Surgical management of the biconcave (B2) glenoid

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Published online: 15 February 2016
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Abstract Glenohumeral osteoarthritis produces a wide spectrum of glenoid pathology. The B2 glenoid is defined by asymmetric posterior bone loss with the development of a biconcavity and posterior translation of the humeral head. Progressive bone loss results in increasing glenoid retroversion, which must be corrected during anatomic shoulder arthroplasty. The goals of arthroplasty should also include centering the humeral head and restoring the normal glenoid joint line. When there is minimal bone loss, this may be accomplished with a standard glenoid component and asymmetric reaming. More significant bone loss requires bone grafting or the use of an augmented glenoid component. Reverse shoulder arthroplasty is also an option for older patients or patients with severe bone loss.

Keywords B2 glenoid · Biconcave glenoid · Shoulder arthroplasty

Background

Walch et al. classified glenoid morphology in advanced glenohumeral osteoarthritis [1] (Fig. 1). The location of bone loss and position of the humeral head relative to the glenoid are important to this classification. The biconcave (B2)

glenoid is characterized by a normal anterior glenoid (paleoglenoid) that represents the native glenoid fossa and varying amounts of posterior bone loss. The humeral head translates posteriorly to articulate with the new posterior concavity (neoglenoid). The anterior-posterior dimension and depth of this concavity are highly variable. In the classic B2 glenoid, the anterior 50 % of the native glenoid fossa is preserved. Alternatively, some cases have less than 10 % of the native anterior glenoid remaining (Fig. 2).

When there is minimal anterior glenoid remaining, the biconcavity is less pronounced and the glenoid appears to have more uniform retroversion. The humeral head also becomes more centered. In some cases, this morphology resembles a type C glenoid. The vault model can be used to differentiate a B2 glenoid with these characteristics from a type C glenoid with congenital retroversion [2•] (Fig. 3). The glenoid vault model has been shown to be a highly consistent and conserved 3D shape across individuals and can be used to estimate native glenoid version and inclination in both nonpathologic and pathologic shoulders [2•, 3–5]. A pathologic glenoid with acquired bone loss, such as a B2, will have a vault version measurement within the range of normal, while a pathologic glenoid with developmental or congenital retroversion, such as a C, will have a vault version measurement that shows increased retroversion. Determining the premorbid glenoid version has important surgical implications. High retroversion in the pathologic B2 glenoid should be corrected during arthroplasty. This may not be the case in the pathologic type C glenoid, where high retroversion is typical of normal premorbid anatomy. Vault modeling software is currently available for research use through Custom Orthopaedic Solutions, Cleveland, OH, USA.

According to the original Walch classification, type B glenoids are distinguished by posterior translation of the humeral head. Sabesan et al. have defined this translation in two

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

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Fig. 1 Walch Classification of glenoid morphology in primary glenohumeral arthritis (reprinted with permission from Elsevier from Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. *J Arthroplasty* 1999;14:756–60)

ways. They described humeral glenoid alignment (HGA) as translation relative to the center of the glenoid fossa and humeral scapular alignment (HSA) as translation relative to the axis of the scapula [6] (Fig. 4). These two measurements should be considered independently. Increased glenoid retroversion produces posterior humeral head translation relative to the scapular axis. The amount of this translation is proportional to the degree of glenoid retroversion. This is true regardless of whether there is increased retroversion due to posterior glenoid bone loss or increased retroversion due to dysplasia. The relationship between glenoid retroversion and HGA is less dependent on the amount of glenoid retroversion. Sabesan et al. found no correlation between HGA and absolute glenoid version or the amount of bone loss in B2 glenoids, as these relationships are also likely impacted by the amount of posterior humeral head subluxation [6].

The wide variation in pathology among B2 glenoids makes it difficult to compare the treatment methods or outcome of any one specific surgical procedure in the overall management of the B2 glenoid. Standard total shoulder arthroplasty (TSA) may offer excellent functional results but requires careful correction of pathologic bone deformity, restoration of the native joint line, and proper soft tissue balancing to ensure glenoid implant stability. Glenoid component malposition, particularly component retroversion, is a significant risk factor for early lucent lines and failure [7–9]. Increasing glenoid retroversion has been associated with increased risk of component malposition particularly when standard components are used [8, 10].

Undercorrection of retroversion can result in persistent posterior humeral head subluxation, which causes eccentric loading of the glenoid component and premature loosening [11–13]. Biomechanical studies suggest that this risk can be minimized by placing the glenoid component in less than 10° of retroversion [11].

Traditionally, the two most common treatment strategies to address excessive retroversion and glenoid bone loss include asymmetric reaming of the anterior glenoid and posterior glenoid bone grafting. More recently, augmented glenoid components have been introduced. These components address posterior glenoid bone loss, correct pathologic retroversion, and restore the native joint line without the need for bone grafting (Depuy, Warsaw, IN, USA; Smith & Nephew, Memphis, TN, USA; Exactech, Gainesville, FL, USA). Reverse TSA is also now increasingly used for older patients with more advanced posterior glenoid bone loss and biconcavity [14].

Preoperative planning and intraoperative techniques

Preoperative assessment of the B2 glenoid begins with plain radiographs including anteroposterior (Grashey) and axillary views. Posterior humeral head translation and glenoid biconcavity are assessed on the axillary radiograph. CT scans are helpful to further assess the amount of glenoid retroversion and posterior bone loss. We routinely reformat scans into three

Fig. 2 Examples of B2 glenoids with mild, moderate, and severe bone loss (left to right)

Fig. 3 **a** Vault model in a type B2 glenoid demonstrating acquired retroversion due to bone loss. Bone pathology measurements: version = -22.3° , inclination = 16.3° . Vault model measurements: version = -10° , inclination = 15° . **b** Vault model in a type C glenoid

demonstrating congenital retroversion. Bone pathology measurements: version = -29.7° , inclination = 6.5° . Vault model measurements: version = -25° , inclination = 7°

dimensions along the plane of the scapula. This decreases measurement error due to variations in the plane of image acquisition (gantry angle) [15, 16]. The anterior glenoid is a critical landmark for determining the native version, inclination, and joint line position of the B2 glenoid, as it represents the preserved premorbid anatomy that the pathologic glenoid should be corrected back to (Fig. 5).

In standard TSA, the ease of placing the guide pin in anatomic version and inclination depends upon the amount of native anterior glenoid remaining and the presence of anterior osteophytes. When there are few osteophytes and more than 50 % of the native anterior glenoid is preserved, any simple convex pin guide can be used if placed parallel to the anterior paleoglenoid. The guide is positioned so that it lies flat on the anterior glenoid after peripheral soft tissue is removed. The pin is then placed perpendicular to the surface of the anterior glenoid, matching the native version and inclination. Understanding this anatomy allows for easier management of a biconcave glenoid. This method becomes less accurate when there is less than 20 % of the native anterior glenoid remaining or when there are large anterior osteophytes distorting the native plane of the anterior glenoid. In this situation, it is critical to recognize and remove anterior

osteophytes in order to appreciate the version and inclination of the small area of remaining paleoglenoid. Incomplete removal of anterior osteophytes will cause the guide pin to be inserted in too much retroversion. As less of the anterior glenoid remains, it becomes more challenging to place a standard concave pin guide flat on this surface. Accurate pin placement can be greatly improved by preoperative planning with advanced imaging.

Advanced imaging is a valuable tool for preoperative assessment of the B2 glenoid. Multiple studies have supported the role of 2D CT imaging for preoperative planning in total shoulder arthroplasty [17–22]. 3D CT imaging has been shown to offer superior accuracy over 2D CT imaging for determining the location of glenoid bone loss and guiding surgical decision-making [23, 24, 25]. The glenoid vault model is a 3D virtual tool that can be used to determine premorbid glenoid anatomy. The vault model has been shown to be accurate for predicting premorbid glenoid version, inclination, and joint line position [2, 3–5]. The vault model can also help the surgeon identify the extent and location of bone loss in the B2 glenoid. This information can be used to assist the surgeon in placing the central guide pin in the location and orientation that best restores native glenoid version and

Fig. 4 Preoperative glenohumeral alignment of a B2 glenoid. The humeral scapular alignment (HSA) is measured between the line bisecting the scapular axis and the center of rotation of the humeral head according to a best-fit sphere. The humeral glenoid alignment (HGA) is measured from the center of rotation of the humeral head to a line placed at the center of the glenoid that is perpendicular to the glenoid plane

Fig. 5 Anteroposterior and axillary radiographs of a B2 glenoid (*above*), with axial CT and 3D CT reconstruction (*below*). The *arrows* and area labeled “A” indicate the anterior native glenoid fossa (paleoglenoid). This area can be used as a reference for the premorbid version, inclination, and joint line position of the B2 glenoid. The convex pin guide must be placed parallel to this surface in order place the pin in anatomic version and inclination

inclination. Additionally, this information can help the surgeon select the optimal implant to restore native glenoid anatomy, while avoiding peg perforation [7, 26, 27]. Patient specific instrumentation has been developed to help transfer information from the preoperative planning software to the patient [25].

Patient-specific instrumentation in shoulder arthroplasty involves creating a custom guide that references surface anatomy on the deformed glenoid. This allows the surgeon to position the guide pin in the desired location, version, and inclination relative to the scapular body. Patient-specific instrumentation for the B2 glenoid is most helpful when there is significant bone loss and retroversion. We have previously shown that patient-specific instrumentation has the greatest benefits when there is more than 16° of glenoid retroversion. Use of patient-specific instrumentation in these patients has been shown to result in less frequent undercorrection of retroversion, less joint line medialization due to overreaming, and decreased peg perforations [28•]. Another recent study found that preoperative planning with 3D CT imaging and templating was the most important predictor of accurate glenoid component placement. In that study, preoperative planning and templating with 3D CT imaging resulted in superior accuracy over 2D CT imaging without

templating, regardless of whether patient-specific instruments were used [24•].

Surgical management

Hemiarthroplasty

Humeral hemiarthroplasty has been described for young high demand patients or patients with inadequate bone stock to accommodate a standard glenoid component. Traditional hemiarthroplasty has been shown to have poor outcomes in patients with eccentric posterior glenoid wear [29]. For this reason, some have advocated for glenoid reaming in conjunction with hemiarthroplasty. This technique, termed “ream and run,” aims to center the humeral head by correcting pathologic glenoid biconcavity. The proponents of this method report that the reamed glenoid remodels with fibrocartilage to create a new concentric surface that balances the humeral head [30]. This technique has been shown to improve centering of the humeral head contact point on the face of the glenoid when evaluated on axillary radiographs at average 3-year follow-up [31]. The main limitation of the ream and run procedure is that it invariably produces joint line medialization. The amount of medialization is proportional to the depth of the glenoid

biconcavity. This may result in soft tissue laxity and persistent posterior instability in the setting of a B2 glenoid and require additional procedures for posterior stabilization, such as posterior capsular plication, rotator interval plication, increased humeral head anteversion, or anterior offset of the humeral head [31, 32]. Additional studies are needed to further define the limits of the ream and run procedure as well as the long-term outcome.

Total shoulder arthroplasty with asymmetric reaming

Asymmetric reaming with a standard glenoid component is currently the most common method of treating the B2 glenoid. This technique corrects glenoid biconcavity by removing the normal anterior glenoid. Asymmetric reaming can address posterior bone loss of up to 5 to 8 mm from the joint line and can correct version by up to 10 to 15°. Although this medializes the joint line, implant thickness may make up the difference [33, 34]. Correction of retroversion by more than 15 to 20° results in excessive joint line medialization and is associated with glenoid implant perforation [34, 35]. This amount of reaming also removes a significant amount of cortical bone, which may further destabilize the implant, as the loss of cortical bone and the narrowed anteroposterior glenoid dimension decreases backside support [12, 36]. Joint line medialization may also decrease efficiency of the rotator cuff and result in shoulder instability. Use of a bone graft or an augmented glenoid component instead of a standard component allows less bone removal for the same degree of version correction (Fig. 6). This reduces joint line

medialization as well as the incidence of central peg perforation and may better restore soft tissue tensioning and humeral head centering. A previous study recommended the use of posterior bone grafting or an augmented component when there is more than 16° of preoperative glenoid retroversion. That study suggested correcting glenoid retroversion to 6° rather than 0° in order to minimize joint line medialization and best restore native anatomy [37].

Total shoulder arthroplasty with bone grafting

Posterior bone grafting is an option to address glenoid deformity that is too severe to correct with asymmetric reaming alone. In this technique, a standard glenoid component is used after autograft has been secured to the glenoid with screws. Correcting glenoid retroversion and bone loss with this method is technically demanding and requires graft union. Four large series evaluating this technique have reported favorable outcomes. Neer and Morrison reported good results in 16 out of 19 shoulders (84 %) at an average follow-up of 52.5 months. All bone grafts healed without significant loosening or shifting of the glenoid component; however, the authors noted incomplete lucent lines around the glenoid component in six patients [38]. Steinmann and Cofield reported good clinical results (82 % excellent or satisfactory) despite a high incidence of radiographic lucency (54 %) in their series of 28 patients with average follow-up of 63 months. All bone grafts in their series healed without displacement; however, glenoid component loosening occurred in three patients [39].

Fig. 6 **a** B2 glenoid with superimposed vault model. Retroversion 24.9° and inclination 4.9°. **b** B2 glenoid after simulated reaming to accommodate an Anchor Peg Glenoid (Depuy, Warsaw, IN, USA). Reamed volume measures 6.3 cc with correction of version to -7°. Note medialized location of the glenoid component (*green*) relative to the vault model (*orange*). **c** B2 glenoid after simulated reaming to accommodate a 5 mm step-augmented glenoid (Depuy, Warsaw, IN, USA). Reamed volume measures 3.6 cc with correction of version to -7°. Note anatomic location of glenoid component (*pink*) relative to the vault model (*orange*)

Sabesan et al. reported good clinical results in 12 patients with minimum 2 years follow-up (average 53 months). That study included nine B2 glenoids and had a mean preoperative glenoid retroversion of 44°. At the time of final follow-up, 10 out of 12 (83 %) shoulders had graft incorporation without any resorption and two had minor resorption. Graft fixation failed in two cases and was attributed to early postoperative trauma and *propionibacterium acnes* infection, respectively [40•]. Klika et al. reported favorable clinical outcome in 23 of 25 shoulders (92 %) at average follow-up of 8.7 years. This was despite unfavorable radiographic results, which included 13 cases of postoperative glenohumeral subluxation, 20 cases of glenoid radiolucency, 6 cases of glenoid component shift, and 6 cases of bone graft resorption. The authors concluded that 10 glenoids (40 %) were at risk for failure, 5 of which had Neer II metal-backed components [41•].

All of these studies, except for the one by Sabesan et al., included both all-polyethylene and metal-backed implants with a polyethylene insert. Metal-backed components are attractive because of the potential for graft fixation using screws in the metal backing. However, metal-backed designs have been associated with increased polyethylene wear and premature loosening [42, 43]. The Klika study was the only study to specifically report the failure rate of metal-backed implants. It is not possible to know how much metal-backed designs influenced the results of the other two studies including them. Regardless, the use of bone grafting with a standard glenoid component introduces additional risk for failure. Augmented glenoid components have been developed to offer an alternative method of treating posterior glenoid bone loss without the need for bone grafting.

Total shoulder arthroplasty with augmented glenoid components

The introduction of augmented glenoid components has eliminated the need for bone grafting in many B2 glenoids. An early metal-backed, wedge-shaped design was used in the 1990s (Smith and Nephew; London, UK), but this implant suffered from the same problems as other metal-backed implants. A recent study comparing this implant to other designs reported a 10-year revision-free survivor rate of only 31 % [43]. More recently, a variety of all-polyethylene implants have been used. These augmented designs either have a wedge shape (Exactech; Gainesville, FL) or a backside surface with a posterior step (DePuy; Warsaw, IN). In vitro testing has shown that a stepped design has improved stability with eccentric cyclic loading when compared to a wedge-shaped design [44].

The biomechanical properties of augmented glenoid components may vary according to the shape of the deformed glenoid. For example, a stepped augment is ideal for the classic B2 glenoid with a posterior concavity involving less than 50 % of the glenoid. In this setting, the stepped design requires the least amount of bone removal to correct glenoid version and inclination while maintaining a lateral joint line location (Fig. 7). In contrast, wedge-shaped designs require reaming the glenoid to a single flat surface. This results in anterior bone loss that is proportional to the depth of the posterior concavity. In glenoids with a deep posterior concavity, this may compromise anterior cortical bone important for implant stability. Conversely, in a B2 glenoid that has minimal native anterior glenoid remaining, a wedge-shaped component may be more suitable. Because the glenoid in this scenario is mostly a flat surface, the wedge-shaped design requires minimal reaming. Using a stepped component would require a substantial amount of reaming anteriorly to reach the midpoint of the glenoid. This would result in significant bone loss and joint line medialization.

Minimum 2-year clinical results have not been reported for any of the newer augmented components. Early clinical results in a series of 24 patients with average retroversion of 22° have demonstrated the ability of the all-polyethylene stepped glenoid to correct glenoid version and inclination with less joint line medialization than a standard component [33•]. These findings have also been shown in computer simulations of patients with varying degrees of glenoid deformity [37•]. In our clinical experience, this implant has been able to

Fig. 7 Intraoperative photograph of a B2 glenoid after preparation for a stepped augment illustrates retention of anterior and posterior cortical bone

correct glenoid version and inclination in a classic B2 glenoid, while maintaining centered humeral head alignment at 2–3 years follow-up (Fig. 8). We believe that long-term maintenance of humeral head alignment requires normalization of the joint line in addition to correction of glenoid version and inclination. We suspect that recurrence of posterior humeral head subluxation results from undercorrection of pathologic version and/or medialization of the native joint line.

Reverse total shoulder arthroplasty

Some patients have combinations of acquired central and posterior bone loss. These deformities do not fit into any one Walch classification category and present as the most challenging cases for standard shoulder arthroplasty. Walch et al. identified neoglenoid retroversion greater than 27° in B2 glenoids as the strongest predictor of glenoid loosening and recurrent posterior humeral head subluxation in patients treated with anatomic TSA and a standard glenoid component [45]. The use of augmented components also becomes difficult in patients with excessive posterior bone loss. Augmented components should be avoided when the amount of bone loss risks peg perforation or precludes restoration of the native joint line. In this situation, reverse shoulder arthroplasty is the treatment of choice, with or without posterior glenoid bone grafting (Fig. 9).

Mizuno et al. reported good results with reverse shoulder arthroplasty in patients with a B2 glenoid. That study included 27 patients with mean preoperative retroversion of 32° and mean humeral head subluxation of 87 %. Seventeen patients had reverse shoulder arthroplasty without bone graft, and ten had a bone graft to address posterior glenoid bone loss. Bone grafting was performed when glenoid version could not be corrected to $<10^\circ$ with asymmetric reaming or when bone loss resulted in an unsupported base plate of $>20\%$. At mean follow-up of 54 months, patients had improved constant score and range of motion without recurrence of posterior instability [14•]. Reverse shoulder arthroplasty for bone loss is particularly attractive in older and less active patients. Management of this pathology in younger or more active patients remains an unsolved problem.

Conclusion

The biconcave (B2) glenoid includes a broad spectrum of pathology. Varying amounts of bone loss produce distinctly different types of deformity within this category of the Walch Classification. Meticulous preoperative planning is important to determine the best surgical approach. 3D CT imaging and use of the vault model help quantify the amount and location of bone loss. For

Fig. 8 Preoperative radiographs of a B2 glenoid demonstrating posterior humeral head subluxation (*above*). Postoperative radiographs demonstrating centered glenohumeral alignment 2 years after arthroplasty with a 7 mm stepped glenoid component (*below*)

Fig. 9 **a** A glenoid with severe acquired central and posterior bone loss and minimal native anterior glenoid. A 7-mm step augment (*red*) is unable to restore the anatomic joint line location reflected by the vault model (*purple*). **b** The extent of bone loss results in peg perforation. **c** Reverse total shoulder arthroplasty with a 8.82 mm posterior bone graft allows the lateral base plate (*blue*) to be positioned in line with the vault model (*purple*). **d** 3D reconstruction illustrates containment of the central peg. **e, f** Six-month postoperative anteroposterior and axillary radiographs demonstrate incorporation of the glenoid bone graft with good alignment of the reverse prosthesis

mild deformity with less than 8 mm of posterior bone loss and less than 16° of preoperative retroversion, asymmetric reaming with a standard glenoid component is a reliable approach. With more significant deformity, treatment options include bone grafting with a standard glenoid component or use of an augmented component.

The size of the posterior glenoid concavity relative to the anterior-posterior dimension of the glenoid is an important consideration when selecting between step and wedge shaped augments. In cases of extreme bone loss, reverse TSA offers a reliable solution that is particularly attractive for older and less active patients.

Compliance with ethics guidelines

Conflict of interest Kenneth W. Donohue declares that he has no conflict of interest.

Eric T. Ricchetti has been a paid presenter or speaker for, and has received research support from, DePuy, a Johnson & Johnson company.

Joseph P. Iannotti reports stock or stock options from Custom Orthopaedic Solutions. He has received IP royalties and consultant fees from, and been a paid presenter or speaker for, DePuy, Synthes. He has also been a paid presenter or speaker for DJ Orthopaedics. He has received IP royalties from Integra, Tornier, and Zimmer, as well as publishing royalties, financial or material support from Wolters Kluwer Health–Lippincott Williams & Wilkins. He has served on the editorial or governing board of the *Journal of Shoulder and Elbow Surgery*.

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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