Background: In this glenoid loosening study, we compared the fixation strength of multiple generic reverse shoulder glenoid baseplates that differed only in backside geometry and shape and size to optimize design from a fixation perspective.

Methods: The fixation strength of 4 generic baseplates was quantified in a low-density polyurethane substrate to isolate the contribution of baseplate profile and size (25 mm circular vs 25 × 34 mm oval) and backside geometry (flat back vs curved back) on fixation using 2 center-of-rotation glenospheres (0 mm and 10 mm lateral). The cyclic test simulated 55° of abduction as a 750 N load was continuously applied to induce a variable shear and compressive load. Before and after cyclic loading, baseplate displacement was measured in the directions of the applied static shear and compressive loads. Each generic baseplate was cyclically tested 7 times with each offset glenosphere for a total of 56 samples.

Results: Circular baseplates were associated with significantly more shear displacement in both the superior-inferior (SI) and anterior-posterior (AP) directions after cyclic loading than oval baseplates. No such significant differences in fixation were observed between flat-back and curved-back baseplates. Circular baseplates were also associated with significantly more SI and AP shear displacement with 10 mm glenospheres than with 0 mm glenospheres. No significant difference in SI or AP motion was observed with oval baseplates between 0 mm and 10 mm glenospheres.

Discussion: Our results suggest that baseplate shape and size affects fixation strength more than backside geometry. The 25 × 34 mm oval baseplates showed better fixation characteristics than their 25 mm circular counterparts; no discernible difference in fixation was observed between flat-back and curved-back baseplates.

No institutional review board approval was required (biomechanical evaluation in polyurethane bone-substitute substrate blocks).
Reverse total shoulder arthroplasty (rTSA) is an effective salvage solution for many difficult-to-manage degenerative shoulder conditions. As the use of rTSA continues to expand to younger, more active patients and to patients with more eroded and poorer quality bone, the need for improved fixation increases. Achieving long-term glenoid fixation with the reverse prosthesis is an outcome that is partially under the surgeon’s control. Some authors have shown that screw positioning can improve initial fixation strength in both the intact glenoid and the glenoid with bone defects, whereas other authors have suggested that glenoid baseplate or glenosphere inclination may increase the susceptibility to aseptic loosening. Another factor that is under the surgeon’s control is prosthesis choice.

Multiple manufacturers have developed different rTSA glenoid designs over the past decade. Although many share similar characteristics, these devices often vary with respect to their specific design parameters, such as baseplate shape, baseplate size, baseplate backside geometry or curvature, baseplate surface finish, number of screws used to achieve fixation, type of screws used to achieve fixation, and position of the center of rotation. At this time, it is unclear to what extent these different rTSA design parameters affect performance and which are the most significant contributors to achieving glenoid fixation.

An rTSA glenoid loosening test methodology was developed to simulate the clinical loading pattern of the reverse shoulder and quantify initial implant fixation. Previous studies using this method have shown that various implant designs, substrate densities, bone morphologies, and wear patterns can significantly affect rTSA glenoid fixation strength. However, it is unknown how each rTSA glenoid design parameter individually contributes to these observed differences in fixation strength. Experimentally isolating and examining various design parameters in the rTSA implant would increase our understanding of the factors contributing to fixation and would aid efforts to optimize rTSA designs from a fixation perspective. To that end, this study quantifies and compares the fixation strength associated with 4 different “generic” rTSA glenoid baseplates to isolate the contribution of baseplate profile and size (25 mm circular vs 25 × 34 mm oval) and backside geometry (flat back vs 2-inch spherical-radius curved back) on initial fixation using 2 different offset center-of-rotation glenospheres (0 mm and 10 mm lateral).

**Methods**

As described previously, the rTSA glenoid loosening test method is composed of a displacement test and a cyclic test and is conducted in 3 phases: phase 1, pre–cyclic displacement test; phase 2, cyclic test; and phase 3, post–cyclic displacement test (Fig. 1). In the pre– and post–cyclic displacement tests, the axial testing machine (model 8872; Instron, Norwood, MA, USA) (axial resolution of 0.001 mm and accuracy of 0.017 mm) and 3 digital indicators (model ID-C112EB; Mitutoyo, Kawasaki, Japan) (resolution of 0.001 mm and accuracy of 0.003 mm) measured baseplate displacement as a 50 N compressive axial load was applied perpendicular to the glenoid and a 357 N shear load was applied parallel to the face of the glenoid baseplate along its superior-inferior (SI) axis; we then performed the procedure a second time, turning the component 90° and loading it along its anterior-posterior (AP) axis. Two dial indicators were used to subtract out any compliance of the test construct; displacement was measured in the direction of the applied shear and compression loads to the nearest micron and applied along the SI and then the AP axes of each prosthesis. During the cyclic test, the glenosphere was dynamically rotated in a 55° arc at 0.5 Hz for 10,000 cycles along the SI axis (to simulate humeral abduction) as 750 N was constantly applied through a humeral liner.

In this study, we assessed the fixation of 4 different generic rTSA glenoid baseplate designs that were identical except for baseplate profile and size (25 mm circular vs 25 × 34 mm oval) and backside geometry (flat back vs 2-inch spherical-radius curved back): (1) oval/curved back, (2) oval/flat back, (3) circular/curved back, and (4) circular/flat back (Fig. 2). All baseplates achieved initial fixation in a 0.24 g/cm² polyurethane bone-substitute block (76 mm × 57 mm × 48 mm; Pacific Research Laboratories, Vashon, WA, USA) (conforming to American Society for Testing and Materials [ASTM] F1839) using an 8 × 16.5 mm press-fit tapered cage peg and 4 identical, 4.5 × 30 mm polyaxial compression screws that were oriented perpendicular to each baseplate and locked with caps. It should be noted that the tapered central cage peg of each baseplate was of identical size, shape, and length and was implanted into each substrate block at the same location with the same instruments to achieve the same amount of press fit (0.5 mm). We tested a quantity of 7 of each generic baseplate using 2 different lateral offset 38 mm glenospheres (0 mm and 10 mm) (Fig. 3), for a total of 56 tests. A 2-tailed Student unpaired t test (with significance defined as P < .05) was used to compare the SI and AP shear displacements associated with each baseplate with each offset glenosphere before and after cyclic loading. Baseplates of similar features were also grouped and compared by use of the same statistical method.

**Results**

All devices remained well fixed after 10,000 cycles of loading. The mean SI and AP shear displacement before and after cyclic loading for each baseplate design when grouped as oval or circular and when grouped as curved back or flat back with the 0 mm and 10 mm glenospheres is presented in Tables I and II, respectively. As shown
in Table I, circular baseplates were associated with significantly more shear displacement in both the SI and AP directions after cyclic loading than oval baseplates. In addition, circular baseplates were associated with significantly more SI and AP shear displacement with 10 mm glenospheres both before and after cyclic loading than with 0 mm glenospheres. Conversely, no significant difference in SI or AP motion was observed with oval baseplates either before or after cyclic loading between the 0 mm and 10 mm glenospheres.

As shown in Table II, no significant difference in SI or AP motion either before or after cyclic loading was observed between the curved-back and flat-back baseplates. However, flat-back baseplates were associated with significantly more SI motion both before and after cyclic loading and significantly more AP motion after cyclic loading with 10 mm glenospheres than with 0 mm glenospheres. Conversely, curved-back baseplates were only associated with significantly more AP motion before cyclic loading with 10 mm offset glenospheres than with 0 mm glenospheres.

The mean SI and AP shear displacement before and after cyclic loading for each individual baseplate design (eg, oval/curved back, oval/flat back, circular/curved back, and circular/flat back) with the 0 mm and 10 mm glenospheres

Figure 1  Glenoid loosening before and after cyclic displacement test (left) and cyclic test (right).

Figure 2  Four generic rTSA glenoid baseplates, from left to right: oval/curved back, oval/flat back, circular/curved back, and circular/flat back. The top row and bottom row depict the top view and side view, respectively.

Figure 3  Representative generic glenoid baseplate assembled to 0 mm offset (left) and 10 mm offset (right) 38 mm glenosphere.
is presented in Table III. As shown in Table III, circular baseplates (both curved back and flat back) with the 10 mm offset glenospheres were associated with significantly more SI and AP shear displacement than when used with 0 mm glenospheres. No difference in either SI or AP shear displacement was observed with oval baseplates (both curved back and flat back) when used with the 0 mm and 10 mm glenospheres.

Comparing oval/curved-back and oval/flat-back baseplates, we observed no significant differences in displacement between baseplates in the SI or AP directions before or after cyclic loading using either the 0 mm or 10 mm glenospheres. When oval/curved-back and circular/curved-back baseplates were compared, shear displacement after cyclic loading was significantly larger with the circular/curved-back baseplates in the SI direction using the 0 mm glenosphere ($P = .008$) and significantly larger in both the SI ($P = .0046$) and AP ($P = .0034$) directions using the 10 mm offset glenosphere than that with the oval/curved-back baseplates. In addition, shear displacement after cyclic loading trended larger with the circular/curved-back baseplates in the SI direction using the 0 mm glenosphere ($P = .063$) than that with the oval/curved-back baseplates. When oval/flat-back and circular/flat-back baseplates were compared, shear displacement after cyclic loading was significantly larger with the circular/flat-back baseplates in the SI direction using the 0 mm glenosphere ($P = .0019$) than that with the oval/flat-back baseplates. In addition, shear displacement after cyclic loading trended larger with the circular/flat-back baseplates in the AP direction using the 0 mm glenosphere ($P = .061$) than that with the oval/flat-back baseplates. Finally, when circular/curved-back and circular/flat-back baseplates were compared, shear displacement was significantly larger with the circular/curved-back baseplates in the SI directions both before ($P = .0258$) and after ($P = .0438$) cyclic loading and significantly larger in the AP directions both before ($P = .0173$) and after ($P = .0329$) cyclic loading using the 10 mm offset glenosphere than that with the circular/flat-back baseplates.

**Discussion**

The results of this rTSA glenoid loosening study of 4 different generic baseplate designs show that each device remained well fixed after cyclic loading and that each device achieved comparable initial fixation using the same testing method as that of other currently marketed devices in the same density substrate. However, numerous differences in fixation were observed. A comparison of these
generic implants shows that baseplate size and shape contributes more to baseplate fixation than baseplate backside geometry, with 25 mm circular baseplates being associated with significantly more SI and AP displacement after cyclic loading than 25 × 34-mm oval baseplates in this low-density bone-substitute substrate model. No such differences in fixation were observed between curved-back and flat-back baseplates in the generic implants tested in this study. In addition, circular baseplates were more affected by the use of larger offset glenospheres than oval baseplates, with circular baseplates being associated with significantly more SI and AP shear displacement with 10 mm offset glenospheres both before and after cyclic loading than with 0 mm glenospheres. No significant differences in SI or AP displacement were observed before or after cyclic loading with oval baseplates when used with 0 mm and 10 mm glenospheres.

The smallest mean shear displacement before and after cyclic loading observed with the 0 mm glenosphere occurred with the oval/flat-back baseplate, and the smallest mean shear displacement before and after cyclic loading observed with the 10 mm offset glenosphere occurred with the oval/curved-back baseplate. Conversely, the circular/curved-back baseplate was observed to have the largest mean shear displacement before and after cyclic loading with both the 0 mm and 10 mm offset glenospheres. The most likely reason for the improved performance associated with oval baseplates is that they are larger in the primary direction of loading (eg, the SI direction) and have greater surface contact area than the smaller circular baseplates. Greater surface contact area at the bone-implant interface may be an important contributing factor to improving fixation strength. Another potential reason for the improved performance associated with the oval baseplates is that they have a slightly larger SI spread in their screw pattern than that of the circular baseplates (19.2 mm vs 14.2 mm); all generic devices have the AP screw pattern spread of 14.2 mm. Future testing of different-sized oval baseplates against different-diameter circular baseplates (matched with equivalent surface area to these corresponding oval baseplates and equivalent screw position) may help to clarify this relationship and elucidate whether surface contact area or the extended SI axis and resulting larger spread in screw position are the primary reasons for these observed improvements in fixation strength.

Table III: Comparison of mean baseplate shear SI and AP motion in 0 mm and 10 mm offset glenospheres

<table>
<thead>
<tr>
<th></th>
<th>Shear displacement (μm): before/after cyclic loading</th>
<th>P value (before/after cyclic loading)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 mm Glenosphere</td>
<td>10 mm Glenosphere</td>
</tr>
<tr>
<td>Oval/curved back</td>
<td>SI 161 ± 18/156 ± 30</td>
<td>156 ± 15/160 ± 16</td>
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<tr>
<td></td>
<td>AP 165 ± 28/168 ± 24</td>
<td>175 ± 24/175 ± 14</td>
</tr>
<tr>
<td>Oval/flat back</td>
<td>SI 150 ± 15/144 ± 5</td>
<td>202 ± 108/204 ± 114</td>
</tr>
<tr>
<td></td>
<td>AP 157 ± 21/154 ± 15</td>
<td>215 ± 129/198 ± 63</td>
</tr>
<tr>
<td>Circular/curved back</td>
<td>SI 169 ± 17/202 ± 51</td>
<td>224 ± 31/310 ± 113</td>
</tr>
<tr>
<td></td>
<td>AP 168 ± 32/203 ± 49</td>
<td>238 ± 47/286 ± 79</td>
</tr>
<tr>
<td>Circular/flat back</td>
<td>SI 162 ± 7/166 ± 14</td>
<td>194 ± 8/212 ± 20</td>
</tr>
<tr>
<td></td>
<td>AP 173 ± 16/174 ± 21</td>
<td>187 ± 11/210 ± 25</td>
</tr>
</tbody>
</table>

* Statistically significant (P < .05).
These results suggest that when the orthopaedic surgeon is using such a device, he or she should consider selecting a larger, more oval-shaped baseplate to increase fixation strength and resist the greater expected torque on the glenoid fixation surface resulting from the use of a lateralized center-of-rotation device.

No difference in fixation was observed between flat-back and curved-back baseplates. Two different computer studies have previously shown that curved-back baseplates are associated with more glenoid bone surface contact area than flat-back baseplates, which, as stated previously, may contribute to improved fixation strength.13,16 However, implantation of some curved-back baseplates may require more bone removal. Roche et al16 previously quantified the cortical and cancellous bone volume removed during a simulated implantation of a flat-back baseplate and 2 different curved-back baseplates. They reported that the 26 mm circular/curved-back RSP baseplate (DJO, Austin, TX, USA) necessitated removal of the most cancellous glenoid bone and most overall glenoid bone (3.7 cm³), the 29 mm circular/flat-back Delta III baseplate (DePuy, Warsaw, IN, USA) removed the second most cancellous bone and the second most overall glenoid bone (3.6 cm³), and the 25 × 34 mm oval/curved-back Equinoxe baseplate (Exactech, Gainesville, FL, USA) removed the least cancellous bone and least overall glenoid bone (3.3 cm³).16 Conversely, James et al13 quantified the bone volume removed to simulate implantation of 2 other rTSA baseplate designs—one circular/flat back (28 mm Trabecular Metal Reverse; Zimmer, Warsaw, IN, USA) and one oval/curved back (23 × 34 mm Anatomica Inverse; Zimmer)—and reported that the flat-back baseplate removed less bone than the curved-back baseplate. It is important to note that each of the aforementioned curved-back baseplates have a different backside curvature; this curvature influences the amount of bone removed and the amount of surface contact area with the glenoid. Because this rTSA glenoid loosening study was conducted in a uniform low-density bone-substitute substrate, future testing of curved-back baseplates with different backside curvatures should be conducted in dual-density substrates or actual cadaveric bone to clarify the relationships between cortical and cancellous surface contact area, cortical and cancellous bone removed, and fixation strength.

Our rTSA glenoid loosening study investigated the contribution of rTSA baseplate design in generic baseplates, isolating the impact of baseplate size and shape and baseplate backside geometry and how each relates to achieving fixation strength in a uniform, low-density bone-substitute model before and after cyclic abduction using 2 different offset glenospheres. To our knowledge, no other investigation has isolated and compared the impact of these parameters on initial fixation using generic implants. However, this study has some limitations. First, we did not evaluate the impact of implanting devices in a dual-density scapula model or in actual cadaveric bone as some other studies have done.1,3,12 In addition, we implanted each of the 4 generic baseplates perpendicular to the substrate and did not evaluate the impact of implanting each glenoid device with an inferior tilt, with an inferior shift, or in bones or bone-substitute models with a defect (simulating the impact of a partially unsupported baseplate) as some other studies have done.7,19-21 Finally, this study achieved initial fixation identically for each of the 4 generic baseplates using an 8 × 16.5 mm press-fit tapered cage peg and four 4.5 × 30 mm polyaxial compression screws that were oriented perpendicular to each baseplate and locked with caps; it did not evaluate the impact of other methods of achieving initial fixation; the impact of using screws with different lengths, pitches, or diameters; or the impact of different numbers of screws or types of screws used to achieve fixation (eg, only locking or only compression screws) as some other studies have done.10,12,17

Conclusions

This study compared the fixation strength of multiple generic rTSA baseplate designs that differed only in backside geometry and shape or size. Although all tested devices remained well fixed, the relative displacement results suggest that baseplate shape and size affects initial fixation strength to a greater degree than baseplate backside geometry in this rTSA glenoid loosening test model. In a low-density polyurethane bone substitute, 25 × 34 mm oval baseplates showed better fixation characteristics than their 25 mm circular counterparts. Circular baseplates in this generic baseplate model were associated with the largest post–cyclic loading displacements overall, and when used with 10 mm offset glenospheres, they showed significantly larger displacements before and after cyclic loading than when used with 0 mm glenospheres. No discernible difference in fixation was observed between flat-back and curved-back baseplates in this generic baseplate model. Given the variety of rTSA prostheses available in the global marketplace, each with its own unique combination of design parameters, further studies are required to quantify the impact of other variables and characterize how different combinations of design parameters interact to affect fixation to optimize rTSA baseplate design and reduce the clinical occurrence of aseptic glenoid loosening.

Disclaimer

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References


