis, TN). The Neer II was introduced in 1974 and consisted of a redesigned humeral component and an all-polyethylene glenoid resurfacing component. Over 70 different shoulder prosthetic systems have been developed since the introduction of Neer's initial design in 1974.

Indications for shoulder arthroplasty currently include severe proximal humeral fractures, primary glenohumeral osteoarthritis, post-traumatic arthritis, shoulder girdle tumors, osteonecrosis, and failed shoulder arthroplasty. Although Charles Neer's original prosthesis underwent several modifications, the Neer type humeral component has largely persisted [2, 4–10].

Native glenoid anatomy

Anatomic parameters of the glenoid relevant to prosthesis design and placement include glenoid height, width, inclination, and shape, and version. The considerable natural variability in these parameters, as demonstrated in cadaveric studies, affects prosthesis design, instrumentation, and intraoperative implantation techniques.

The normal glenoid cavity is shaped like an inverted comma, with a narrow upper superior field (the tail of the comma) and a broad inferior field (the head of the comma)

M. Schrumpf (✉) · T. Maak · S. Hammoud · E. V. Craig
Hospital for Special Surgery,
535 E 70th St.,
New York, NY 10021, USA
e-mail: schrumpfm@hss.edu

T. Maak
e-mail: maakt@hss.edu

S. Hammoud
e-mail: hammouds@hss.edu

E. V. Craig
e-mail: craige@hss.edu

[11]. Glenoid height is defined as the distance from the most superior and inferior points on the glenoid where as width is the distance from most anterior to posterior points. Mean glenoid height has been reported to range from 35.1 to 39 mm [12–15]. Churchill et al. and Mallon both reported on gender differences in glenoid size with Churchill concluding that there is an average difference of 4.9 mm while Mallon concluded that the difference is only 1.8 mm [16, 17]. Iannotti et al. reported a mean upper glenoid width of 23 mm (range, 18–30 mm) and a mean lower glenoid width of 29 mm (range, 21–35 mm) [14]. Other authors have reported widths ranging from 28.3 mm to 23.6 [13, 16, 17].

Glenoid version is defined as the angular orientation of the axis of the glenoid articular surface relative to the long (transverse) axis of the scapula. Churchill et al. reported that on average the glenoid has 1.2° of retroversion (range, 9.5° anteversion–10.5° retroversion), while Saha noted that 75% of shoulders had retroverted glenoids and 25% were anteverted [16, 18].

Patho-anatomy

Glenoid wear frequently accompanies glenoid arthritis. Walch et al. classified the various glenoid wear patterns in the arthritic glenoid [19]. Posterior subluxation of the humeral head was observed in 45% of the cases. The main glenoid types were defined as Types A, B, and C. Type A (59%) features a well-centered humeral head with symmetric erosion and the absence of humeral head subluxation. Type B (32%) is characterized by posterior humeral head subluxation with a posterior glenoid wear pattern. Type C (9%) was defined by glenoid retroversion of more than 25°, regardless of erosion.

Cofield and Matsen have described posterior glenoid wear with varying degrees of posterior subluxation of the humeral head as the most common pattern of glenoid wear for primary osteoarthritis [20, 21]. An internal rotation contracture often develops as the condition progresses increasing contact of the humeral head with the posterior aspect of the glenoid. Posteriorly worn glenoids are also associated with posterior instability [4, 20, 22, 23].

Glenoid involvement varies with respect to the type of arthritic process affecting the glenohumeral joint [20, 21]. Inflammatory arthritis is often associated with central, symmetric glenoid erosion, which may be accompanied by cysts within the glenoid vault [20]. Anterior glenoid erosion may also be encountered, but is much less common. Assessment of extent and location of glenoid wear should be done preoperatively with axillary radiographs, axial CT scans, and 3D CT reconstructions.

The techniques generally used to address nonconcentric glenoid wear include eccentric anterior reaming of the

glenoid or the use of bone grafting to correct glenoid version and improve fixation. Augmented glenoid designs have also been proposed [24]. In order to assess the amount of correction that can be achieved with eccentric anterior reaming, Gillespie et al. conducted a cadaveric analysis of 8 specimens [25]. They found that anterior reaming to correct a posterior defect of 10° resulted in a significant decrease in glenoid diameter (26.7 ± 2.5 mm to 23.8 ± 3.1 mm, $p=0.006$). Furthermore, after correcting for 15° of posterior bone loss, placement of a glenoid prosthesis was not possible in 50% of the specimens. Their results led them to recommend bone grafting with defects requiring more than 10° of anterior correction [25]. Clavert et al., in a similar study, concluded that glenoid retroversion of 15° or more cannot be satisfactorily corrected simply by reaming to lower the anterior edge of the glenoid and restore neutral version when using a glenoid component with peripheral pegs [26].

Management of the glenoid

When the decision has been made to replace or resurface the glenoid many choices remain about the best means to achieve long-term pain free shoulder. The anatomy of the glenoid vault makes achieving stable fixation a challenge even in the best circumstances. Implant loosening continues to be a common problem. The options on how to address the glenoid range from biologic solutions to ream and run to polyethylene and metal components. Most traditional total shoulder designs rely on some combination of polyethylene and metal. In the following sections we will review some of the major factors in implant design and placement.

Component types

There are two major shapes for glenoid component that are currently available—anatomic and oval. There are minimal data demonstrating performance for either type, while both have theoretical advantages. An anatomically shaped glenoid simulates the normal, pear-shaped glenoid. The theoretical advantage of this component design is to avoid internal impingement of soft tissues on the polyethylene component. Nevertheless, this pear shape also reduces the contact surface area and may increase the risk of dislocation [27]. The oval design, on the other hand, mimics the arthritic glenoid and theoretically utilizes the pathologically enlarged glenoid to maximize articular surface area. The increased superior wall height may decrease the risk for dislocation [28, 29].

Glenohumeral implant conformity

Conformity of the glenohumeral total shoulder articulation has significant impact on the biomechanics of the joint, specifically loading and stability. The degree of conformity is directly related to the relative matching the surface of the glenoid and humeral head components. An equal convexity and concavity will result in a humeral head position that is directly dictated by compression into the glenoid concavity [21, 30]. The conforming design has the theoretical advantage that it more evenly distributes load to the glenoid. However, this compression constrains the humeral component such that translation cannot occur without glenohumeral separation and edge loading of the glenoid [31]. A number of authors have suggested that a glenoid radius of curvature greater than that of the humeral component (“radial mismatch”) may decrease the risk of glenoid loosening [28, 31–37], [38•]. Nho et. al. reported on a retrieval study comparing conforming and non-conforming glenoid components where they showed a loosening score of 3.2 in the conforming group compared to 2.4 in the non-conforming group [38•]. This reduced loosening may be due to a reduction in edge loading.

However a balance must be achieved between over- and under-conforming articulations, as prior data have documented increased polyethylene wear, fracture and decreased joint stability with minimally conforming designs [31]. Walch et al. evaluated radiolucent lines and Constant scores in 319 TSAs with four different radial mismatch groups [31]. The groups studied were: <4 mm, 4.5–5.5 mm, 6–7 mm, and 7–10 mm. The fewest radiolucent lines were seen in the 7–10 mm group and the highest mean Constant scores were documented in the 6–7 mm group. These data led the authors to conclude that the optimal radial mismatch both clinically and radiographically is 6–7 mm.

Component fixation

The techniques that have been described to fix the glenoid component include cemented all poly components with keels and pegs, metal backed components with and without in-growth designs, screws and finally hybrid designs that use both cemented poly and in-growth metal [39]. No one single fixation modality has become the standard method, reflecting the continued interest in developing a more durable construct with greater implant longevity.

Clinical results for glenoid replacement

Optimizing component design has been extensively studied through many retrospective studies. The experience of the

Mayo Clinic was recently reviewed for six different of implant designs placed at the same institution over 20 years [40••]. These included the Neer II all poly, Neer II metal-backed, Cofield I metal backed in-growth (Smith & Nephew, Memphis, TN), Cofield I all poly, Cofield II all poly keeled and Cofield II all poly pegged (Smith & Nephew, Memphis, TN). One hundred twenty-five shoulders were revised due to glenoid failure. Survival rates for the different designs ranged from 95% to 67%. The authors concluded that glenoid component type was significantly associated with revision. The poorest survival seen for the Cofield I metal backed components while the best results were seen with the all Poly Neer II.

In another comparison between metal backed implants and all poly keeled components Boileau et al. performed a prospective randomized controlled study using the same system with two different glenoid designs [41]. Forty shoulders were randomized to keeled vs metal backed designs with expansion screws. At 3 year follow up the authors documented a 20% failure of the metal group vs 0% in the keeled group. Additional studies have also found troublingly high rates of both clinical and radiographic failure for metal backed components. Taunton, et al. studied metal backed glenoid components with a mean 9.5-year follow-up. The documented five-year survival of 79.9% and ten-year survival of 51.9% led the authors to raise significant concerns regarding the use of metal backed, non-cemented glenoid components [42•].

Alternatively, better results have been reported for some metal backed designs. Specifically, Clement et al. showed a 91.7% 5 year survival and a 89% 10 year survival in rheumatoid patients using the Bio-modular (Biomet Warsaw, Indiana) implant [43]. They posited that the use of a screw construct, a fully coated bone in-growth surface at the bone interface and a low profile tray were critical factors in their improved survival. Likewise Castagna reported promising results in a series of 35 glenoids stabilized with screws and a large hallow central peg with a bone in-growth surface [44]. They had no patients who needed revision of their glenoid components during their follow up.

Cemented all poly designs

The experience with metal backed designs can at best be described as mixed. An alternative to metal backed designs is a traditional all poly cemented design. This style of glenoid implant has been used for many years with good clinical success. The first total shoulder arthroplasty implanted by Dr. Neer in the early 1970's used an all poly keeled cemented component. He observed no loosening of the glenoid component; though he only had 37 months of

follow up and he observed 30% rate of lucent lines the majority of which were seen on the initial post operative x-rays [4]. Similar results have been shown by Cofield who showed 19.2% of glenoids 2 weeks after implantation had lucent lines and an additional 31.5% develop in the first 2 months [5].

Gartsman et al. prospectively compared pegged and keeled components and documented periprosthetic radiolucency in 39% of keeled components, as compared to only 5% of pegged components at 6 week follow-up [45]. Moreover, the extent of radiolucency was greater with the keeled components. Prior two-year follow-up data has demonstrated that keeled components experienced significantly increased translation and rotation, as compared to pegged components [46].

In addition to pegs and keels component fixation is also influenced by the geometry of the glenoid component-bone articulation. Flat and curve-backed cemented components have been studied in this regard. Two-year follow-up radiographic data from 66 TSAs documented optimal component seating in 65% of curved back, as compared to 26% of flat-back components [47]. Moreover, at final follow-up, increased radiolucency was documented in flat-backed components. These data were further substantiated by laboratory and finite element analyses that documented both reduced distraction and peak strains with curved-back glenoid components [22, 32].

One explanation for the observed early radiolucency has been offered by Churchill. They posit that the heat generated with the exothermic reaction during the curing of polymethylmethacrylate cement is responsible for bone necrosis [48]. They showed that during curing of the cement that the temperature reached an average of 64.7° Centigrade. These observed temperatures were well in excess of the 56° Centigrade known to cause bone necrosis.

An alternative explanation for the lucency is cementing technique. “Modern” technique has been shown to improve radiographic results but the exact definition of modern technique remains somewhat unclear. A number of authors including Norris, Miletic and Kasten have all written on the “modern” technique for fixation though there is considerable variation in what that means [49–51]. Common elements to modern technique include lavage and drying of the vault and cement pressurization into the glenoid with a syringe [52].

Hybrid glenoid

As an alternative to either a metal backed component or an all poly cemented glenoid the senior author (EVC) prefers to use a hybrid glenoid. Hybrid fixation is a combination of the two main forms of fixation, cemented and metal backed

in-growth [39]. Our preferred component for primary osteoarthritis uses 3 outer pegs with a porous titanium in-growth central peg [See Fig. 1]. We believe that this design combines the benefits of a cemented all poly pegged construct with multiple points of immediate fixation that resist shear forces and the feature of long term incorporation with an in-growth metal peg. We feel that with good incorporation of the porous central peg the issues that have been observed with osteolysis and loosening over the long term will be avoided. Additionally, the outer cemented pegs with their ability to immediately resist shear forces allow for a stable environment where solid bony incorporation can occur along the central in-growth peg. Preliminary data from this glenoid has shown improved clinical scores for both UCLA and SST, and range of motion at 2 year follow up on 54 shoulders [53]. Further along the central bone in-growth peg there were no lucencies greater than 1 mm [53]. All of the titanium porous in-growth implants showed radiographic evidence of incorporation by 1 year [53]. Finally, at 2 year follow up no patients showed either clinically significant or progressive lucency though longer follow up is clearly needed [53].

One additional author has published on a glenoid component which also uses a combination of minimal cement and biologic incorporation. Their implant uses radial fins on the central peg that are packed with bone graft from the glenoid reaming and peripherally cemented pegs [54]. They used CT scans to evaluate the bone implant

Fig. 1 Preferred glenoid implant of the senior author (EVC) using a titanium porous ingrowth central peg with 3 outer pegs fixed with cement. Radiograph shows incorporation of the central peg at 2 year follow up

interface in 35 patients, they were able to show bone between the fins in a six compartments in 23/35 shoulders and on average 4.5/6 compartments had bone. By plain radiographs the mean Lazarus radiolucency scores were 0.45 at 43 months. A similar study with promising results was also recently reported by Churchill with 5 year follow up, though CT scans were not used to evaluate the bone implant interface [55]. The use of minimally cemented glenoid components with some form of in-growth potential is an exciting trend in glenoid fixation. We will have to await more data before the efficacy of this hybrid concept can be fully determined.

Long term complications

Glenoid failure can be broken down into a number of distinct categories. These include component failure, inadequate seating the component, failure of fixation, and osteolysis. Glenoid loosening can drive many symptoms including increased pain, decreased shoulder function and may eventually lead to the need for revision surgery. Loosening occurs in as many as 96% percent of implanted glenoids if we assume that lucent lines are indicative of loosening [39]. The rate of revision due to symptomatic loosening is significantly lower, however the rate is still troublingly high with published rates as high as 13% [40•].

Component failure is typified by changes in the poly portion of the component after implantation. These changes include pitting and third body wear which has been shown to be associated with osteolysis [56]. Additionally, cold flow and wear contribute to the thinning and eventual failure of the poly in the glenoid components [57]. Catastrophic failure of the poly can occur from these processes though they are more commonly associated with sterilization by radiation in air [58].

When the bone stock of the glenoid has not been adequately prepared or when the component fails to fully seat on the surface the risk of micromotion, fatigue and eventual clinical loosening is significant. It has been shown that when the surface has been prepared thoroughly and the component seats the risk of wobble and warp are minimized [29]. In a clinical series of 328 glenoids Lazarus showed that 1/3 were poorly seated. Further they showed that the keeled implants seated more poorly than the pegged versions [59].

Matsen has popularized the concept of “the rocking horse glenoid” phenomenon which is believed to be a significant source of glenoid loosening [60]. The phenomenon is caused by eccentric loading on one edge of the component causing the opposite edge to lift off the glenoid bone. This mechanism is thought to lead to loosening in the setting of rotator cuff tears as well as component mal

positioning. Component positioning primarily varies in a superior-inferior dimension such that placement of the glenoid or humeral components in suboptimal positions may increase the risk of glenoid edge loading and the resultant “rocking horse” phenomenon. Farron reported on a finite element analysis that lends credence to Matsen’s rocking horse theory [61]. They showed that glenoid retroversion lead to a 700% increase in micro-motion and a 326% increase in stress at the bone-cement interface compared to neutrally oriented components. Hopkins also reported on a finite element analysis examining the role of implant position on stability. Those implanted centrally had the lowest potential for failure. Where as those implanted superiorly or inferiorly inclined have the greatest potential for failure [62].

Rotator cuff insufficiency also leads to eccentric loading and the rocking horse phenomenon. Anteroposterior eccentric loading can occur with massive subscapularis ruptures, or more commonly, failure of the operative repair of the subscapularis [63–65]. Massive supraspinatus and infraspinatus insufficiency can produce superior migration of the humeral component producing a relative malpositioning and eccentric loading of the glenoid [9, 29, 32, 60, 66, 67].

In addition to poor seating, eccentric loading, and failure of the poly, resorption of the bony support for the glenoid also leads to implant failure. As has been well documented, radiolucent lines are commonly seen at the bone cement interface in many glenoid components [39, 40•, 42•, 44, 48, 50, 51, 54, 55, 57, 60, 62]. The postulated causes of this bone loss are motion, heat induced necrosis, and infection. Kepler has shown that osteolysis is most associated with screw fixation of the glenoid component and third body wear [56]. When the loss becomes extreme it may result of the loss stability of the glenoid component.

Predictors of failure

Some authors have isolated predictive factors that lead to glenoid failure. In one series of mid to long term follow-up Fox et. al. were able to show that in addition to specific implants with poorer track records, male gender, and post-traumatic or avascular necrosis (as opposed to degenerative arthritis) lead to increased rates of revision [40•]. In their multiple regression analysis male gender had a hazard ratio (HR) of 2.2, post-traumatic arthritis had a HR of 1.8 and avascular necrosis had a HR of 2.7. Additionally, it has been observed that patients with deficient rotator cuffs have increased rates of glenoid failure, as well as glenohumeral instability [57, 60]. One final group of patients who are observed to have increased rates of failure are those patients who rely on their upper extremities for ambulation (through the use of a cane or crutches) [57].

Managing a failed glenoid

When deciding to attempt to manage a loose glenoid, one has a number of choices which range from arthroscopic removal of the component to complete revision with structural allograft of the glenoid vault. The least invasive option is to remove the glenoid component via arthroscopic methods. When the component is frankly loose it can be extracted through an enlarged anterior portal [68, 69]. The component can be removed whole or morialized. In some cases removal of the loose component can adequately address the symptoms. As Antuna described in their 4.9 year follow up of shoulders that underwent revision glenoid surgery, 66% of patients had satisfactory pain relief with removal alone [63]. However this same study also revealed a greater rate of success in those patients who underwent reimplantation where the authors observed 86% pain relief. Raphael et al. addressed a similar series of patients with symptomatic loose glenoid components [69]. They noted that while functional scores were slightly higher in the reimplantation group, patient satisfaction was equally high in both the resection and reimplantation groups.

Prior to placing a new glenoid component the remaining vault must be accessed. This is best accomplished via a CT scan with 3-D reconstructions [70]. If there is inadequate bone, grafting can be performed with cancellous graft in a two stage procedure as described by Cheung [71]. If there is a large cavitory defect with loss of the wall of the glenoid vault a structural allograft is likely indicated where bulk femoral head is contoured to the defect [72]. It is necessary to use these structural grafts when the wall is compromised as cancellous graft cannot be contained in these cases.

Clinically a number of authors have all found that reimplantation of a glenoid component provides superior results to resection of the failed glenoid component alone [63, 69, 71, 73]. The improvements include greater relief of pain and increased external rotation.

Other resurfacing options

Significant challenges exist in the setting of poor glenoid bone stock or glenohumeral arthrosis in young patients. In these settings, placement of a prosthetic glenoid component may not be a favorable option. Fortunately, other resurfacing options exist including the “ream-and-run” procedure and biologic resurfacing.

Ream-and-run procedure

Concentric reaming of the glenoid to a radius of curvature of 1 to 2 mm greater than the prosthetic humeral head

component has been termed the “ream-and-run” procedure [74]. This concentric reaming is designed to re-contour the glenoid to improve glenohumeral stability and reduce the eccentric erosion and subsequent instability that has been previously associated with isolated humeral hemiarthroplasty [75]. Prior data has documented healing and glenoid remodeling potential following the ream-and-run procedure [76]. In addition, cadaveric model biomechanical data demonstrated increased glenohumeral stability following the ream-and-run procedure, as compared to a glenoid with denuded articular cartilage [77]. While some data suggest favorable outcomes following this procedure, in the current authors’ opinion, this procedure should be reserved for use only in the setting of salvage, as results that have been reported for the short and mid term have been inconsistent.

Biologic resurfacing

Biologic resurfacing has been employed primarily in the setting of younger patients. Many different types of interposition graft resurfacing have been attempted including joint capsule, fascia lata, Achilles tendon allograft, lateral meniscal allograft, and processed human dermis (GraftJacket, Wright Medical Ltd, Arlington, TN, USA) [78]. These methods are used in concert with placement of a humeral hemiarthroplasty in an attempt to eliminate both the high failure risk of the glenoid component in TSA and the poor or inconsistent outcomes that have been associated with hemiarthroplasty alone [79, 80].

Long term follow-up data with mixed interpositional graft types demonstrated excellent, satisfactory and unsatisfactory results in 18, 13 and five out of 36 shoulders, respectively [81]. The authors identified re-injury, infection, and use of capsule as interposition material as the causes of unsatisfactory results. Additionally, they identified Achilles tendon allograft as leading to excellent to satisfactory results. Additional data using lateral meniscal allograft resurfacing has documented improvements in ASES scores from 38 to 69 at eighteen-month follow-up [3]. However a 17% revision rate was documented in the first post-operative year. Savoie et al. documented statistically significant improvements for young patients with arthroscopic glenoid resurfacing with the Restore patch (Restore, DePuy Orthopaedics, Warsaw, IN, USA) at three to six-year follow-up [82]. Other data from capsule, fascia lata and Achilles tendon interposition grafts demonstrated ASES mean improvement scores from 39 to 91 at a mean seven-year follow-up [81]. Similar to prior studies, anterior capsule interposition graft was associated with poor results [22, 83]. These data led the authors to recommend Achilles tendon allograft as the best option.

Elhassan et al., however, studied 13 patients with a mean age of 36 years, 11 of which were treated with Achilles tendon allograft glenoid resurfacing [84••]. 77% of patients required revision to TSA at a mean of 14 months due to pain and decreased range of motion. Therefore, these authors concluded that Achilles allograft glenoid resurfacing was not a reliable method of treatment in the young, active patient. It is also the senior authors' (EVC) experience that biologic glenoid resurfacing does not produce satisfactory outcomes and thus primary resurfacing of the glenoid should be performed whenever possible.

Conclusion

Arthrosis of the glenoid continues to offer challenges to the treating surgeon. The glenoid with its variable anatomy, minimal bone stock and inherent instability makes addressing the glenoid one of the most difficult procedures in orthopedics. The continuing evolution of implant design offers the hope that we will be able to achieve a stable, long lasting and predictable solution to glenoid resurfacing for patients of all ages. In the mean time understanding and managing failed glenoid components provides the shoulder surgeon with challenges that continue to fuel future implant design.

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