The effect of glenoid version on internal and external rotation in reverse total shoulder arthroplasty

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ABSTRACT

Background: There is currently limited understanding of the contribution of glenoid version to postoperative internal (IR) and external rotation (ER) after reverse total shoulder arthroplasty (RTSA). The purpose of this study was to determine the impact of glenoid version on postoperative rotation after RTSA.

Methods: Forty-five 3-dimensional (3D) computer models of human scapulae were created from de-identified computed tomography (CT) scans. The scapulae were divided into 3 separate groups based on glenoid version: normal (10° to -10°), moderate (-10 to -25°), and severe (< -25°). The scapulae then underwent virtual implantation with a Grammont-style RTSA prosthesis at either 0°, -20°, or -30° of retroversion based on the severity of the native glenoid version (normal, moderate, severe). Internal, external, and total rotation (TR) were determined for each construct at both 30° and 60° of humeral abduction.

Results: Glenoids with a narrow width (< 25 mm) were noted to have minimal bony impingement on rotational testing and were excluded. In the remaining scapulae (n = 34), the achievable TR and IR for the humeral component decreased as glenoid retroversion increased. Changes in rotation for all categories were in general more pronounced at 60° of humeral abduction. Overall, ER generally increased as glenoid retroversion increased, with the largest increase occurring when going from 0° to -20° of retroversion, and minimal increase from -20° to -30° of retroversion regardless of humeral abduction.

Conclusion: Placement of the glenoid component in increasing retroversion during RTSA results in a loss of IR and a corresponding increase in ER.

Level of Evidence: Basic Science Study

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Obtaining full internal (IR) and external rotation (ER) after reverse total shoulder arthroplasty (RTSA) is a challenging task even with modern, highly modular implant designs [2,17,30,36,45]. Clinically, a lack of rotation after RTSA is associated with reduced outcome scores, decreased patient satisfaction, and difficulty in performing activities of daily living [2,8,17,36,38,40,46]. In patients with a total shoulder arthroplasty (TSA) and contralateral RTSA, a lack of internal rotation on the RTSA side has been described as the main factor leading to inferior outcomes [2,8,10,41]. In addition to poor
clinical outcomes, a lack of rotation after RTSA due to bony impingement can lead to scapular notching [20] which is a risk factor for early loosening and premature failure of the arthroplasty [23,26,31].

Achieving full range of motion for activities of daily living after RTSA requires appropriate modification of a combination of variables on both the humeral and glenoid sides of the arthroplasty. Glenoid determinants of motion include glenosphere version, lateralization, inclination, size, and offset [4,5,13,16,18,22,24,42,44]. Humeral determinants of motion include humeral component version, angle of inclination, depth of the humeral tray, and humeral tray offset [9,13,16,18,22,35,39,42]. Bone and soft tissue factors can also play a significant role in determining ultimate rotation of a RTSA and include glenoid version, scapular anatomy, and the presence or absence of rotator cuff musculature [5,6,16,20,33,37].

Choosing the appropriate glenoid and humeral implant position, combined with addressing the patient’s native anatomy, could theoretically allow for full range of motion in RTSA. Previous research with both cadaveric and virtual simulation has been performed on a variety of these variables to determine the optimal combination resulting in the best chances of impingement free range of motion [4,5,9,13,16,18,25,27,32,42,44]. However, the specific contribution of glenosphere version to the overall rotation of RTSA has limited data [5,16,32]. Positioning the glenesophere in neutral glenoid version has been suggested as the ideal orientation during RTSA, in that this would theoretically produce the most optimal range of internal and external rotation as the humeral socket travels around the glenosphere. However, there is little clinical or biomechanical data to support this assumption [16].

Clinically, positioning the glenosphere in neutral version can be complicated by glenoid deformity in up to 38% of patients during primary RTSA, with more frequent and severe deformity expected in revision cases [12]. Recent data has shown that 50% contact of the base plate with native bone is necessary to achieve stable fixation [11]. In patients with severe posterior wear this percentage of contact may not be achievable without placing the component in significant retroversion even with the use of augments or grafts. As RTSA becomes a more widely used option for patients with severe glenoid deformity, glenosphere retroversion will likely be an important determinant of overall rotation of the shoulder [29]. The amount of retroversion the glenoid component can tolerate before it negatively affects the overall rotation of the reverse total shoulder arthroplasty is currently unknown.

The purpose of this study was to use computer simulation of a Grammont-style RTSA implant in increasingly dysplastic scapulae to determine the effect of glenoid component retroversion and increasing glenoid dysplasia (0° placement/normal anatomy, -20° placement/moderate dysplasia, or -30° placement/severe dysplasia) on the internal and external rotation of the humeral component.

**Methods**

Forty-five three-dimensional (3D) models of human scapulae were created from de-identified preoperative computed tomography (CT) scans of 45 patients who had undergone shoulder arthroplasty. Each scapula was segmented and reconstructed using semi-automated thresholding techniques. The models were then imported into SolidWorks as a solid body mesh file. The scapular plane, glenoid version, and glenoid width were calculated using standard 3D modelling techniques [7,12,23]. Scapulae were divided into three separate groups based on glenoid version: normal version (10° to -10°), moderate retroversion (-10 to -25°), and severe retroversion (< -25°). Glenoids were also categorized by width (normal > 25 mm or narrow < 25 mm) for additional subset analyses as glenoids < 25 mm in width were found to permit large ROM with minimal dependence on version.

A Grammont-style inlay design RTSA component was then created virtually in Solidworks based on existing commercial designs which included a 36mm non-eccentric glenosphere without lateral offset, a 155° humeral neck-shaft angle and a polyethylene liner 2 mm above the rim of the inlay design. Scapulae then underwent virtual RTSA using the created components. All glenosphere base plates were placed at the inferior aspect of the glenoid in 10° of inferior tilt. In the normal version group, base plates were placed in 0° of glenoid version, in the moderate retroversion group base plates were placed in 20° of glenoid retroversion, and in the severe glenoid group the base plate was placed in 30° of retroversion. In the event of significant glenoid deformity resulting in >50% baseplate contact with the native glenoid, components were translated to maintain >50% glenoid baseplate contact. Osteophytes which projected greater than the level of the back surface of the glenosphere were removed in line with the plane of the glenosphere as would be accomplished with a reamer to simulate normal surgical implantation techniques. The humeral component was implanted in 20° of retroversion referencing the epicondylar axis.

Rotational analysis of the humeral component was performed at 30° and 60° of abduction [Fig. 1]. Internal and external rotation was applied to the humerus until impingement of the component on the scapula occurred. All impingement was between the humeral liner and the scapula. The humeral and glenosphere articular surfaces were constrained together throughout all motions. Impingement between the polyethylene tray and scapula was detected by utilizing the dynamic clearance aspect of the move component tool for SolidWorks assemblies. Once a point of impingement (~0.01 mm) was reached, the current position of the epicondylar axis was projected onto a plane perpendicular to the humeral axis. The angle between this projected line and the line corresponding to neutral internal/external rotation was considered to be the internal or external range-of-motion available before impingement [Fig. 2].

For each abduction angle, and for each range-of-motion measure (internal, external, and total), one-way ANOVA with Tukey-Kramer multiple comparisons test was used to compare range of motion among the three version groups.

**Results**

Of the 45 original scapulae, 11 had a glenoid width < 25 mm and 34 had a glenoid width > 25 mm. In our initial analysis of all 45 scapulae, we did not detect statistically significant
differences in rotation between glenoids with severe and moderate retroversion. Closer inspection of the data and models showed that glenoids with a narrow width < 25 mm permitted significant rotation due to decreased bony impingement, with less effects from glenoid retroversion ($P > .05$). Additional analyses were then conducted on the 34 scapulae with glenoid width > 25 mm.

For normal width (>25 mm) glenoids, there were 9 in the normal glenoid version group, 15 in the moderate glenoid version group, and 10 in the severe glenoid version group ($n = 34$). The achievable total rotation and internal rotation for the humeral component decreased as glenoid retroversion increased [Fig. 3, Table I]. Changes in rotation for all categories were in general more pronounced at 60° of humeral abduction. With the arm in 60° of humeral abduction; internal, external, and total rotation differences between each of the three version categories were statistically significant ($P < .05$), with the exception of external rotation moderate vs. severe version. Similarly, at 60° of humeral abduction, decreases in IR, ER and TR were significant both when going from 0° to -20° and from -20° to -30° (moderate to severe native glenoid retroversion, respectively). At 30° of humeral

![Graphical representation of each of the 3 version categories (Normal, Moderate, Severe) with implanted prosthetic at both 30° and 60° of abduction. Humeral rotation is at maximum external rotation.](image-url)

Figure 2 – Graphical representation of each of the 3 version categories (Normal, Moderate, Severe) with implanted prosthetic at both 30° and 60° of abduction. Humeral rotation is at maximum external rotation.
abduction the majority of the decrease in total and internal rotation came as component retroversion increased from 0° to 20° (normal and moderate native glenoid version, respectively) [Table I]. Overall, external rotation generally increased as glenoid retroversion increased, with the largest increase occurring when going from 0° to -20° of retroversion, and minimal increase from -20° to -30° of retroversion regardless of humeral abduction.

Figure 3 – Total, internal, and external rotation following RTSA for 34 virtually implanted scapulae having ‘normal’ glenoid width (>25 mm). Normal glenoid version was defined by a native (prior to surgery) range of -10° to 10°, with the component placed in 0° version; Moderate version had a native range of -25° to -10°, with the component placed in -20° version; Severe version had a native range less than -25°, with the component placed in -30° version. Error bars show +/- standard error. \( P < .05 (*) \), \( P < .001 (**) \)
Discussion

This study analyzed the effects of glenoid implant version on prosthetic IR and ER after RTSA implantation in patients with mild (+10° to +10°), moderate (-10° to -25°), and severe (< -25°) glenoid retroversion. Placement of a glenoid baseplate in the setting of glenoid wear and accompanying retroversion poses a significant technical challenge, and there is currently little guidance available in the literature to suggest optimal glenoid component version to promote full postoperative internal and external rotation. Berhouet et al [5] have suggested that correction of tilt and version do not significantly affect the prosthetic ROM in patients with moderate deformity, while Keener et al [16] suggest that placement of the glenoid in neutral or in slight retroversion would be the ideal position for optimal postoperative ROM. Our study shows that with a traditional Grammont-style RTSA placed in 10° of inferior tilt without augments, as the glenoid component is placed in increasing retroversion (0° to -30°) there is a decrease in IR which is partly offset by an increase in ER. Similarly, our data suggest that the highest achievable total range of motion (combined IR and ER) was seen with glenoid implants placed in neutral version indicating that efforts to correct retroversion to neutral may optimize IR and ER in the postoperative period.

In shoulders with severe retroversion deformity (< -25°), placement of the glenoid implant in neutral version can require significant alterations to a standard RTSA procedure including bone grafting, baseplate augmentation, or alternate centerline positions [19,43]. Even using these types of modifications, it may not be possible to fully correct an implant to neutral glenoid version and achieve a minimum of 50% baseplate contact with the native bone [11]. In such cases, the surgeon may be left with a glenoid component with significant retroversion. Our data suggest that in patients with severe deformity where full correction of glenoid version may not be possible, correction of glenoid implant version to < -20° of retroversion would have a significant effect on both TR and IR of the humeral component, while implants in -20 to -30° of retroversion would have similar outcomes in terms of overall rotation. Our study also suggests that a goal of < -20° of retroversion for the glenoid component optimizes prosthetic IR. In patients where this is not achievable, it would be reasonable to consider additional changes to the operative plan to optimize the IR of the prosthetic including changes to humeral stem version or neck angle, altering the offset or eccentricity of the glenosphere, placing the glenoid component in neutral tilt, or altering the diameter of the articulation [21,27,35,39].

The effect of poor IR on patient outcomes after RTSA can be significant, with difficulty with activities of daily living’s and toileting leading to suboptimal outcome scores and decreased patient satisfaction [2,8,18,28,30,36,38,40,46]. Although there are many determinants of the ultimate ability of patients to have functional IR after RTSA, our study shows that the retroversion of the glenoid component in isolation can have a significant effect on both total rotation and IR of the humeral prosthetic. In patients who have a limitation in IR on a contralateral shoulder, and will be using the prosthetic shoulder for toileting and other IR-intensive activities, it is reasonable to consider how best to return their ability to do IR activities. In our study, placing the glenoid component in neutral version allows the most optimal impingement-free IR of the humerus. Combining this with additional modifications to glenosphere or humeral implant position may allow for IR similar to that of the native glenohumeral articulation and lead to improved outcome scores and satisfaction, possibly leading eventually to a “forgotten joint,” as described in the total hip and knee literature [3].

In our results [Fig. 3, Table I] we focused on glenoids with >25 mm of width, as our initial analysis showed that narrower glenoids had essentially no bony impingement associated with IR and ER of the prosthetic. Average nonarthritic glenoid width has been reported to be between 28 ±3.3 mm and 29±3.1 mm, with the glenoid width being between 21-25 mm in only 12% of scapulae [12,15]. Glenoid width for arthritic glenoids, as are encountered in RTSA, have been reported as 32.6 ±6.3 mm [12]. As such, very narrow glenoids (<25 mm) are not a common occurrence in RTSA. However, it is interesting to note that patients with narrow glenoid vaults may have less risk of bony impingement in IR and ER during RTSA.

One strength of this study was the 3D modeling of a relatively large number of individual scapulae which allows for accurate representation of the wide variety of deformity that is frequently found when performing RTSA. An additional strength was the modeling of the entire humerus, including the distal humeral anatomic landmarks, to determine our
range of motion. Prior studies have used modeling of only the proximal humerus to determine humeral version, and may have been unable to accurately determine the real humeral implant version. While our study was not intended to determine the effect of humeral version on IR and ER of the shoulder, we can confidently say that the humeral implant is located at 20° of retroversion compared to the epicondylar axis of the distal humerus.

This computer modelling study has several limitations. The most significant limitation is that we employed only one implant design and did not include additional variables including lateral offset, glenosphere size, humeral angle of inclination, glenosphere eccentricity, base plate tilt, humeral version, or humeral neck cut height, which could significantly change the location of bony impingement of the humeral implant and thus alter the results. We chose instead to focus on glenoid version alone as the primary variable in this study, as this has received limited attention in the orthopedic literature. An additional limitation of this study is that we did not model soft tissue constraints around the shoulder. This is particularly relevant to internal and external rotation, as RTSA can change the moment arms of the rotator cuff tendons which can result in a clinical decrease in rotation [1,14]. A third limitation is that we did not determine the scapular inclination, glenosphere eccentricity, base plate tilt, humeral version, or humeral neck cut height, which could significantly change the location of bony impingement of the humeral implant and thus alter the results. We chose instead to focus on glenoid version alone as the primary variable in this study, as this has received limited attention in the orthopedic literature. An additional limitation of this study is that we did not model soft tissue constraints around the shoulder. This is particularly relevant to internal and external rotation, as RTSA can change the moment arms of the rotator cuff tendons which can result in a clinical decrease in rotation [1,14].

A fourth limitation is that we did not take into account the relationship between humeral retroversion and glenoid version to determine our humeral component position [34]. However, in clinical practice many surgeons use a fixed angle of humeral version or change the humeral version based on intraoperative/preoperative findings depending on the patient’s needs. As such we feel that choosing a fixed angle of humeral retroversion simulates the clinical practice of a significant portion of practitioners.

**Conclusion**

Placement of the glenoid component in increasing retroversion during RTSA results in a loss of internal rotation and a corresponding increase in external rotation. In patients where it is necessary to place the glenoid baseplate in retroversion due to anatomic constraints, a goal of <20° of retroversion provides the best opportunity to maintain internal rotation of the humeral component.

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