Evaluation of the role of glenosphere design and humeral component retroversion in avoiding scapular notching during reverse shoulder arthroplasty

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**Background:** Scapular notching is a common observation during radiological follow-up of reverse shoulder arthroplasty. The purpose of this study was to evaluate the effect of glenosphere design and humeral component retroversion on movement amplitude in the scapular plane and inferior scapular impingement.

**Materials and methods:** The Aequalis Reversed Shoulder Prosthesis (Tornier) was implanted into 40 cadaver shoulders. On the glenoid side, 8 different combinations were tested:
- 36-mm glenosphere: centered (standard), eccentric, with an inferior tilt, or with the center of rotation (COR) lateralized by 5 or 7 mm; and
- 42-mm centered glenosphere: used alone or with the COR lateralized by 7 or 10 mm.

The humeral component was positioned in 0°, 10°, 20°, 30°, and 40° of retroversion. Maximum adduction and abduction were measured when inferior impingement and superior impingement, respectively, were detected.

**Results:** The average increase in abduction amplitude was 10° and inferior impingement occurred 18° later with a 42-mm glenosphere, especially when it was lateralized by 10 mm, relative to a 36-mm centered glenosphere (P < .05). These 2 combinations provided a 28° increase in the movement amplitude in the scapular plane. Positioning of the humeral component in 10° or 20° of retroversion or in anatomical retroversion was most effective at avoiding inferior impingement but had less effect on abduction range of motion (except with the 42-mm glenosphere).

**Conclusion:** Our study confirmed published results with various glenosphere designs but was unique in describing the effect of humeral retroversion on scapular impingement. Inferior scapular notching can be most effectively prevented by using large-diameter glenospheres with lateralized COR and by making sure to replicate the patient’s native humeral retroversion.

**Level of evidence:** Basic Science Study, Biomechanics, Cadaver Model.

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**Keywords:** Reverse shoulder arthroplasty; glenoid modularity; humeral version; scapular notching

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The reverse shoulder prosthesis developed by Grammont in 1985 is now the preferred treatment option in older patients with cuff tear arthropathy. The survival rate in this indication has been reported to range from 89% to 91% at 10 years. The most common radiological complication with this implant is the occurrence of notching in the scapular pillar, which has been reported in 56%
The average age at death was 79.1 years (range, 61-95 years). The

Materials and methods

Impingement, from 30

version.18 Stephenson et al 25 recently described that

humeral component should be implanted with slight retro-

notching. Walch and colleagues have shown that the

seemed to be with use of an eccentric glenosphere.

Various solutions have been proposed to get around this

problem. One is to provide less medialization of the center of

rotation (COR). Franklin6 used a glenosphere that was more

than a half-sphere. No scapular notching was observed after an

average follow-up of 33 months. Kalouche14 and Valenti29

proposed an implant by which the COR was lateralized by

8.5 mm. No scapular notching was evident after an average

follow-up of 36 months. On the basis of this observation,

a bone graft lateralization technique called BIO-RSA (bony

follow-up of 36 months.1

was reduced to 20%, and no glenoid loosening was observed

with an average follow-up of 28 months.1

Other technical modifications have been recommended to

prevent scapular notching. Nyffeler19 proposed lowering the

glenosphere by positioning the base plate in line with the

lower edge of the glenoid. Kelly15 positioned the central

peg of the glenoid base plate 12 mm above the lower edge of

the glenoid, which resulted in a 3.5-mm inferior over-

hang with use of a 29-mm-diameter base plate. Around the

same time, eccentric and tilted glenspheres became available and were used in attempts to reduce inferior im-pingement by moving the joint COR downward. Limited
data exist on these newer implants. Gutiérrez showed that the greatest abduction range of motion occurred when
glenospheres with a lateralized COR were used.10-12

Conversely, the most effective way of preventing notching

seemed to be with use of an eccentric glenosphere.

The humeral component, specifically the retroversion

of this implant, can also be altered to prevent scapular

notching. Walch and colleagues have shown that the

humeral component should be implanted with slight retro-

version.18 Stephenson et al25 recently described that

placement of the humeral component between 20° and 40°
of retroversion restores a functional arc of motion without

impingement, from 30° glenohumeral abduction in the

scapular plane.

The purpose of this study was to evaluate the effect of various glensphere and humeral retroversion combinations

on abduction amplitude and the occurrence of scapular

impingement.

Materials and methods

Shoulders and implants

This was a cadaver study involving 40 arms (20 right, 20 left). The

average age at death was 79.1 years (range, 61-95 years). The
perpendicular to the glenoid surface. On the basis of the 12-mm rule,\textsuperscript{15} the glenoid was reamed with a 29-mm motorized reamer and then a 36- or 42-mm peripheral manual reamer. A 29-mm-diameter glenoid base plate was then impacted. If the hold was not satisfactory, a screw was added.

The humerus preparation consisted of finding the entry point for reaming in the extension of the diaphyseal axis, then cutting the humeral head with use of a guide. This guide allowed the humeral head to be resected in its anatomical retroversion position, which was measured relative to the axis of the forearm. Diaphysis reaming, metaphysis preparation with a 36-mm-diameter reamer, and then metaphysis and epiphysis junction reaming were performed manually. An intramedullary drill bit was then passed all the way through the olecranon with the elbow flexed at 90°. This allowed the implantation of the humeral component onto a threaded intramedullary rod. The protractor used to measure internal and external rotation was screwed onto this rod. The humerus component (in anatomical retroversion) was then linked to the articulated arm on the metal column. A small antirotation K-wire was placed in the metaphysis piece to lock the retroversion into place. Finally, the 36-mm-diameter lateralized humeral liner was implanted (Fig. 1).

**Zero position**

Before any measurements were taken, the zero position of the glenoid base plate was set. An alignment system with a bubble level and a center-punch centered over the base plate was used to level the plate and to make sure that it was perpendicular to the metal column where the measurement instruments were located. The zero position was set in various planes to ensure that the COR of the glenohumeral joint and the articulated arm were on the same axis (Fig. 2). Once the horizontal alignment of the glenoid was acceptable, the glenosphere was screwed onto the base plate. Each time a different base plate or glenosphere was used, the zero position was verified and reset as needed. The humeral retroversion was set with a K-wire that was adjusted relative to the axis of the forearm.

For each of the 40 shoulder specimens, the 8 previously described glenoid combinations were tested with 5 different levels of retroversion (0°, 10°, 20°, 30°, 40°). These measurements were made relative to the scapular plane; zero rotation was defined as the forearm with the elbow flexed at 90° being perpendicular to the scapular plane. The maximum range of motion in abduction and adduction was measured; the maximum amplitude value was determined when superior impingement and inferior impingement, respectively, were visible. When no impingement was visible in the range of the measurement instruments, an arbitrary value of 130° abduction was recorded.

**Statistical methods**

For the descriptive analysis, the results were presented as mean values with 95% confidence intervals. To evaluate the effect of various glenoid combinations on range of motion, the measurements were made with the humeral component in the anatomical retroversion position. To evaluate the effect of humeral version on the range of motion, the measurements were performed with each glenoid implant, and only the amount of humeral retroversion was changed. The Wilcoxon rank sum test was used to compare the ranges of motion between the various glenoid implants and humeral retroversion amounts. A \( P \) value below .05 was considered statistically significant. The statistical analyses were performed with StatView software (Version 4.1, Abacus Concepts Inc., Berkeley, CA, USA).

**Results**

**Effect of glenoid modularity on abduction and inferior scapular impingement** (Table I)

The shortest abduction range of motion of 86.5° ± 3.4° was found with use of a 36-mm-diameter centered glenosphere; this finding was significantly different from all the other glenospheres \( (P < .0001) \). Use of 42-mm-diameter glenospheres, especially in combination with 7- or 10-mm lateralization spacers, resulted in significantly more abduction than in the other cases \( (P < .03) \). No significant
Inferior impingement occurred the earliest (16.3° ± 2.9° of abduction; \( P < .0001 \)) when the 36-mm-diameter centered glenosphere was used. When 42-mm-diameter glenospheres and 7- or 10-mm lateralization spacers were used, the inferior impingement occurred the latest, respectively, at \(-1° ± 2°\) and \(2° ± 2°\) of abduction \( (P < .0001) \). Only the combination “glenosphere 42 mm + 10 mm lateralization” provided a slight amount of adduction \( (2° ± 2°) \) (Fig. 4).

The glenoid combinations providing the largest to smallest movement amplitude in the scapular plane in order are as follows: 42-mm glenosphere with 10-mm \( (P < .001) \) and 7-mm \( (P < .001) \) lateralization spacers; 42-mm glenosphere \( (P = .21) \) was equal to 36-mm-diameter glenosphere with 7-mm lateralization spacer \( (P = .02) \); 36-mm-diameter glenosphere with 5-mm lateralization spacer \( (P = .8) \) was equal to 36-mm eccentric glenosphere \( (P = .0017) \), 36-mm glenosphere with 10° tilt \( (P = .0001) \), and 36-mm centered glenosphere (Figs. 5 and 6).

**Effect of humeral retroversion on abduction and inferior scapular impingement**

The average anatomical humerus retroversion was 17° (range, 0° to 40°). The greatest abduction occurred with 40° of humeral retroversion and the least abduction occurred with 10° of retroversion for all the glenoid combinations evaluated \( (0.3 < P < .08) \). However, when 42-mm glenospheres were used with and without lateralization spacers, no retroversion effect was observed \( (P > .20) \). In anatomical retroversion, the abduction range of motion was similar to the 10° retroversion condition.

The progression of the maximum movement amplitude in the scapular plane as a function of humeral retroversion was similar for each glenoid implant tested. The inferior impingement occurred the earliest with 40° of humeral retroversion for all the tested implants, except for 36-mm-diameter centered or 10°-tilted glenospheres, for which no significant effect of retroversion was observed. Although the findings were not statistically significant, the impingement seemed to occur later with 10° and 20° of humeral retroversion, no matter which 36-mm glenoid combination was tested. In anatomical retroversion, the inferior impingement occurred at about the same adduction amplitude as with 10° of retroversion \( (P < .05) \).

Finally, humeral retroversion had no significant effect on the overall abduction range of motion.

**Discussion**

**Effect of glenoid modularity on abduction and inferior scapular impingement**

Scapular pillar notching (48% at 1 year and 60% at 2 years according to Sirveaux\(^{24} \)) is the main drawback observed during the radiological monitoring of reverse shoulder arthroplasty. For avoidance of this problem, technical recommendations for prosthesis implantation, especially for the overhang and inferior placement of the glenosphere, have been published.\(^{12,15,17,19,20,22,23} \) Others have chosen to lateralize the glenosphere, either by use of an appropriately shaped implant\(^{6,14,28} \) or by the addition of a bone graft.\(^{1} \) Different glenosphere shapes (eccentric, inclined) are now available. The purpose of this study was to evaluate the effect of these changes on shoulder range of motion and the risk of impingement.

Our results showed that the combination of 10-mm lateralization with a 42-mm glenosphere (resulting in a 6.5-mm overhang) provided the greatest range of motion in abduction and was more effective at preventing inferior scapular notching than when each of these parameters was used separately. One of the limitations of our study was the anatomical variation in our cadaver specimens. The shape of each scapular pillar was not analyzed. The length on the glenoid neck on the scapula can be classified as short or long.\(^{27} \) Consequently, the observed differences cannot be attributed only to the geometry of the tested implants. The variability in the implantation of the prosthesis components...
is another limitation of this study, although the surgical technique for this implant provided by the manufacturer was followed carefully. The evaluation of the impingement itself is also a study limitation because the effect of the soft tissues (mostly resected) was most likely underestimated relative to the clinical scenario. Similarly, blocking the scapulothoracic joint experimentally did not allow us to evaluate its role in preventing inferior impingement, which is said to occur through rotational movement of the scapula.13

### Table I

<table>
<thead>
<tr>
<th>Glenosphere combination</th>
<th>Maximum abduction</th>
<th>Maximum adduction</th>
<th>Abduction-adduction difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 mm + 10° tilt</td>
<td>87 (3)</td>
<td>16 (3)</td>
<td>70 (4)</td>
</tr>
<tr>
<td>36 mm + 5° eccentric + 2 mm lateralization</td>
<td>91 (3)</td>
<td>9 (3)</td>
<td>82 (4)</td>
</tr>
<tr>
<td>36 mm + 7° eccentric + 2 mm lateralization</td>
<td>91 (3)</td>
<td>9 (3)</td>
<td>82 (4)</td>
</tr>
<tr>
<td>42 mm (+ eccentric) + 2 mm lateralization</td>
<td>91 (3)</td>
<td>9 (3)</td>
<td>82 (4)</td>
</tr>
<tr>
<td>36 mm + 10 mm lateralization</td>
<td>96 (3)</td>
<td>-1 (2)</td>
<td>95 (4)</td>
</tr>
<tr>
<td>36 mm + 7 mm lateralization</td>
<td>96 (3)</td>
<td>-1 (2)</td>
<td>95 (4)</td>
</tr>
<tr>
<td>42 mm + 7 mm lateralization</td>
<td>96 (3)</td>
<td>-1 (2)</td>
<td>95 (4)</td>
</tr>
</tbody>
</table>

Data shown are mean values with 95% confidence intervals.

### Figure 3
Maximum elevation in degrees for the various glenoid combinations tested in anatomical humerus retroversion. Data shown are mean values with 95% confidence intervals.

### Figure 4
Maximum adduction in degrees for the various glenoid combinations tested in anatomical humerus retroversion. Data shown are mean values with 95% confidence intervals.
Other published studies have explored the same issues as the current study did. With an experimental Sawbones model, Gutiérrez compared the effect of 10-mm COR lateralization on 32-mm-diameter or 40-mm-diameter glenospheres, each positioned without overhang or inferior tilting. There was a 30° increase in abduction amplitude. In a second study, the abduction amplitude increased by 77° going from a 30-mm-diameter, nonlateralized, nonoverhanging glenosphere to a 42-mm-diameter, 10-mm lateralized glenosphere with inferior overhang. The benefit provided by each glenosphere positioning parameter was prioritized in a third study. A comparison between the Gutiérrez results and our results is difficult to accomplish because each parameter was presented independently. Gutiérrez reported that 10 mm of COR lateralization produced a 31° increase in abduction amplitude. This result was slightly better than in our study, although the 10-mm lateralization resulted in a 9-mm inferior overhang. Gutiérrez reported a 28° increase in amplitude with a 10-mm overhang and a 12.5° increase with a tilt of less than 10°. These increases were greater than the ones found in our study. In our study, the inferior overhang of 36-mm glenospheres was 6 mm, thus nearly 2 times less. Gutiérrez also analyzed the effect of glenosphere diameter: going from a 30-mm to a 42-mm glenosphere resulted in a 7° gain, which is half of what we observed going from 36 to 42 mm. This difference can be related to the approximate placement of the base plate relative to the inferior glenoid border.

In a computer simulation study, going from 38 to 46 mm increased the abduction amplitude and delayed the appearance of inferior impingement. However, use of a 46-mm-diameter glenosphere is not practical. Nyffeler also used cadaver shoulders to evaluate the effect of inferior glenosphere overhang but looked at only 8 samples. He noted that lowering the glenosphere by 2 mm was equivalent to providing a 15° tilt. Also, if a 4-mm gap existed between the lower edge of the glenosphere and the lower bony edge of the glenoid, abduction amplitude was greater and inferior impingement occurred later in the range of motion. These results were confirmed through postoperative radiological analysis. Notching was visible when the glenoid overhang was less than 4 mm.

The combined effect of these two parameters was evaluated on a Sawbones model. Inferior impingement occurred later in the range of motion when a larger diameter glenosphere was used (44 mm vs 36 mm) and when it was eccentric (4 mm vs 2 mm vs 0). An 18° difference in abduction amplitude was found when a 36-mm centered glenosphere was used versus a 44-mm eccentric glenosphere. The large-diameter factor seems to be most important as it was the only parameter to have had a significant effect on the abduction amplitude.

One of the strong points of our study was that a large number of shoulders were tested, which took individual anatomical variation into account. Also, the position of the humeral component was set each time on the basis of the anatomical retroversion, which was not done in any of the other studies. The same protocol was followed each time the glenoid component was implanted. Because none of the shoulders had visible signs of arthritis on the glenoid side, there were few barriers to proper implantation of the glenoid component. Thus the measured differences can be attributed to each of the tested implants.

On the basis of our work, lateralization (through use of a spacer) and a 6.5-mm inferior overhang (42-mm glenosphere with 29-mm base plate) seem to be the two most...
Avoiding scapular notching: glenoid and humeral factors

important criteria for optimizing range of motion and preventing notching. However, use of a large-diameter glenosphere is difficult in practice, in part because good surgical exposure is required to ensure proper positioning. The patient suffering from cuff tear arthropathy is often a woman of small stature. Use of a large-diameter glenosphere, even without lateralization, will be difficult and even impossible in this case because of its excessive volume. Although COR lateralization through the use of BIO-RSA leads to improvements, the inferior scapular notching could occur at the “newly formed long neck scapula.” The risk of glenoid component loosening is also greater because of higher loads at the glenoid base plate–bone interface, but this problem may be only a theoretical one. In a recent biomechanical study, the pull-out forces on the base plate fixation screws were the same for standard reverse implants and ones in which bone grafting or an offset implant design is used to achieve lateralization. Only the location of the loading differed, mostly on the upper screw for the lateralized implant design and mostly on the lower screw for the prosthesis with BIO-RSA. In another computer simulation study, there were no significant differences between implants without or with 10 mm of lateralization in the movement of the base plate when in contact with the glenoid. These data confirm the concept put forward by Boileau that keeping the COR inside the bone by using a bone graft to achieve lateralization does not increase the risk of glenoid loosening.

**Effect of humeral retroversion on abduction and inferior scapular impingement**

Currently, there is only one report on positioning of the humeral component in retroversion. Placing it between 20° and 40° of retroversion is recommended to restore a functional arc of motion in rotation without impingement; but this result was observed at 30° of glenohumeral abduction in the scapular plane, which is not a position of rest in daily living. There are also no details provided in the methodology about how the version of the glenosphere was controlled. In our study, superior impingement occurred later in the range of motion with 30° and 40° of retroversion, whereas inferior impingement occurred earlier. The effect of a large amount of retroversion on preventing superior impingement was statistically significant, no matter which glenosphere was used. Conversely, the effect of a large amount of retroversion on the occurrence of premature inferior impingement was significantly less important when the glenosphere was lateralized. We looked at the influence of humeral component retroversion on the inferior impingement because we wanted to know what happens when the arm hangs down at a person’s side. Nevertheless, the appropriate humeral retroversion cannot be recommended on the basis of these results because only abduction movements were assessed. A study of internal and external rotation should be performed because any limitations in these movements result in unpleasant consequences during activities of daily living for patients receiving a reverse shoulder arthroplasty. Along with glenosphere design, the effect of the neck-shaft angle of the humeral component should also be considered in trying to prevent inferior notching.

**Conclusion**

Glenoid combinations associating a 7- or 10-mm-thick lateralization plate and a 42-mm glenosphere were most effective at reducing the risk of scapular pillar notching and increasing the range of arm elevation in the scapular plane. In current practice, large-diameter implants, with or without lateralization, are difficult to work with. Use of an intermediate-sized, 39-mm glenosphere could be a good compromise.

Inferior impingement with the scapular pillar occurred later with the humeral component in 10° or 20° of retroversion. However, before this retroversion value is adopted in current practice, the effect on internal and external rotation and the occurrence of anterior-posterior impingement must be evaluated.

**Disclaimer**

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