The effect of glenoid bone loss on reverse shoulder arthroplasty baseplate fixation

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Background: Glenoid bone loss is commonly observed during primary and revision reverse shoulder arthroplasty. Glenoid baseplates are often implanted with incomplete glenoid bone support. The purpose of this study was to evaluate the glenoid component fixation of the glenoid baseplate with variable amounts of incomplete coverage.

Methods: Twenty-eight polyurethane trabecular bone surrogates were instrumented with the same center screw–type glenoid baseplate with 4 peripheral 5.0-mm locking screws in a glenoid bone loss model consisting of 25\%, 50\%, 75\%, and 100\% coverage. Each construct was tested through a 55° arc of motion with both compressive and shear forces across the glenosphere. Baseplate micromotion was recorded throughout 10,000 cycles for each model.

Results: There was no significant difference in baseline micromotion between the 4 experimental groups ($P = .099$). In the 25\% baseplate coverage group, 3 of 7 exhibited micromotion above the 150-\textmu m threshold (624.5, 469.1, and 712.1 \textmu m) during cyclic loading. After 10,000 cycles of loading, the 25\% coverage group exhibited significantly more micromotion than the 50\% ($P = .049$), 75\% ($P = .026$), and 100\% ($P = .040$) coverage groups. There was no significant difference between the 100\%, 75\%, and 50\% coverage groups ($P = 1.00$).

Conclusions: Glenoid baseplate fixation in the setting of glenoid bone loss is no different when 50\%, 75\%, or 100\% of the baseplate is supported by glenoid bone. Bone loss resulting in only 25\% coverage results in significantly greater micromotion, often above the 150-\textmu m threshold.

Level of evidence: Basic Science Study, Biomechanics.

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been shown to be beneficial for improving fixation, providing optimal implant stability, and reducing scapular notching.\textsuperscript{5,6,15,19} may lead to further uncovering of the superior aspect of the glenoid baseplate. During preparation of the bone-deficient glenoid, the surgeon is typically left with the decision to ream farther medial until a flush concentric surface is created, to bone graft the defect, or to implant the baseplate with some degree of incomplete coverage.

Eccentric reaming until a flush surface with the preferred inclination and version is created might be considered ideal. However, with further medial reaming of the glenoid, the bone volume continues to decrease and may compromise the ability to achieve stable implant fixation.\textsuperscript{9,21} In addition, medialization has the potential to lose the stabilizing effects of lateralization and to increase the risk of instability. Bone grafting of the defect has become an attractive option to aid in correction of the glenoid morphology without the need for excessive reaming and medialization of the component.\textsuperscript{11,13,14,26} Ultimately, the glenoid baseplate must be implanted with sufficient fixation to facilitate osseous integration to the native glenoid. Unfortunately, the proper amount of native glenoid bone required to support glenoid baseplate fixation has not yet been defined.

The purpose of this study was to evaluate RSA glenoid component fixation in a surrogate glenoid bone loss model simulating differing percentages of the glenoid baseplate unsupported by native bone. The hypothesis was that increasing amounts of glenoid bone loss would result in progressively increasing amounts of baseplate micromotion.

**Materials and methods**

Twenty-eight synthetic trabecular bone surrogate cylinders (Sawbones Model #1522-12, rigid cellular foam; Pacific Research Laboratories, Vashon, WA, USA) with a nominal density of 0.32 g/cm\textsuperscript{3} (ASTM F1839-08) were used in the current investigation. This density was chosen as an intermediary between poor-quality (0.24 g/cm\textsuperscript{3}) and good-quality (0.48 g/cm\textsuperscript{3}) cancellous bone used in studies of similar scope.\textsuperscript{7} On receipt of the foam test blocks (40 × 130 × 180 mm), each was machined into cylinders measuring 44.5 mm in diameter and 40 mm in height in preparation for instrumentation.

This study used the glenoid components of a single RSA system (RSP; DJO Global, Austin, TX, USA). The baseplate of this system consists of a single central 6.5-mm lag screw in combination with 4 peripheral screw holes, which can be used in locked or nonlocked fashion. For this study, we evaluated RSA glenoid component fixation in a glenoid bone loss model simulating 4 differing percentages of the glenoid baseplate unsupported by native bone using 7 cylinders per baseplate coverage group: (1) 100\% baseplate coverage (control), (2) 75\% baseplate coverage, (3) 50\% baseplate coverage, and (4) 25\% baseplate coverage. The amount of foam cylinder removed to simulate the various baseplate coverage conditions was accomplished with 3 polyvinylchloride tubing templates and a belt sander (Fig. 1). Foam removal was performed in a dry environment. Use of the polyvinylchloride sanding templates served to ensure repeatability regarding the amount of foam removed within each experimental group (Fig. 2).

The pattern of superior glenoid wear simulation was chosen on the basis of clinical experience as patients with rotator cuff arthropathy, and thus candidates for a reverse shoulder replacement, often present with radiographically evident superior glenoid erosion.\textsuperscript{12}

All baseplates were fixed perpendicular to the bone block substitutes by the manufacturer’s recommended technique. Briefly, a 2.5-mm drill was used to define the trajectory for the baseplate’s central screw. A 6.5-mm tap was used to create the threads for the central screw. With the tap still in place, a reamer was used to create the circumferential concavity required to accommodate the underside of the baseplate, which was then inserted and tightened to a maximum torque of 3.5 N-m (Model DID-04 Digital Torque Screwdriver; Imada, Inc. Northbrook, IL, USA). Peripheral fixation of the baseplate to the synthetic tissue surrogate was accomplished with 4 locked screws of 22 mm in length. This length was determined by a retrospective analysis of a consecutive series of 100 RSA surgeries using the same glenoid baseplate, an analysis of which identified an average peripheral screw length of 21 mm. Given that the blocks in the experimental wear groups were prepared before baseplate instrumentation and

**Figure 1** (A) Polyvinylchloride template used to create the 25\% bone coverage specimens. (B) Foam cylinder in polyvinylchloride tube after sanding and baseplate placement.
peripheral screw placement, the final orientation of the peripheral screw holes relative to the simulated superior wear was variable within and between experimental groups. Whereas repeatable baseplate orientation and peripheral screw positioning relative to the wear may have been desirable from an experimental standpoint, we thought that this approach more closely resembled the clinical scenario. For peripheral screw placement, a 4-in-1 drill guide was used, which allows drilling and placement of screws (after the inner sleeve is removed) in a constant perpendicular orientation to the baseplate. A 4-mm drill was used to define the screw trajectory in the cylinder. The screws were advanced to a 22-mm depth in the foam cylinder and tightened to 2.5 N-m, with care taken not to cross the threads on locking into the baseplate. Thereafter, a differential variable reluctance transducer (DVRT) (Model MG-DVRT; LORD MicroStrain Sensing Systems, Williston, VT, USA) with 3-μm accuracy was mounted to the instrumented Sawbones surface in the inferior-superior direction with a custom-designed attachment rig such that the sensor was in contact with the periphery of the baseplate above the simulated superior wear (Fig. 3). Inferior-superior micromotion was of primary interest, given the orientation of the applied loads in our test setup, which were applied to the baseplate in the scapular plane to simulate abduction and the primary function of RSA. Out-of-plane micromotion in the anterior-posterior direction was not measured as no shear loads were applied in the axial plane. After screw placement and DVRT attachment, a 32-mm neutral glenosphere (DJO Global) was impacted onto the baseplate. This glenosphere has a center of rotation 10 mm from the glenoid surface.

For mechanical testing, the instrumented Sawbones cylinder was mounted in a swing arm attached to the torque motor of a servoelectric test frame (Model 800LE; TestResources, Shakopee, MN, USA). Test specimens were cycled through a 55° arc of motion at 1 Hz while the test frame’s actuator applied a constant 750 N compressive force through a glenosphere size-matched humeral component polyethylene neutral liner, in similar fashion to the methods adopted by previous authors.16,17 The test block’s orientation was such that the 55° arc of motion occurred in the scapular plane defined by the location of superior wear in the experimental groups, thus serving to approximate a 25° to 80° humeral abduction motion relative to a fixed scapula.18 Thus, our cyclic test setup simulates the primary abduction motion generated by the deltoid in RSA. This loading setup induces a maximum shear force of 346 N at the extremes of the motion arc from neutral (i.e., ±27.5°) and a 750 N compressive load at the neutral position (Fig. 4). The DVRT’s continuous analog voltage output was queried at the beginning of testing and every 500 cycles thereafter through 10,000 cycles of loading. The measured voltage was related to baseplate micromotion using the manufacturer’s provided linear calibration coefficient. Here, micromotion was defined as the average of the absolute values of micromotion measured by the DVRT at the arc of motion extremes (+27.5° and −27.5°) during 20 loading cycles for each data
collection time point. Testing was stopped at any time if catastrophic failure of the test construct was grossly observed.

Micromotion data were analyzed by a 2-way analysis of variance for intragroup (time) and intergroup (baseplate coverage) comparisons, and post hoc multiple comparisons were performed with Bonferroni correction. The analyses were performed with SPSS v22 (IBM, Armonk, NY, USA) at a significance level of .05. The number of test constructs in which micromotion was measured above the 150-μm threshold commonly accepted for osseous integration was reported.

**Results**

All 28 instrumented foam blocks survived the entire 10,000-cycle loading protocol without catastrophic failure. There was no significant difference in baseline micromotion between the 4 experimental groups ($P > .021$). For those constructs tested in the 25% baseplate coverage group, mechanical stability was highly variable (Fig. 5) as 3 of 7 of the constructs exhibited micromotion well above the 150-μm threshold (625, 469, and 712 μm) during cyclic loading. For these 3 constructs, the 150-μm micromotion threshold was exceeded at 1250, 6500, and 3500 cycles of simulated abduction loading, respectively (Appendix A). After 10,000 cycles of loading, the 25% baseplate coverage group exhibited significantly more micromotion (average, 301 μm; range, 44-712 μm) than the 50% (average, 75 μm; range, 36-144 μm; $P = .049$), 75% (average, 54 μm; range, 39-73 μm; $P = .026$), and 100% (average, 68 μm; range, 45-91 μm; $P = .040$) baseplate coverage groups.

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**Figure 3** (A) Close-up image of fixation construct in test frame. (B) Picture of entire biomechanical test setup. (C) Differential variable reluctance transducer (DVRT) in contact with baseplate.

**Figure 4** Shear and compressive forces throughout the 55° arc of simulated abduction motion.
There was no significant difference between the 100%, 75%, and 50% baseplate coverage groups ($P = 1.00$).

**Discussion**

Glenoid bone loss is commonly encountered during RSA, as many of the common pathologic processes treated in both primary and revision surgery result in progressive amounts of glenoid bone loss, wear, and deformity. In a characterization of variations in glenoid morphology seen in patients treated with RSA, Frankle et al. observed abnormal glenoid wear in approximately 40% of cases. In addition, surgical techniques designed to avoid impingement, such as implanting the baseplate with inferior tilt and alteration of glenoid version, may result in further uncoverage of the baseplate. Because the ultimate goal is to achieve osseous integration of the glenoid component to the native glenoid, it is important to understand the consequences of implanting the baseplate with incomplete support of the native glenoid bone. Results of this study suggest that when a central screw–based baseplate with 4 peripheral locked screws is used, glenoid bone coverage of 50% or more results in stable fixation within the acceptable limits of micromotion for bone-implant ingrowth to occur.

Management of glenoid bone loss with use of RSA has evolved, with a variety of surgical techniques and advancements in prosthetic designs being introduced during the past 15 years. Because RSA designs universally use a metal baseplate with peripheral screw fixation, obtaining secure fixation together with opportunities for bone graft fixation is enhanced. Eccentric reaming is often required during glenoid preparation, as the glenoid baseplate requires a matched surface for optimal fixation and ultimate osseous integration. However, eccentric reaming has limitations, as available glenoid bone diminishes when the glenoid is medialized. Recently, the introduction of augmented baseplates has been proposed for cases in which incomplete corrections of deformities are encountered.

Eccentric reaming is a simple and effective technique that can correct the glenoid to the desired version by reaming the “high side” down to match the level of the worn surface. During RSA, eccentric reaming is used to correct not only alterations in glenoid version but also inclination as rotator cuff tear arthropathy, the most common indication for RSA, typically has eroded the glenoid superiorly, increasing glenoid inclination. This technique is straightforward and adds little time to the operative procedure, but it can also have significant disadvantages. With further medial reaming, glenoid bone stock is depleted and the joint line is inherently medialized. Excessive medialization of the joint may increase the risk of instability as soft tissue tension of surrounding muscle attachments is diminished. In addition, initial fixation of the baseplate may be compromised as the peripheral baseplate screws have less bone remaining for purchase. Walch et al. have reported on subsidence and radiographic loosening of the glenoid component in total shoulder arthroplasty with aggressively reamed glenoids that violate the subchondral bone. This has the potential to occur with RSA as well with extreme amounts of reaming.

Bone grafting of the glenoid defect has been performed to effectively correct the glenoid version and avoids the removal of excess bone and joint line medialization. In the setting of primary RSA, the native humeral head provides an excellent source of autograft. In the revision setting, options include autograft harvesting from the iliac crest or use of various forms of structural allograft. Neyton et al. reported their short-term results of 1- or 2-stage glenoid bone grafting for RSA in the setting of abnormal glenoid wear, demonstrating no evidence of early loosening or graft failure. Studies showing the long-term results of bone grafting for correction of abnormal glenoid wear and its effect on implant survival, however, have yet to be published.

Augmented baseplates have recently been introduced as a potential solution for implant coverage in abnormal glenoid wear, obviating the need to remove excessive bone to create a flush surface. Roche et al. performed a biomechanical analysis comparing the fixation of superior augmented baseplates using off-axis reaming with standard
baseplates using an eccentric reaming technique in composite scapulae with a superior glenoid defect. They found both techniques to have similar fixation throughout cyclic loading, maintaining micromotion below the 150-μm threshold for implant-bone ingrowth. The clinical results of augmented baseplates in RSA, however, have yet to be reported.

Incomplete seating of the baseplate may occur as a compromise by the treating surgeon to avoid excessive reaming, may be a late result of bone graft resorption beneath the baseplate, or may be contributed to by an unrecognized incomplete bone preparation or baseplate insertion. Critical to the survivability of the glenoid component of the reverse shoulder replacement is obtaining sufficient fixation on the glenoid bone to facilitate osseous integration. Minimization of micromotion below 150 μm between an implant and bone has been shown to be optimal in achieving a biologic environment for bone growth onto metal arthroplasty surfaces. The results of the present study demonstrate that in a trabecular surrogate bone model, stable baseplate fixation can still be achieved with up to 50% of the implant undersurface unsupported by bone. There was no significant difference in micromotion at baseline and after 10,000 cycles between the 100%, 75%, and 50% baseplate coverage groups. When the baseplate was implanted with only 25% coverage, 3 of the 7 constructs exhibited micromotion well above the 150-μm threshold (624.5, 469.1, and 712.1 μm) during cyclic loading (Appendix A).

Several steps were performed to help maintain uniformity of the tested constructs and strengthen the validity of the data. The method of cyclic loading used in this study mimics the stresses that might be observed in vivo and was similar to the technique used by Roche et al. This consisted of a 750 N axial load applied through the humeral component while the glenosphere was rotated about the humeral component in a 55° arc of motion. This loading profile induces a maximum calculated shear force of 346 N and a maximum compressive load of 750 N. The applied compressive load magnitude of 750 N is in good agreement with data published by Bergmann et al, who measured the in vivo glenohumeral joint loads during abduction in patients with load/moment-measuring total shoulder arthroplasty prostheses. However, the loading approach used here may be considered worst case scenario, as muscle forces in RSA patients have been reported to vary between 30% and 50% less than in anatomic arthroplasty patients because of a compromised rotator cuff. It was thought that this method of testing would better simulate what would be observed clinically rather than the methodologies noted by Harman et al. The lengths of the peripheral screws were kept identical and represented the average-size peripheral screw used in a consecutive surgical sample of 100 RSA procedures. The glenosphere selected was the 32 neutral glenosphere (DJO Orthopaedics, Austin, TX, USA), which has a center of rotation 10 mm lateral to the glenoid. This created a worst-case scenario of glenosphere options as it relates to baseplate micromotion. Finally, the central screw baseplates were implanted with an identical maximum torque to ensure that uniform compression was achieved with each tested model.

Limitations of this paper include the evaluation of a single device and findings that may not be extrapolated to RSA systems with different baseplate designs. The magnitude and orientation of the forces applied through the testing blocks were chosen on the basis of the methodologies of previous biomechanical and in vivo studies evaluating glenohumeral joint loading during shoulder motion but may not fully simulate all the forces that may occur in vivo with RSA. The test setup used a uniform defect oriented over the superior glenoid, which varied by 25% in size between groups and may not accurately simulate the variations in size and orientation of the defects seen in vivo. Other limitations relate to the use of polyurethane foam. Whereas efforts were made to simulate the clinical environment, including placement of screws within torque limits, variations in patient bone quality may have different effects on baseplate fixation strength. In addition, the screws placed were all within the foam model and did not obtain bicortical purchase that may occur in vivo. Finally, this study represents the initial fixation obtained by the glenoid baseplate. With the restrictions of postoperative rehabilitation protocols, osseous integration of the glenoid baseplate may occur well before the 10,000 cycles tested in this study.

Conclusions

Glenoid baseplate fixation in the setting of glenoid bone loss is no different when 50%, 75%, or 100% of the baseplate is supported by glenoid bone. However, bone loss resulting in only 25% of the baseplate supported by glenoid bone results in significantly greater micromotion, often above the 150-μm threshold necessary for bone ingrowth. If >50% of the baseplate will be unsupported by bone after the preferred glenoid preparation, a decision to employ other techniques, such as further reaming, bone grafting, or use of an augmented baseplate, should be considered.

Disclaimer

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References

Appendix A. Raw data from individual testing blocks, by group.

RSP baseplate motion (reported in micrometers) as a function of baseplate coverage (4 locked screws used).

| Cycle number | Treatment Specimen | Baseline | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 | 6500 | 7000 | 7500 | 8000 | 8500 | 9000 | 9500 | 10,000 |
|--------------|-------------------|----------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 1            | 50% baseplate      |          |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |
| 23%          | 1                 | 33.3     | 32.9 | 34.3 | 35.6 | 36.2 | 35.8 | 37.4 | 41.3 | 38.9 | 39.1  | 39.5 | 40.9 | 42.4 | 41.1  | 41.1  | 41.5  | 42.8 | 41.7  | 43.0  | 43.6  | 43.8  | 44.2  |
| 24%          | 2                 | 49.9     | 46.3 | 49.9 | 50.1 | 49.3 | 50.7 | 52.1 | 52.3 | 49.5 | 54.6 | 51.3 | 52.7 | 51.5 | 51.1  | 51.3  | 51.7  | 53.1  | 52.5  | 53.7 | 51.5  | 56.6  | 56.8  | 54.1  |
| 25%          | 3                 | 33.3     | 32.9 | 34.3 | 35.6 | 36.2 | 35.8 | 37.4 | 41.3 | 38.9 | 39.1  | 39.5 | 40.9 | 42.4 | 41.1  | 41.1  | 41.5  | 42.8 | 41.7  | 43.0  | 43.6  | 43.8  | 44.2  |
| 26%          | 4                 | 44.0     | 44.0 | 44.4 | 45.6 | 46.3 | 46.5 | 46.0 | 46.1 | 43.3 | 52.8 | 56.3 | 60.2 | 64.1 | 67.4  | 71.4  | 73.3  | 76.8 | 73.4  | 73.8  | 82.5  | 85.0  | 86.6  |
| 27%          | 5                 | 32.8     | 32.8 | 33.7 | 33.7 | 33.9 | 33.2 | 33.2 | 33.1 | 32.2 | 32.4 | 32.7 | 33.9 | 33.3 | 33.9  | 33.9  | 33.7  | 34.3 | 34.1  | 34.9  | 34.6  | 35.0  | 35.6  |
| 28%          | 6                 | 47.5     | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5  | 47.5  | 47.5  | 47.5 | 47.5  | 47.5  | 47.5  | 47.5  | 47.5  |
| 29%          | 7                 | 57.5     | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5  | 57.5  | 57.5  | 57.5 | 57.5  | 57.5  | 57.5  | 57.5  | 57.5  |
| 30%          | 8                 | 67.5     | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5  | 67.5  | 67.5  | 67.5 | 67.5  | 67.5  | 67.5  | 67.5  | 67.5  |

Avg, average; SD, standard deviation; Min, minimum; Max, maximum.