Quantification of B2 glenoid morphology in total shoulder arthroplasty

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\textbf{Background:} B2 glenoid morphology is challenging to address with shoulder reconstruction. Deformity often renders current techniques inadequate, necessitating compromises that limit long-term implant durability. The purpose of this study was to perform in vivo measurements of glenoid deformity to better appreciate the orientation of the B2 biconcavity demarcation and erosion that surgeons face intraoperatively.

\textbf{Materials and methods:} A consecutive 106 total shoulder arthroplasty cases for primary glenohumeral osteoarthritis were studied. We classified glenoids by direct visualization and noted lines of biconcavity demarcation and erosion in B2s. We then calculated the “angle of erosion” as that between the back side of the unsupported, smooth-backed glenoid sizer disk and the neoglenoid. We obtained depth measurements throughout the reaming process and monitored subchondral bone.

\textbf{Results:} We classified 43 of 106 glenoids (41\%) as B2. A biconcavity demarcation line between the paleoglenoid and the neoglenoid was present, on average, from the 1-o’clock to the 7-o’clock position for a left shoulder. Mean depth of erosion was 4.4 mm, occurring at 114° on a Cartesian coordinate system for a left shoulder. The mean angle of erosion was 18° (range, 8°-43°). Despite reaming, 20 of 43 B2 glenoids (47\%) had incompletely supported components at final seating.

\textbf{Conclusions:} Arthritic B2 glenoids are common, and their maximal erosion is usually posteroinferior. Use of standard glenoid components to reconstruct them may require significant subchondral bone removal to achieve complete bone support. Alternatively, as a compromise, maintenance of subchondral bone in these cases requires implanting components with incomplete bony support.


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\textbf{Keywords:} Shoulder arthroplasty; B2 glenoid; shoulder reconstruction; glenoid erosion

Glenoid reconstruction remains a challenge for irregular arthritic glenoids, especially Walch B2s.\textsuperscript{9,21,22} Recent work has better elucidated these erosion patterns.\textsuperscript{1} Typically, B2 glenoid erosion is found in the postero-inferior quadrant with the biconcavity demarcation line from posterosecondary to antero-inferior.\textsuperscript{1,8,18-20} Several reconstruction methods have been used to reconstruct the deformities.\textsuperscript{3-5,10,11,14,16,23,24} Clinical and radiographic results have been poorer in B2 reconstructions than in other osteoarthritic shoulders.\textsuperscript{4,5,23,24}
It has become clearer that bone support of an all-polyethylene component is important to resist compressive and eccentric forces, ultimately leading to increased component longevity. Moreover, recentering of the humeral head after unconstrained total shoulder arthroplasty (TSA) is not correlated with glenoid version or version correction. Thus, glenoid morphology may be more important to postoperative humeral head subluxation than is glenoid version. Vigilant subchondral bone monitoring during reaming is an active and important part of any glenoid reconstruction. Preoperative imaging prepares the surgeon, but intraoperative observation gives real-time feedback about bone density and reaming alterations. Churchill proposed a classification system in 2012 that focused on glenoid bone presentation and preparation.

The purpose of this study was to identify demarcating lines of erosion and orientation and to monitor bone changes as part of preparing bony glenoids in unconstrained TSA. The particular group of interest was the B2 variety. To better understand the morphology and bone removal for reconstruction, we performed erosion depth measurements and calculated the angle of erosion between the paleoglenoid and the neoglenoid. An additional goal was to identify and to measure subchondral bone loss during preparation. We also quantified erosion and its changes during preparations. Last, we wished to identify and to quantify final component bone support.

**Materials and methods**

Between April 11 and December 12, 2011, 3 fellowship-trained shoulder surgeons at separate centers performed 106 consecutive unconstrained TSAs for primary glenohumeral osteoarthritis. All operations were performed with a consistent technique and prosthesis: an anatomic Tornier Affiniti total shoulder (Tornier Inc., Edina, MN, USA). During glenoid exposure, remaining labral tissue was sharply excised and residual glenoid articular cartilage was curetted to completely expose glenoid subchondral bone. Intraoperative classification of glenoid morphology was completed according to the Walch classification. Glenoids were sized to the closest matching smooth-backed Affiniti trial disks available in 40, 44, 48, 52, and 56 mm. All glenoids of B2 morphology were further measured before any glenoid reaming.

**B2 glenoid subset**

The “line of initial erosion” or “biconcavity demarcation” between the noneroded anterior glenoid surface (paleoglenoid) and the eroded posterior glenoid surface (neoglenoid) was identified and measured as points on a clock face to within the closest 30 minutes. In a left shoulder, this line often runs from 1 o’clock to 7 o’clock. For standardization of data, all right shoulder clockface measurements were converted to left shoulder clockface measurements (Fig. 1). To quantify the extent of posterior erosion, the glenoid sizer disk was held in intimate contact with the paleoglenoid. With this held firmly in place, a smooth K-wire or an arthroscopic measurement probe was then placed alongside the posterior rim of the disk at the point of maximal neoglenoid erosion. Depth of erosion was recorded to the nearest millimeter. Glenoid reaming was initiated. Whereas our goal was 100% bone support of each component, we were willing to accept <100% support to maintain some glenoid subchondral plate to help reduce the glenoid component’s risk of medialization. Thus, we focused more on component bone support vs. “reorienting” glenoid version to “normal,” which could significantly sacrifice bone. An arbitrary number of 80% bone support was chosen as the minimum that the surgeons were willing to accept at the time of final implant placement, recognizing that exact measurements are not currently possible. Throughout the reaming process, the subchondral plate was monitored and measured. If reaming perforated 50% of the subchondral plate by visualization, it was halted and a repeated posterior depth measurement was obtained by the technique described previously. Additional reaming was then continued if necessary to achieve at least 80% support. Ultimate reaming end points were 100% support of the glenoid trial disk, acceptance of <100% support (but at least 80%), and downsizing of the glenoid to achieve maximum support. If 100% support was not achieved despite reaming >50% of the subchondral plate, a third, final depth measurement was obtained with the aforementioned technique. The post-treatment grade of the glenoid, as previously described by Churchill, was then recorded (Table I). As a measurement-only study, no changes in patient treatment were made because of or as part of the study. Figure 2 illustrates the algorithm for reaming and all possible end points.

The extent of posterior glenoid erosion was quantified by calculating the angle of erosion of the neoglenoid from the normal, paleoglenoid surface. The angle of posterior glenoid erosion was determined on the basis of the transition point between the paleoglenoid and neoglenoid, the width of the neoglenoid face, the width of unsupported glenoid trial, and the maximal depth of posterior erosion. The angle of erosion can be compared to the apex angle of an isosceles triangle, where the matching sides of the triangle are the width of the neoglenoid face and the width of unsupported glenoid.
Table I Post-treatment glenoid classification in primary total shoulder arthroplasty

<table>
<thead>
<tr>
<th>Type</th>
<th>Glenoid Subtype Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No glenoid reaming</td>
</tr>
<tr>
<td>I</td>
<td>Glenoid reaming into but not through the subchondral bone</td>
</tr>
<tr>
<td>IA</td>
<td>100% bone support of the prosthesis</td>
</tr>
<tr>
<td>IB</td>
<td>Region of unsupported prosthesis is present</td>
</tr>
<tr>
<td>II</td>
<td>Glenoid reaming perforating through the subchondral bone with &gt;50% of the subchondral plate surface area remaining</td>
</tr>
<tr>
<td>IIA</td>
<td>100% bone support of the prosthesis</td>
</tr>
<tr>
<td>IIB</td>
<td>Region of unsupported prosthesis is present</td>
</tr>
<tr>
<td>III</td>
<td>Glenoid reaming perforating through the subchondral bone with &lt;50% of the subchondral plate surface area remaining</td>
</tr>
<tr>
<td>IIIA</td>
<td>100% bone support of the prosthesis</td>
</tr>
<tr>
<td>IIIB</td>
<td>Region of unsupported prosthesis is present</td>
</tr>
<tr>
<td>IV</td>
<td>Structural bone grafting to correct for glenoid bone deficiency</td>
</tr>
<tr>
<td>V</td>
<td>Implantation of augmented glenoid prosthesis to correct for glenoid bone deficiency</td>
</tr>
</tbody>
</table>

Results

Of the 106 consecutive TSA cases, there were 54 male and 52 female patients; 43 left shoulders and 63 right shoulders were studied. Walch glenoid classification consisted of the following: A1, 40; A2, 16; B1, 6; B2, 43; C, 1.

B2 glenoid subset

The 43 B2 glenoids' line of initial erosion had a mean superior point of 12:48 (range, 11:00-3:00) and a mean inferior point of 6:48 (range, 4:00-8:30) on a clock face (left shoulders). These points correspond to 24° and 204° on the Cartesian coordinate system. The mean point of maximal depth occurred at 3.8 o’clock, or 114° on the Cartesian coordinate system. The mean depth of maximal erosion was 4.4 mm (range, 2-10 mm).

The post-treatment glenoid grade is listed in Table II. There were no type 0, type IA, or type IB glenoids. No bone grafting (type IV) or posterior augmented prosthetic implants (type V) were used in the study.

The mean angle of erosion was 18° (range, 8°-43°). There were 19 glenoids between 8° and 15°, 18 glenoids between 16° and 25°, 5 glenoids between 26° and 35°, and 1 glenoid >35° (Table III).

Discussion

Neer described an osteoarthritic glenoid morphology that resembled a chronic posterior dislocation in 1982. Its features included posterior glenoid bone loss and posterior humeral head subluxation. Walch et al used computed tomography (CT) scans to better understand and characterize the deformity, classifying it as a B2 in 1999. In shoulder reconstruction literature, many studies demonstrate good to excellent results after unconstrained TSA for osteoarthritis. Unfortunately, for shoulders in which B2 glenoids were present, glenoid component durability and stability as well as functional results have been less consistently obtained.

While classifying glenoid subtype intraoperatively, we described deformity dimensions. On average, we found that the resultant “line of erosion” ridge between the paleoglenoid and the neoglenoid ran approximately between the 1-o’clock and 7-o’clock positions of a left glenoid. Moreover, we found the average angle of erosion of the neoglenoid to be 18°. Finally, we found that the maximal average bone loss was in the postero-inferior quadrant and measured 4.4 mm. These deformity dimension results are similar to those of Walch et al in which 92 TSAs with B2 glenoids were evaluated by preoperative 2-dimensional CT scans. In that study, the maximal average bone loss depth was 7.3 mm, and the average neoglenoid retroversion angle was 25°. Intraoperative correlations were not made. In addition, a recent study by Beuckelaers et al evaluated 3-dimensional reconstructions of the CT scans of 48 B2 glenoids. They found the maximum depth of the erosion was 4.5 mm, and its average location was 113° using Cartesian coordinates. This compares favorably to our results of 4.4 mm and 114°, respectively. In our cohort, we found B2 glenoids to be more prevalent than previously reported as 41% were B2s, whereas Walch found 15% in his initial CT study. This difference may be due to demographics, sample size, interobserver variability, and, finally, the fact that we classified glenoids with intraoperative visualization.

B2 glenoid morphology presents the clinician with several dilemmas for which compromises are often required when reconstruction is being considered. In the current study, we wished to define B2 deformities intraoperatively using simple tools while reconstructing the deformities with the then-available nonaugmented glenoid components. Despite shoulder reconstruction fellowship training of all 3 surgeons and nearly 4000 shoulder arthroplasties performed, 47% of the prosthetic glenoid components used for B2 glenoids had some unsupported region; 30% of the B2 glenoids were reamed such that the component was supported by <50% subchondral bone. Although we placed primary importance on subchondral bone maintenance, more reaming was necessary in these cases to obtain our minimum requirement of 80% bone support for the glenoid component. We accepted some retroversion of glenoid.
components in the severe cases while attempting to “reorient” their version to within roughly 10° of the paleoglenoid version, recognizing that measuring glenoid version intraoperatively is an inexact science. Despite our attempts, we were still unable to obtain 100% back side support for many.

Compromises in reconstructions have been made with unconstrained TSAs. Unfortunately, hemiarthroplasty has been associated with decreased satisfaction of the patient.13 With unconstrained TSA, paleoglenoid reaming to “correct” glenoid version at the expense of the subchondral bone has led to unacceptable glenoid loosening.25

We chose to correct the version to within 10° of the paleoglenoid version but placed greater importance on the preservation of the subchondral bone and achieving at least 80% component bone support. Unfortunately, in a study by Walsh et al23 of 92 shoulder arthroplasties with B2 glenoids reconstructed in a manner similar to ours, 20% of glenoid components demonstrated radiographic loosening at 6 years. This is concerning when 47% of the components

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**Figure 2** Reaming algorithm for B2 glenoid subset.
placed in B2 shoulders in our cohort had some unsupported segment of the prosthetic glenoid in the posteroinferior quadrant. A recent finite element analysis further validates the concern as it revealed that a partial correction of version with only partial bone support of the implant was associated with higher stresses in the posterior cement mantle.\textsuperscript{27}

Churchill’s classification system was originally proposed as a system to help us ascertain how reaming techniques affect clinical and radiographic outcomes; but it also allows one to better understand the deformities faced intraoperatively and what future systems may be better equipped to address deformity issues if compromises with bone support and version must be made. We used his classification system with this in mind.\textsuperscript{2} Moreover, we found that 13 of 43 components required reaming such that <50% subchondral plate remained before implantation, which may predispose these components to a higher rate of medialization.

Other means of addressing B2 glenoids include posterior glenoid bone grafting, reverse TSA, and the use of posterior augmented glenoid components. Bone grafting is challenging, and results can be unpredictable.\textsuperscript{6,16} Reverse TSA is generally reserved for older, lower demand patients and severe cases of bone loss and is not without limitations. A study of 12 patients in whom an unconstrained primary TSA was performed on one side and a reverse on the other noted that whereas the functional scores were improved on both sides, shoulder motion was better with unconstrained TSAs.\textsuperscript{12} Understanding that further study is needed, posterior augmented glenoid components may reduce intraoperative compromises. Biomechanical data and simulations suggest that it is a viable option and can preserve the anatomic joint line.\textsuperscript{11,17}

Our study is not without limitations. First, this was an anatomic measurement study only. No attempt was made to observe our patients clinically or radiographically. Second, we made no correlations between preoperative imaging and the intraoperative measurements. Third, we downsized glenoid components in some cases to achieve better support. We do not have data that reflect how those shoulders may have been affected other than theoretically decreased motion. However, none of these limitations nullifies our in vivo efforts to define glenoid morphology in patients undergoing unconstrained TSA to better understand and reconstruct deformities. To our knowledge, this is the first study that describes intraoperative B2 glenoid morphology and intraoperative component seating in this group of difficult patients.

Ultimately 47% of our B2 glenoid implants were placed with incomplete bone support with intraoperative compromises to balance stability, bone support, and motion. These compromises included correcting glenoid retroversion to within at least 10° of paleoglenoid version while maintaining as much glenoid subchondral bone as possible to obtain a minimum of 80% component bone support. Future studies should focus on the long-term effects of this approach and other means of addressing the B2 glenoid in an effort to maintain bone and soft tissue without compromising stability and motion.

**Conclusions**

In this series of 106 consecutive TSA cases, the B2 glenoid had a prevalence rate of 41%. The line of erosion from the paleoglenoid to neoglenoid occurred roughly from the 1-o’clock to the 7-o’clock position for a left shoulder. The mean angle of erosion between the original paleoglenoid and the eroded neoglenoid was 18°. The point of maximal erosion occurred posteroinferior at 114° on the Cartesian coordinate system and had a mean depth of 4.4 mm. Glenoid reaming to obtain 100% support of the glenoid implant in B2 glenoids...
Acknowledgment

The authors wish to acknowledge Jessica L. Churchill for her artwork.

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References