Curr Rev Musculoskelet Med (2016) 9:23–29
DOI 10.1007/s12178-016-9314-2

SHOULDER ARTHROPLASTY (G ATHWAL, SECTION EDITOR)

The arthritic glenoid: anatomy and arthroplasty designs

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Published online: 23 January 2016

Abstract The number of shoulder arthroplasty procedures has increased dramatically in recent years, with the primary indication being osteoarthritis (OA). Thus, morphology and subchondral bone changes associated with OA may be important factors to consider when choosing a replacement component. For surgical treatment, many implant options exist and survivability is often dependent on patient age, activity level, and progression of OA. In the placement of these replacement components, patient-specific guides now exist to improve component positioning, with the goal to improve long-term survivability by ensuring that intra-operative placement meets component design.

Keywords Glenohumeral · Osteoarthritis · Biconcave · Glenoid erosion · Type B2

This article is part of the Topical Collection on *Shoulder Arthroplasty*

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Introduction

Shoulder arthroplasty procedures have been shown to reduce pain and improve joint function when non-surgical options have been exhausted [1, 2]. The primary indication for anatomic total shoulder arthroplasty is glenohumeral osteoarthritis (GHOA) [3•], with secondary indications including inflammatory arthritis and post-traumatic arthritis. A retrospective study of hemi-arthroplasty and total shoulder arthroplasty (TSA) performed in the USA from 1993 to 2008 found GHOA as the primary indication for both hemi-arthroplasty and TSA procedures (hemi 44 %; TSA 77 %) [4]. A systematic review of 3853 TSAs performed between 1976 and 2007 also found GHOA to be the primary indication in 74 % of cases [3•].

The prevalence of shoulder replacements has been seen to have a dramatic increase in the past two decades [4, 5]. Additionally, with an ageing population and the typical age of patients ranging from 65 to 84 years [4], the prevalence of revision surgeries is also projected to increase dramatically [5]. The cost of revision surgery is much greater than that of a primary procedure and is associated with increased risks due to advanced age, potential for infection, and poor bone quality, resulting in a significant burden on health-care systems. Improving the survivorship of shoulder replacement components could dramatically reduce this burden.

A particularly difficult problem to treat in GHOA is glenoid bone loss. In cases of acquired bone loss, anatomic total shoulder arthroplasty may be conducted in association with bone grafting or with the selection of an augmented glenoid component [6•]. Understanding the pathoanatomy of glenoid bone loss due to GHOA and the post-operative biomechanics of the available implant solutions may assist with improving our understanding of implant survivability.

Glenoid bone loss

Cartilage degradation and bone remodelling in osteoarthritis, with associated soft tissue alterations, are believed to lead to glenoid bony erosion. This results in pain and loss of joint function due to bone-to-bone contact and osteophyte formation. It is unknown whether soft tissue abnormalities lead to the progression of osteoarthritis (OA) or if OA and the associated joint inflammation lead to soft tissue changes. At the time of arthroplasty, static subluxation of the humeral head is frequently observed, which increases the complexity of the procedure [7, 8]. A static subluxation is usually identified with a shift of the articulation, which implies an alteration of normal joint kinematics and contact forces, which leads to glenoid morphological changes characterized by wear and subchondral bone remodelling.

Glenoid morphology

Walch et al. classified glenoid erosion into five types (A1, A2, B1, B2, and C) based on erosion morphology [9•]. Types A1 and A2 classify symmetric glenoid erosions to minor and major degrees, respectively. Type B1 exhibits subluxation with a narrowed joint space but without bone loss. Types B2 and C refer to glenoids with posterior (asymmetric) bone loss, with type C being a dysplastic glenoid retroverted more than 25° [9•]. Walch type B2 biconcave glenoids are further characterized as having two articular facets: the posterior *neoglenoid*, which represents the region of new glenohumeral contact, and the anterior *paleoglenoid*, the remaining anterior native glenoid articular surface [10•, 11].

The B2 arthritic triad (glenoid biconcavity, acquired glenoid retroversion, and humeral head posterior subluxation) presents one of the most challenging and controversial osteoarthritis patterns when managed with joint replacement [12•, 13]. The recent literature has suggested that in these biconcave asymmetrically eroded glenoids, maximum bone loss occurs in a posteroinferior direction with the erosion being directed towards the 8 o'clock position in a right shoulder [14–17]. The surgical options in these cases include hemi-arthroplasty, eccentric reaming, glenoid bone grafting, augmented glenoid components, or reverse shoulder arthroplasty [6•, 12•]. Eccentric reaming with a standard glenoid component aims to restore the native glenohumeral joint position by reaming down the anterior non-eroded 'high side', approaching the level of the neoglenoid, in order to achieve full backside contact of the component. This results in a reduction of available bone stock and medializes the native surface. In an effort to preserve a glenoid bone stock, implant manufacturers have developed glenoid components augmented with deeper posterior backsides, adapted to characteristic B2 morphology (Fig. 1).

Recent clinical [19•, 20, 21], experimental [22–26], and computational [27–31] studies addressing asymmetric posterior glenoid erosion have focused on eccentric reaming and/or retroversion correction. It has been suggested that retroversion correction greater than 15° cannot be achieved with eccentric reaming alone [26, 32]. When correcting version using eccentric reaming, bone grafting, or augmented glenoid components, it is important to recognize the degree of component medialization required for full backside contact of the glenoid component. In order to accommodate the design of some augmented glenoid components, glenoid vault peg perforation may occur [29, 30]. Perforation may also occur when using standard components with eccentric reaming in patients with large degrees of acquired retroversion and may be one contributing factor to the reported maximum version correction. Peg perforation, however, may not be the most relevant clinical endpoint as it does not necessarily portend a poor outcome.

Although retroversion correction is often the main focus in the management of arthritis-related glenoid erosion, the degree of inclination correction for normal joint function and component stability is also important. A relatively large number of studies have addressed the improved accuracy of retroversion measurements using 3D versus 2D techniques [30, 33–35]; however, few studies have addressed 3D measurements of glenoid inclination. Habermeyer et al. [36] presented a glenoid inclination classification system based on the degree of inclination observed in 2D radiographs. All types are relative to 'the coracoid base line' (a vertical line drawn from the lateral aspect of the coracoid). Type 0 refers to a glenoid inclination line parallel to the coracoid base line, type 1 the coracoid base line and glenoid inclination line that intersect below the glenoid rim, type 2 the coracoid base line and glenoid inclination line that intersect between the inferior and centre aspects of the glenoid, and type 3 the coracoid base line and glenoid inclination line that intersect above the coracoid base. This classification system is useful in determining the degree of inclination correction to reduce the potential for glenoid component loosening due to 'the rocking-horse effect' [37]. However, in cases of asymmetric erosion of type B2 glenoids having biconcave surfaces, 2D radiographs may not capture the degree of inclination correction required on either the anterior or posterior side.

Osteoarthritic glenoid morphology has a dramatic effect on surgical technique and may result in varying clinical outcomes [20]. Although patients with asymmetric glenoid erosion are assumed to have suboptimal outcomes, a recent study of 196 patients with symmetric glenoid erosion compared to 148 patients with asymmetric glenoid erosion found similar clinical improvements in both groups with a 98 % revision-free survivorship at a mean of 51 months [19•]. All patients had a similar treatment method with all-polyethylene glenoid components and press-fit humeral components. Similar studies with long-term results and studies assessing the results of various implants (reverse TSA, hemi-arthroplasty, TSA,

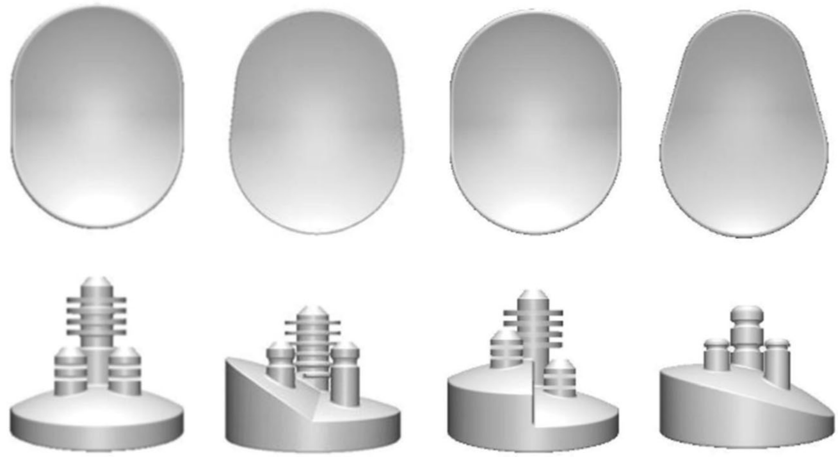

Fig. 1 Examples of current total shoulder arthroplasty standard and augmented glenoid component designs. *From left to right* a standard glenoid component, a posterior-wedged augment, a stepped augment, and a full-wedged augment. Images are adapted with permission from [18]

augmented TSA) would provide valuable insight into the effectiveness of these devices in the management of GHOA.

Subchondral bone changes

The altered glenohumeral contact mechanics of the osteoarthritic joint results in extensive bone remodelling of the glenoid subarticular bone. In regions of increased bone-to-bone contact, bone remodelling may result in dense sclerotic bone areas. This alteration in the density of underlying bone may alter the load transfer from glenoid components, affecting component stability.

In symmetrically eroded glenoids, humeral contact is uniformly distributed across the glenoid articulation. Bone remodelling, as cartilage degrades in these cases, results in uniform glenoid bone density in all regions of the glenoid [38, 39]. In asymmetrically eroded glenoids, humeral articular contact is concentrated on the posterior neoglenoid region. This region typically represents around 50 % of the total glenoid surface area [15], thereby concentrating the region of load transfer and contact over a decreased area. The result of this is substantially denser and less porous bone in the neoglenoid [38, 39]. In contrast, the paleoglenoid no longer experiences joint loading, as the humeral head is subluxated posteriorly and articulates with the neoglenoid. In response, the paleoglenoid bone becomes substantially less dense and more porous. In asymmetrically eroded biconcave glenoids, it has been suggested that preservation of the dense sclerotic bone in the neoglenoid region may reduce implant migration and early implant failure [11, 38]. All of these factors are important to consider when assessing implant fixation in the B2 glenoid.

Arthroplasty options

The degree of osteoarthritis-related bony erosion, patient age, activity level, and soft tissue deficiencies are all factors affecting the choice of surgical procedures for joint replacement. Younger active patients with minimal bone loss may be considered for hemi-arthroplasty procedures [41]. Total shoulder arthroplasty is utilized for advanced arthritis with deformity that is correctable with reaming and a standard implant. For patients with substantial glenoid bone loss, uncorrectable with reaming, total shoulder arthroplasty with a posteriorly augmented glenoid component may be indicated. In patients with a high degree of bone loss that is not correctable or with substantial joint instability, reverse total shoulder arthroplasty (RTSA) is often used. To address these difficult deformities, patient-specific instrumentation has gained traction recently [42–47], with companies beginning to explore patient-specific implants as surgical options to replace population-based implant designs (Stanmore Implants, Zimmer, Mobelife). The following sections address the specific arthroplasty options.

Total shoulder arthroplasty

The survivorship of total shoulder arthroplasty (TSA) at 15 years has been shown to be greater than 85 %; however, glenoid component loosening remains a leading cause of component failure [48]. In a large systematic review comparing metal-backed (MB) ($n = 1571$) and all-polyethylene ($n = 3035$) components (mean follow-up of 5.8 years in MB and 7.3 years in all-polyethylene), 77 % of revisions in all-polyethylene cases were due to component loosening [49•]. A comprehensive review of the modes of glenoid component failure reported mechanical failure, inadequate bone surface preparation and component seating, suboptimal cement techniques, component rim loading, aseptic loosening and osteolysis, and complex pathoanatomy as common reasons for component failure [50]. The authors suggest patient selection, patient counselling, technique optimization, restoration of the normal glenohumeral relationship, component design and the identification of pathologic erosions, and malalignment as ways to minimize the risk of glenoid component loosening. Their review also showed that round-backed and all-polyethylene glenoid components using peg fixation performed better than flat-backed, metal-backed, or keeled glenoid components.

In cases of more complex pathoanatomy, alternative glenoid components have been developed to account for bone deficiencies. A recent study reported on non-standard glenoid component designs for bone deficiency [21]. This study compared three components: an angled keel, an extra-thick (6 mm) component, and an augmented metal-backed component. The authors reported a large percentage of unsatisfactory results, with the effectiveness of these components compromised by loosening. In other cases of bone deficiency, such as asymmetric erosion, eccentric reaming and use of a standard component are preferred by some authors to account for acquired retroversion [6•, 10•, 12•, 32]. However, as previously mentioned, glenoid retroversion greater than 15° cannot be corrected by eccentric reaming alone [26, 32], making augmented glenoid components an attractive choice to preserve bone in patients with greater retroversion.

Augmented glenoid components account for posterior glenoid bone loss by using a thickened posterior step or wedge to address the missing bone (Fig. 1). These designs act to preserve underlying bone and correct acquired retroversion by minimizing bone removal. However, existing designs orient the augment along the central axis of the implant, assuming that maximum bone loss is directed towards the 9 o'clock position in a right shoulder. As previously stated, the recent literature has found bone loss to occur in a posteroinferior direction towards the 8 o'clock position [14–17]. This may result in significant bone removal in order to achieve full backside seating [27, 28]. Furthermore, when using either augmented or standard components in patients with asymmetric erosion, significant differences occur in the bone density and quality of underlying bone [27, 28], which may further complicate the stability and fixation of glenoid components. Both eccentric reaming and augmented components are best utilized in patients with mild to moderate glenoid erosion. In more severe cases, with erosion progressing past the centre of the glenoid, alternative approaches should be considered. Standard components will likely result in peg perforation after eccentric reaming, and current augmented component designs do not account for the increased region of bone loss [15].

Hemi-arthroplasty

Hemi-arthroplasty is an option for younger patients with sufficient glenoid bone stock. Replacement of the proximal humerus with a humeral component and conservative concentric glenoid reaming, without implantation of a glenoid component, removes the risk of glenoid component failure due to loosening [13, 51]. This procedure has also been found to be effective in the treatment of GHOA and may be an effective option in younger patients in order to retain bone for future revision surgeries [13, 51–53]. In type B2 biconcave cases, conservative reaming to restore the glenoid to a single concavity, with the use of a humeral hemi-arthroplasty, may be an effective treatment for the arthritic triad [13]. Unfortunately, disadvantages of the hemi-arthroplasty include glenoid-sided arthritic pain, progressive glenoid erosion, and recurrent instability.

Reverse total shoulder arthroplasty

With the FDA's approval of reverse total shoulder arthroplasty (RTSA) in 2004, RTSA has become increasingly popular in the management of rotator cuff tear arthropathy, showing improved outcomes as compared to hemi-arthroplasty [2]. Short, intermediate, and long-term outcomes of RTSA have shown improvements in joint function, in both younger patients (less than 60) [54] and older patients (greater than 60) [55–58]; however, younger patients tend to report lower satisfaction [54] compared to older patients [55–58]. Reverse total shoulder arthroplasty provides an effective solution for older patients with increased bone loss, and soft tissue imbalance, who require a more constrained prosthesis [12•].

One recurrent issue with RTSA is scapular notching [57, 59]. Scapular notching is controversial as some studies have demonstrated no effect on outcomes while others have shown decreased outcome scores with greater degrees of notching. A classification system for scapular notching was devised by Sirveaux et al., who describes the extent of notching in relation to the inferior screw [58]. This classification describes four levels of scapular notching: 0 = no notch, 1 = small notching short of the inferior screw, 2 = medium notch reaching the inferior screw, and 3 = large notch extending beyond the inferior screw. To reduce scapular notching, a bone graft between the baseplate (with an extended post) and glenoid has been suggested to lateralize the joint [60]. This procedure, termed bony-increased offset reverse shoulder arthroplasty (BIO-RSA), has been suggested in the treatment of asymmetric glenoid erosion with a biconcave glenoid, in order to reconstruct the joint line and reduce scapular notching [10•, 61, 62]. Long-term clinical outcomes of this procedure have yet to be reported, and limitations in standard clinical imaging to assess bone graft resorption at the baseplate should be considered in this procedure [63].

Patient-specific options

The focus of current patient-specific literature in the shoulder has been on the increased accuracy of component placement with patient-specific positioning guides and 3D pre-operative templating. Improved glenoid component positioning accuracy, compared to traditional techniques, has been reported for standard and augmented components [47, 64–66] and in baseplate positioning in RTSA procedures [67]. These devices are possible due to advancements in medical imaging software, 3D printing technologies, and improved knowledge of the osteoarthritic joint. Many implant manufacturers now offer custom software with the use of 3D reconstructions of patient anatomy to assist in the computational pre-operative placement of arthroplasty components. This software also allows for the 3D printing of patient-specific drill guides to assist in drill placement intra-operatively.

Conclusions

Glenoid morphology and subchondral bone changes, as the result of progressive osteoarthritis, cause difficulty in the surgical management of the glenohumeral joint. The level of bony erosion and the corresponding bone adaptations, as well as patient age and activity level, should be considered when choosing joint replacements for patients with advanced OA. To improve previous suboptimal outcomes of glenoid component loosening, patient-specific guides may improve the accuracy of component placement, with the potential to improve the long-term survivability of these components.

Acknowledgments Nikolas K. Knowles is supported in part by the Natural Sciences and Engineering Research Council of Canada and in part by a Transdisciplinary Bone and Joint Training Award from the Collaborative Training Program in Musculoskeletal Health Research at the University of Western Ontario.

Compliance with ethical standards

Conflict of interest Nikolas K. Knowles and Louis M. Ferreira declare that they have no conflict of interest.

George S. Athwal reports receiving grants from DePuy Mitek, Exactech, and Tornier during the conduct of this study.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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