Inferior tilt fixation of the glenoid component in reverse total shoulder arthroplasty: A biomechanical study

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Abstract
Background: Glenoid component fixation with an inferior tilt has been suggested to decrease scapular notching, but this remains controversial. We aimed here to evaluate the effect of glenoid component inferior tilt in reverse total shoulder arthroplasty (RSA) on micromotion and loss of fixation of the glenoid component by biomechanical testing.

Hypothesis: Increased inferior reaming of the glenoid for inferiorly tilted implantation of the glenoid component will decrease glenoid bone stock and compromise the fixation of RSA.

Materials and methods: The micromotions of the glenoid components attached to 14 scapulae from fresh frozen cadavers were measured and compared between neutral and 10° inferior tilts in 0.7- and 1-body weight cyclic loading tests using digital-image analysis. The incidence of bone breakage or loss of fixation was assessed in the 1-body weight fatigue-loading test.

Results: Micromotion was higher with a 10° inferior tilt than with a neutral tilt during both the 0.7-body weight (36 ± 11 μm vs. 22 ± 5 μm; P = 0.028) and 1-body weight (44 ± 16 μm vs. 28 ± 9 μm; P = 0.045) cyclic loading. The incidence of bone breakage or loss of fixation was 17% and 60% with a neutral and 10° inferior tilt, respectively.

Discussion: Glenoid component inferior tilt fixation in RSA may reduce primary stability and increase mechanical failure of the glenoid component, thereby reducing longevity of the prosthesis. Accordingly, we recommend careful placement of the glenoid component when an inferior tilt is used.

Level of evidence: Level III, Basic Science Study.

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1. Introduction

Reverse total shoulder arthroplasty (RSA) is commonly used to treat patients with rotator cuff tear arthropathy [1–3], and the relative indications for RSA have recently expanded. However, glenoid component-related complications remain a concern, and are the most common cause of RSA failure [3–6].

Glenoid component loosening or scapular notching can affect the longevity and functional outcome of RSA [6,7]. Consequently, numerous studies have investigated optimal fixation methods for the glenoid component, such as inferior overhang, inferior tilt, and a more lateral center of rotation of the glenoid component both to improve its durability and minimize scapular notching [7–10]. A recent biomechanical study suggested that a 15° inferior tilt of the glenoid baseplate improved stability and reduced the likelihood of mechanical failure [9]. Meanwhile, using a computerized model, another study reported that inferior tilt resulted in greater impingement-free range of motion and in less scapular notching [8]. However, while several authors have shown that inferior tilt of the glenoid component reduces scapular notching [8,9,11,12], controversy still exists regarding its effects [7,10,13,14].

Therefore, the purpose of this study was to evaluate the influence of glenoid component inferior tilt on initial glenoid component fixation stability using fresh frozen cadavers of female individuals of >60 years of age by biomechanical testing. This particular group was considered suitable for study because it most commonly experiences cuff tear arthropathy. Given that cancellous and cortical bone thicknesses vary depending on the resection level, amount of the inferior glenoid, and peculiarity of the funnel-shaped scapular neck, we hypothesized that increased inferior reaming of the glenoid for inferiorly tilted implantation of the glenoid...
component would decrease glenoid bone stock and compromise the fixation of RSA.

2. Materials and methods

2.1. Specimens and prosthesis implantation

Seven pairs of fresh frozen human scapulae from 7 female donors (mean age ± standard deviation, 65.6 ± 3.9 years) were used. All soft tissues were dissected. Gross inspection showed no post-traumatic deformity or degenerative changes, such as glenoid wear. The length of the long axis from the highest to the lowest point of the glenoid, and the width of the anteroposterior diameters of the glenoid were measured using a caliper. The specimens were randomly assigned to 2 groups (7 scapulae in each): in one group, the glenoid was reamed at a neutral inclination and the glenoid component was implanted with a neutral tilt. In the other group, the glenoid was reamed, and the glenoid component was implanted, at a 10° inferior tilt. All native scapulae were implanted with a Tornier Aequalis® reversed shoulder prosthesis consisting of a 29-mm baseplate and 36-mm glenosphere (Tornier, Inc., Edina, MN, USA), according to the manufacturer’s recommendations. The baseplate was positioned as far inferiorly as necessary relative to the glenoid, while still being fully supported by the bone. Implantation of the baseplate and glenosphere with a neutral or 10° inferior tilt was accomplished using the neutral or 10°-inferior-tilt central guide hole included with the prosthesis instrumentation.

2.2. Biomechanical testing

The scapula with the implant was embedded in a rectangular resin block (Lang Dental Manufacturing Co., Inc., Wheeling, IL, USA) so that the medial border of the scapula was perpendicular to the floor, and bolted to the mounting plate on the custom-made axial-compressive loading machine. The humeral component of the prosthesis, consisting of a 6-mm polyethylene insert and 36-mm metaphysis and stem, was provisionally affixed to the machine. The specimens were mounted at an angle of 60° of abduction of the glenoid component to the humeral component (Fig. 1), and compressive cyclic loading was applied through the humeral cup assembly. Cyclic loads of 0.7-bodyweight (BW; 480 N, 2.5 Hz, 100 cycles) and 1-BW (686 N, 2.5 Hz, 100 cycles) were applied in parallel with the long axis of the humeral stem to the center of the glenosphere. A fatigue-loading test consisting of an application of 27,000 cycles of a repetitive 1-BW (68 N, 2.5 Hz) load was subsequently performed. Micromotion at the inferior third of the glenoid-glenosphere interface during the cyclic loading test and the incidence of bone breakage and loss of fixation during the fatigue-loading test were assessed.

2.3. Digital-image analysis of micromotion

For micromotion analysis, laser markers (1-mm diameter) were engraved 3 mm apart on the glenosphere surface and 1 mm from the rim of the glenosphere prior to implantation. White plastic markers (polyvinyl chloride, 2-mm diameter) were affixed with super glue to the adjacent bone surface near the glenoid-glenosphere interface (Fig. 2A). Micromotion of the glenoid component was defined as the difference in glenosphere displacement from the adjacent bone surface. The locations of the markers were recorded using a camera (Pearl CCD series; IMI Technology, San Diego, CA, USA) and a 2/3° 55-mm telecentric lens (Computar TEC-M55; CBC AMERICAS Corp., Commack, NY, USA) (Fig. 2B). The camera was connected by a frame to the resin box in which the scapula with the implant was embedded and was positioned perpendicular to the micromotion measurement markers. Four surface markers (one and three on the surface of the bone and glenosphere, respectively) at the inferior third of the glenoid-glenosphere interface were used for measuring micromotion during the cyclic loading. Micromotion data were collected using a custom-made LabVIEW graphic interface (National Instruments Corporation, Austin, TX, USA). Each pixel had a value ranging from 0 to 255, which was converted into a binary image with values of 0 and 1. When pixels were present on the top, bottom, left, and right of a pixel, it was considered a particle. Particles with less than 7 pixels (considered noise) were deleted. The midpoint of each particle > 7 pixels in size was determined, and the distance between the vertical cross points was measured. Micromotions parallel (x-axis) and perpendicular (y-axis) to the bone-glenosphere interface were assessed as the hypotenuse of the x- and y-axes measured during the biomechanical testing (Fig. 2C).

2.4. Statistical analysis

Comparisons of the micromotion between the neutral and 10° inferior tilt groups were conducted using Wilcoxon’s rank-sum test. All data are presented as mean ± standard deviation. All reported P-values were two-tailed, and P<0.05 was considered as
Fig. 2. Digital-image analysis of micromotion. A. Markers on the glenosphere and the adjacent bone surface for micromotion analysis. The dashed red circle depicts the measuring area of the micromotion. B. Images captured by the camera. C. Micromotion analysis by particle analysis and caliper function of the custom-made LabVIEW graphic intersurface.

Table 1
Size of the glenoid and length of the screws used for baseplate fixation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Neutral tilt (mm)</th>
<th>10° inferior tilt (mm)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenoid length</td>
<td>32.2 ± 2.3</td>
<td>32.9 ± 2.2</td>
<td>0.646</td>
</tr>
<tr>
<td>Glenoid width</td>
<td>23.0 ± 2.4</td>
<td>24.0 ± 2.3</td>
<td>0.433</td>
</tr>
<tr>
<td>Anterior screw</td>
<td>20.8 ± 5.0</td>
<td>17.1 ± 1.9</td>
<td>0.200</td>
</tr>
<tr>
<td>Posterior screw</td>
<td>16 ± 0</td>
<td>16 ± 0</td>
<td>1.000</td>
</tr>
<tr>
<td>Superior screw</td>
<td>26.8 ± 4.3</td>
<td>26.8 ± 4.8</td>
<td>0.903</td>
</tr>
<tr>
<td>Inferior screw</td>
<td>31.3 ± 6.6</td>
<td>29.1 ± 5.0</td>
<td>0.686</td>
</tr>
</tbody>
</table>

All data are presented as mean ± standard deviation.

a minimum level of statistical significance. All statistical analyses were performed with SAS version 9.2 (SAS Institute Inc., Cary, NC, USA).

3. Results

The means, standard deviations, and P-values for the glenoid size and used screw length are listed in Table 1. The mean micromotion at the inferior third of the glenoid-glenosphere interface was significantly greater in the 10° inferior tilt group than in the neutral tilt group (Fig. 2) [22 ± 5 μm vs. 22 ± 5 μm; P=0.028] and 1-BW cyclic loading (44 ± 16 μm vs. 28 ± 9 μm; P=0.045). Bone breakage or loss of fixation during the fatigue-loading test occurred in 1 specimen in the neutral tilt group between approximately 4000–6000 cycles. In the 10° inferior tilt group, 3 specimens showed bone breakage or loss of fixation during the fatigue-loading test: 1 each between approximately 0–2000, 4000–6000, and 15,000–17,000 cycles. The incidence of bone breakage or loss of fixation was 17% and 60% in the neutral and 10° inferior tilt groups, respectively. All bone breakages occurred at the inferior aspect of the glenoid and scapular surrounding area of the inserted inferior screw (Fig. 3).

4. Discussion

In this study, we found that inferior tilt fixation of the glenoid component was detrimental to the initial glenoid component fixation stability as a result of increased inferior reaming, which consequently lead to decreased glenoid bone stock for inferiorly tilted implantation of the glenoid component.

Several retrospective uncontrolled clinical studies have suggested that glenoid component fixation with inferior tilt increases fixation stability and decreases scapular notching [3,5,12]. Meanwhile, a biomechanical study by Gutierrez et al. showed that implanting a baseplate at a 15° inferior tilt provided a more even distribution of compressive forces and less micromotion at the bone-base plate interface [9]. Moreover, it has been reported that inferiorly tilting the glensphere decreases scapular notching, and

Fig. 3. All bone breakages or loss of fixation of the glenoid component occurred at the inferior aspect of the glenoid and scapular surrounding area of the inferior screw inserted during the fatigue-loading test.

that an inferior tilt of the glenoid component enhances glenoid fixation [8].

Although numerous reports suggest that an inferior tilt of the glensphere improves long-term stability of the reverse shoulder prosthesis, controversy still exists regarding the influence of inferior tilt on the glenoid component [7–9,11,13–15], and biomechanical studies have offered conflicting recommendations for glenoid component inclination. A previous biomechanical study of cadaveric shoulders showed that placing the glenoid component at an inferior tilt alone was not as effective in preventing inferior impingement as placing the component without a tilt but in a more inferiorly translated position of the glensphere to the glenoid [10]. This previous study also showed the range of shoulder motion was limited to a greater extent in the specimens that had a glenoid component inferior tilt [10]. Simovitch et al. [7] showed that inferior tilt of the baseplate and glensphere resulted in an increase in the prosthetic-scapular neck angle, which increased the probability of inferior scapular notching. Moreover, the results of recent clinical studies have indicated that there are no radiographic or clinical benefits of placing the glenoid component of a reverse shoulder prosthesis at a 10° inferior tilt compared with a neutral position [16], and that inferiorly tilting the glensphere does not significantly reduce the incidence of scapular notching [13].

Limitations of the previous biomechanical studies advocating inferior tilting of the glenoid component to enhance glenoid fixation include the use of solid rigid polyurethane foam or sawbone...
blocks to simulate the mechanical properties of the glenoid bone, and the use of a 15° tilt relative to the flat surface of the block [9,14,17]. Furthermore, some studies proposing inferiorly tilted placement of the glenoid component used computer simulation, which does not consider the anatomic variations or material characteristics of a true glenoid bone [8,14], and most of these studies evaluated only the range of motion associated with impingement or inferior scapular notching without assessing fixation stability.

The fundamental strength of the present study is that the influence of an inferior tilt of the glenoid component on the stability of the bone-glenoid component interface was evaluated using fresh frozen cadavers of females aged >60 years, in whom cuff tear arthropathy most frequently occurs. We believe this better reflects the anatomy and mechanical properties of the glenoid bone, and thus enables better assessment of glenoid component stability in RSA.

We used digital-image analysis of micromotion obtained from biomechanical testing, which is more reliable than the gauge method [18]. There are some biomechanical and finite element studies assessing micromotion of the glenoid component of the Delta III design (DePuy Orthopaedics), which is similar to the prostheses used in our study, using polyurethane foam blocks with compressive loads and shear loads of 1-BW. Harman et al. [17], Hopkins et al. [19], and Virani et al. [20] reported 90 μm of motion of the baseplate under experimental conditions, 55–67 μm of motion in a finite element model, and 57–69 μm of motion at the glenoid bone and baseplate interface in a finite element model, respectively. Favre et al. [18] assessed the micromotion of the glenoid component with high-resolution digital imaging and reported 5–20 μm of motion in an experimental setting. In their study, the mean micromotion at the bone-glenosphere interface using human scapulae was 14–44 μm, and the micromotion results in the neutral tilt group were 10–30 μm [18], which are similar to the results of our study.

The present study showed that, compared to glenoid component neutral tilt, an inferior tilt increased the micromotion at the bone-glenoid component interface and induced more bone breakage or loss of fixation of the glenoid component. These results correspond to, and expand on, the findings of Nyffeler et al. [10], who reported that inferior tilt does not yield results as good as those obtained when placing the glenoid component distally and that it reduces the surface area of the glenoid, which may compromise the stable fixation of the glenoid component.

Our study has some limitations. First, the 0.7-BW and 1-BW axial-compressive loads used are near the maximum values estimated to occur in the shoulder during normal daily activities [21–23]. In addition, we applied relatively few loading cycles to simulate shoulder mechanics during activity. Previous assessments of cemented glenoid components have used longer-duration tests (100,000 cycles) to simulate 25 years of in vivo function and to evaluate the strength of the cement interface during prolonged cyclic loading [24,25]. Given the high amount of axial-compressive loading forces in our study, we thought a shorter-duration test would not influence the results in the evaluation of the initial fixation stability of the glenoid component [18,20]. Second, we did not use cadaveric shoulders with rotator cuff arthropathy, which is the most common indication for RSA. The stability of inferiorly tilted glenoid component fixation on a normal glenoid may be different from that on a worn glenoid bone with rotator cuff arthropathy. Third, we assessed glenoid component stability only at an abduction angle of 60°, and a different abduction angle may affect the stability of the glenoid component. Finally, we did not account for the stabilizing effects of the ligaments, joint capsule, or remaining rotator cuff muscles, which may further affect the biomechanics of RSA.

5. Conclusion

This study demonstrates that inferior tilt of the glenoid component in RSA increases micromotion at the bone-glenoid component interface and loss of fixation of the glenoid component. These results suggest that inferiorly tilting the glenoid component may reduce primary stability and increase the likelihood of mechanical failure of the glenoid component and that it may be detrimental to the longevity of the prosthesis.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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