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Factors Associated with Internal Rotation After Reverse Shoulder Arthroplasty: A Narrative Review

Maxwell D. Gruber, BA, MS[a], Kunal M. Kirloskar, BS, MS[b], Brian C. Werner, MD[c], Alexandre Lädermann, MD[d], Patrick J. Denard, MD[e,*]

[a]*Elson S. Floyd College of Medicine, Spokane, WA, USA*
[b]*Georgetown University School of Medicine, Washington, DC, USA*
[c]*University of Virginia, Charlottesville, VA, USA*
[d]*La Tour Hospital, Meyrin, Switzerland*
[e]*Oregon Shoulder Institute, Medford, OR, USA*

A R T I C L E I N F O

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Reverse shoulder arthroplasty (RSA) leads to improvement in pain and function with a durable outcome in most cases. While improvement in forward flexion and to a lesser degree external rotation is predictably seen after RSA, restoration of internal rotation (IR) is much less predictable. The purpose of this review was to provide a narrative of the modifiable factors, including prosthetic design and surgical factors, that may impact postoperative IR after RSA. Overall, the available data suggest that postoperative IR is improved with a lower humeral neck shaft angle and lateralization of the glenoid. Decreasing humeral retroversion to 20° or less improves IR at the cost of decreasing active external rotation. Increasing glenosphere diameter improves IR but often within the setting of additional variables. The association between subscapularis repair is less clear but overall suggests that IR is improved postoperatively when it is repaired.

Reverse shoulder arthroplasty (RSA) has become a mainstay in the treatment of various shoulder pathologies, such as rotator cuff arthropathy, proximal humerus fractures, and primary glenohumeral arthritis with glenoid deformity.[41] Between 2012 and 2017, the number of primary shoulder arthroplasties increased by 104%.[21,52] In particular, the incidence of primary RSA increased by 275%, with 62,705 RSAs performed in the United States in 2017.[4]

Although RSA has solved many challenges in managing shoulder conditions, most notably, the ability to treat rotator cuff deficient shoulders with arthritis and more severe glenoid pathology, certain limitations remain. Although scapular notching and other complications are actively being addressed with modern prostheses and implantation techniques, functional internal rotation (IR) continues to remain limited or even diminished postoperatively after RSA.[32,43] The inability to restore functional IR even deters some surgeons from performing bilateral RSA secondary to postoperative loss of ability to perform activities of daily living requiring IR (perineal hygiene, threading a belt, etc.).[43]

A variety of factors may be related to the limitation in IR after RSA. The constrained nature of the implant inherently limits the rotational range of motion (ROM). In addition, surgical factors such as subscapularis repair and implant position, alongside prosthetic factors such as implant lateralization, glenosphere size, and humeral neck shaft angle (NSA), are highly variable based on surgeon preference and prosthetic design. The purpose of this article was to provide a narrative review of the modifiable factors, including prosthetic design and surgical factors, that may impact postoperative IR after RSA.

Historical RSA design and IR outcomes

The initial Grammont-style RSA protheses adhered to 4 principles: (1) the prosthesis must be inherently stable, (2) the weight-bearing part must be convex and the supporting part must be concave, (3) the center of the sphere must be at or within the glenoid neck, and (4) the center of rotation must be medialized and distalized, thus increasing the lever arm of the deltoid.[2,7] These principles were achieved in the Grammont prosthesis with a half-sphere glenoid component secured to a baseplate with a central press-fit peg and a 155° inlay humeral stem.[2,7,13] Although this construct revolutionized the ability of patients with rotator cuff arthropathy to regain forward flexion by lengthening and

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*Corresponding author: Patrick J. Denard, MD, Oregon Shoulder Institute, 2780 E. Barnett Rd, Suite 200, Medford, OR 97530, USA.

E-mail address: pjdenard@gmail.com (P.J. Denard).

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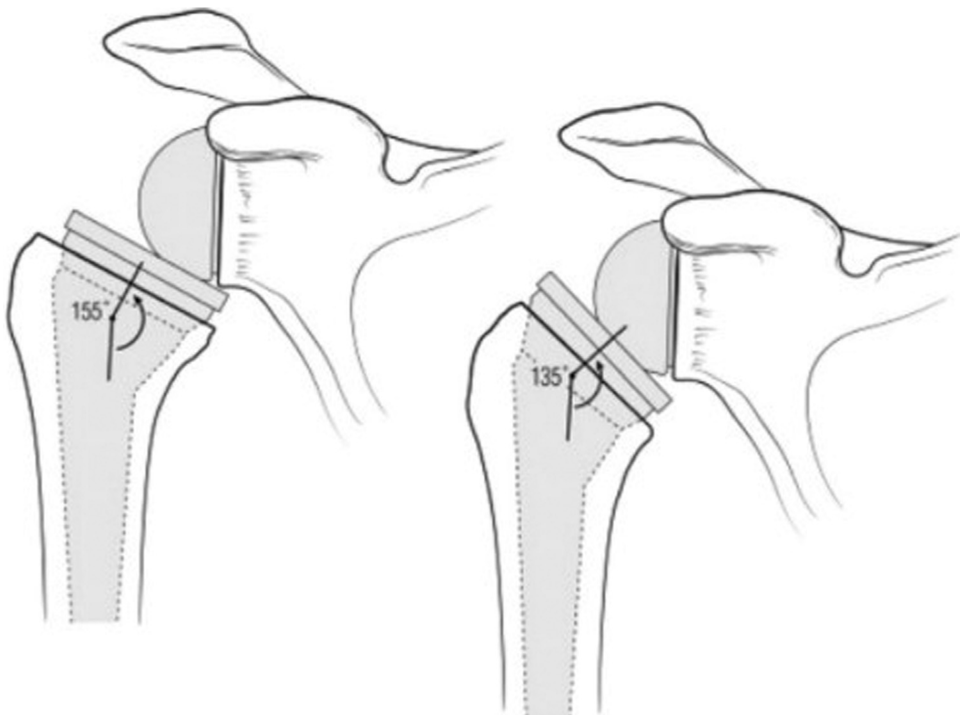

Figure 1 Variations of different humeral neck shaft angle. (Reproduced with permission, from Churchill JL, Garrigues GE. Current controversies in reverse total shoulder arthroplasty. JBJS Rev. 2016;4(6):01874474-201606000-00002. https://doi.org/10.2106/JBJS.RVW.15.00070.)

increasing the lever arm of the deltoid, it inherently created a mechanical conflict between the humeral component and the scapula, which manifested as scapular notching and limitations in rotational ROM. In initial reports, forward flexion was improved from 111° to 139°, whereas external rotation (ER) and IR remained unchanged (24°-27° and sacrum to L5 respectively).[43] In initial constructs, a 36 mm glenosphere with 0 mm of lateralization was used in the majority of cases. In addition, scapular notching with a Grammont-style prosthesis was as high as 88%.[31,34]

To decrease scapular notching and improve rotational ROM, several modifications were gradually made in RSA prosthetic design, most notably modification of the humeral NSA and glenoid lateralization.[13,22]

Prosthetic design

Humeral NSA

Overall, the literature suggests that lowering the NSA from 155° to 145° or 135° results in improved IR.[23,28,44] The majority of this evidence arises from computer simulation studies examining impingement-free ROM (Fig. 1). Virani et al showed a 14% gain of IR/ER when going from a 150° NSA to a 130° NSA.[44] Werner et al compared humeral NSA's of 135° and 145° with neutral and 5 mm lateralized glenospheres. All planes of motion were increased with a 135° NSA except abduction. Specifically, IR (when measured at 0°) significantly increased, from 85° ± 9.2° to 93.5° ± 7.7° when going from a 145° NSA to a 135° NSA.[50] In addition, Jeon et al found that as NSA decreased from 155° to 145° to 135°, IR increased from L2 to L1 to T12.[23] Contrary to these findings, Lädermann et al found no significant decrease in IR while comparing differing degrees of NSA and inlay/onlay stems. Across each category measured, IR measured at 0°, remained at 99°. It should be noted that the results of the study are limited by the fact that only the CT scans of only two patients were used for modeling, thereby limiting external validity.[28] In addition, in the reports of scapular notching, many studies have found decreased incidence of scapular notching secondary to lower NSA.[18,39] Taken together, the literature suggests that lower NSA confers improved postoperative functional and mechanical outcomes.

Glenoid-sided lateralization

Lateralization of the glenoid component decreases the risk of mechanical impingement on the scapula. In addition, it is theorized to provide a more anatomic center of rotation position to allow the remaining rotator cuff to work effectively. While modern glenoid baseplates have provided improved glenoid-sided fixation, allowing for increased glenoid-sided lateralization compared with the initial Grammont design, lateralization increases rotational forces upon the baseplate, which may increase the risk for implant loosening.[16] In addition, glenoid-sided lateralization increases deltoid force requirements, which may have clinical implications for patients with poor muscle reserve (Fig. 2, *A* and *B*).[1,2] Finally, lateralization had been theorized to increase the risk of scapular spine fracture based on a finite element analysis model.[27] However, this finding has not been supported in clinical studies, which have suggested that distalization is a greater risk factor.[1,20]

Several virtual ROM studies have suggested the ability to improve IR with glenoid-sided lateralization.[33,44,48] Virani et al demonstrated that lateralization in glenoid component positioning afforded the greatest predictive change in IR/ER. Specifically, combined IR/ER improves from 67° with 0 mm of lateralization to 84° with 5 mm of lateralization and to 88° with 10 mm of lateralization.[44] Similarly, Keener et al reported that IR improved from 33° ± 36° at 0 mm lateralization to 60° ± 29° at +5 mm lateralization, and to 70° ± 19° with +10 mm of baseplate lateralization ($P < .001$). Finally, Li et al noted glenosphere lateralization of 10 mm

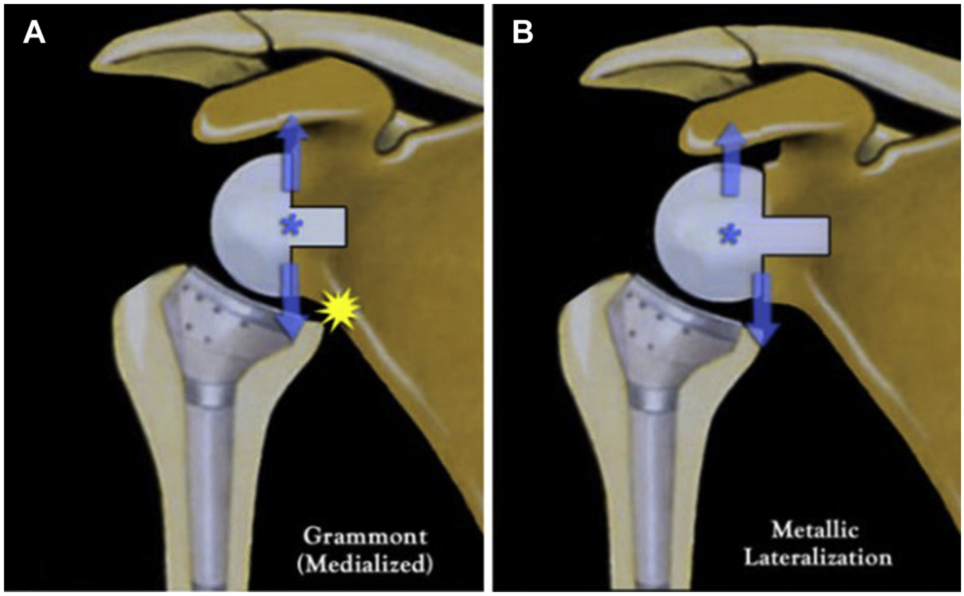

Figure 2 Diagrams show medialization of the glenoid component versus lateralization in RSA. (**A**) Medialization of the center of rotation recruits more deltoid force; thus, increasing muscle utilization but increasing the risk of scapular notching and reducing ROM. (**B**) Lateralization of the COR diminishes necessary deltoid force but decreases the risk of scapular notching and increases overall ROM. (Reproduced with permission, from Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clin Orthop Relat Res. 2011;469(9):2558-2567. https://doi.org/10.1007/s11999-011-1775-4.)

significantly increased impingement-free ROM in IR compared with a neutral glenosphere. IR, evaluated at 0° and 60° of scaption, was greatest at 68.3° ± 29.1°, with 10 mm lateralization compared with a neutral glenosphere position IR of 7.7° ± 11.3°.[33]

In a recent clinical study, Werner et al evaluated IR in 455 patients treated with a 135° NSA inlay humeral prosthesis using varying amounts of glenoid-sided lateralization. At 1-year follow-up, active IR was higher with 6 or 8 mm of glenoid lateralization compared with ≤4 mm, with an overall mean difference of 1.4 spinal levels ($P = .014$). It should be noted, however, that only 50% of patients in the 8 mm offset group achieved a functional level of IR, defined as IR greater than L4 when assessed by spinal level.[48] This suggests that while lateralization improves IR, persistent deficits remain.

Glenosphere diameter

Similar to lateralization, increasing glenosphere diameter has been theorized to improve IR by decreasing mechanical impingement of the humerus upon the glenoid. In a virtual ROM model, Werner et al found that increasing the glenosphere diameter from 36 mm to 39 mm increased impingement-free ROM and increased active IR from 84.3 to 91.4. Furthermore, it was the most predictive factor for extension and ER ($P < .001$). Although IR increased with subsequent increase in glenosphere diameter within this study, the greatest overall increase in IR was resultant of a 39 mm diameter with a 2 mm eccentric tilt (IR: 95.7, standard deviation 7.8).[51]

Cadaveric validation of the impact of glenosphere diameter on IR is more conflicting. Berhouet et al noted a significant difference in both ER and IR with increasing glenosphere diameter ranging from 36 mm to 42 mm. IR/ER ROMs were greater with the 42-mm glenosphere(s), and the best ranges were obtained when a 7-mm or 10-mm lateralized spacer was added (78.8 ± 8.6° and 99.3 ± 6.3°, respectively; $P < .001$ vs. all other glenosphere diameters).[3] In contrast, in another biomechanical investigation, Langhor et al observed that increasing glenosphere diameter from 38 mm to 42 mm resulted in decreased active IR with both neutral and lateral glenosphere positions by an average of 2° ± 3 and 6 ° ± 7 ($P < .05$), respectively. They postulated that the decrease in IR with the larger glenosphere was secondary to over tensioning of the remaining posterior capsule.[30] This suggests that patient-specific sizing is potentially more important than placing a larger glenosphere.

Comparative clinical studies have found little impact of increasing glenosphere diameter. A retrospective review of 297 RSAs with a 145° onlay prosthesis reported no significant association between glenosphere diameter and IR. More specifically, when comparing 38 mm and 42 mm glenospheres, both groups achieved a mean postoperative level of L5.[35] These findings were substantiated by Muller et al, who reported no significant difference between glenosphere diameters (36 mm and 44 mm) and IR at 5-year follow-up.[36]

Together, these findings illustrate mixed evidence supporting greater degrees of IR with increasing glenosphere diameter. The majority of the studies assessed increasing glenosphere diameter in association with at least one confounding variable (ie, glenoid positioning, lateralization); thus, making external validity unlikely. Furthermore, the ability to increase glenosphere diameter is often limited by patient anatomy, overstuffing is a consideration, and larger size may be detrimental to IR due to an increased risk of anterior coracoid impingement (Fig. 3).

Surgical factors

Modifiable surgical or technical factors that may impact IR include humeral version, baseplate position, and subscapularis repair. Baseplate position can be divided into version, superior/inferior position, and inclination.

Humeral version

Primarily evaluated in the setting of impingement-free motion in shoulder abduction and joint stability, humeral retroversion has been theorized to impact IR after RSA[17,42] (Fig. 4).

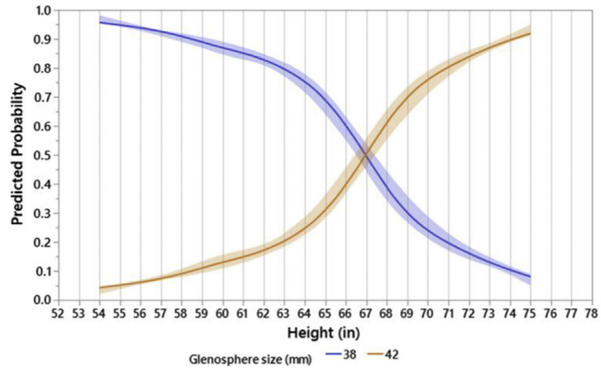

Figure 3 Comparison of predicted probabilities for size (38 mm) and (42 mm) glenospheres across a variety of different heights. (Reproduced with permission, from Schoch B, Vasilopoulos T, LaChaud G, Wright T, Roche C, King J, et al. Optimal glenosphere size cannot be determined by patient height. J Shoulder Elbow Surg. 2019;29(2):258-265. https://doi.org/10.1016/j.jse.2019.07.003.)

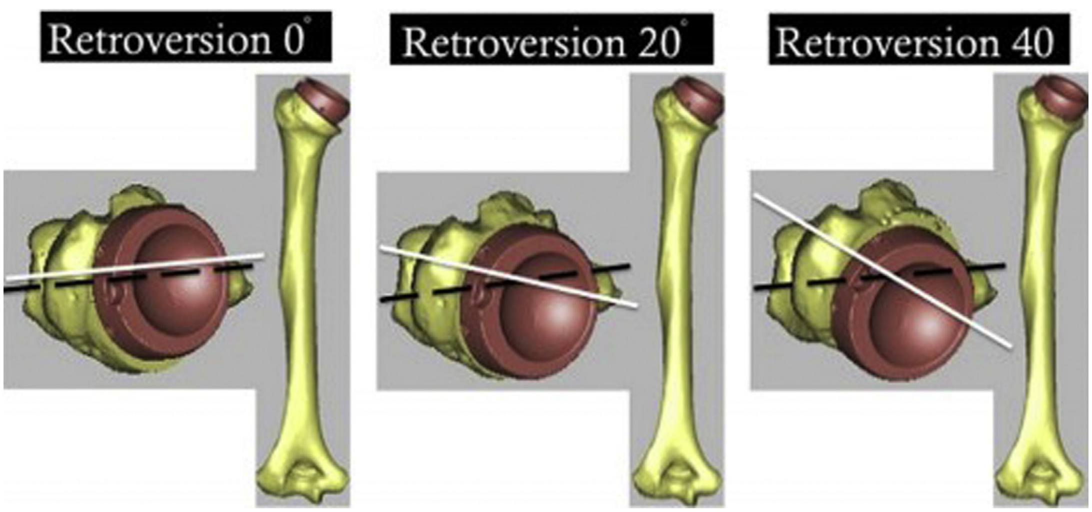

Figure 4 Varying degrees of humeral retroversion as defined as the angular orientation of the humeral head component and the distal axis of the elbow. (Reproduced with permission, from Gulotta LV, Choi D, Marinello P, et al. Humeral component retroversion in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg. 2012;21(9):1121-1127. https://doi.org/10.1016/j.jse.2011.07.027.)

In a cadaveric study examining humeral retroversion on muscles forces, Gulotta et al evaluated IR at 20° and 40° of scaption with a 145° humeral inclination prosthesis (Biomet Comprehensive Reverse Total Shoulder Replacement; Biomet Inc, Warsaw, IN, USA). The investigators noted a predictable pattern of IR and ER ROM based on changes in retroversion. As retroversion was increased, the relative amount of ER increased with a concomitant decrease in IR.[17] In another cadaveric study, Stephenson et al noted similar findings in regard to increasing humeral retroversion with a 155° humeral inclination prosthesis (Aequalis Reversed Shoulder Prosthesis). Stephenson et al found that IR was greatest at 0° of arm abduction, with 20° of humeral anteversion (128 ± 9°), and lowest with 40° of humeral retroversion 83 ± 8°. Furthermore, the greatest degree of ER was achieved at 40° retroversion (110° ± 5°).[43] Although overall it appears that less retroversion improves IR, the results of these studies are difficult to compare based on the difference in arm positioning in measurements and singular prosthesis types in each study.

Clinical evaluation appears to support these biomechanical findings. In a comparative study, Oh et al examined the individualized effect of humeral retroversion and subscapularis repair after lateralized RSA. Examined initially as individualized retroversion ranging from 10° to 40° (mean angle of 27.8°) versus a fixed retroversion of 20°, they noted improved IR with an individualized retroversion angle (individualized: able to reach to T10 vs. fixed: able to reach to T12 [P = .004]). Furthermore, Oh et al greater categorized subgroups by comparing individualized humeral retroversion of <20° and >20° vs. a fixed retroversion angle of 20°. Examined as subgroups, the greatest degree of IR was achieved when comparing individualized retroversion of <20° vs. >20° retroversion (T10 ± 3 SL vs. T11 ± 2 SL [P = .116]).[38]

Baseplate version

Baseplate version serves as a novel variable in identifying optimal functional ROM and decreasing scapular notching. Theorized in computational studies to maximally improve postoperative IR at neutral positioning, appropriate version can be difficult to achieve clinically given the need for adequate baseplate seating despite varying degrees of glenoid wear, retroversion, and anatomic restraints.[24,26,45] Furthermore, attaining neutral positioning insecure glenoid deformity is difficult, considering

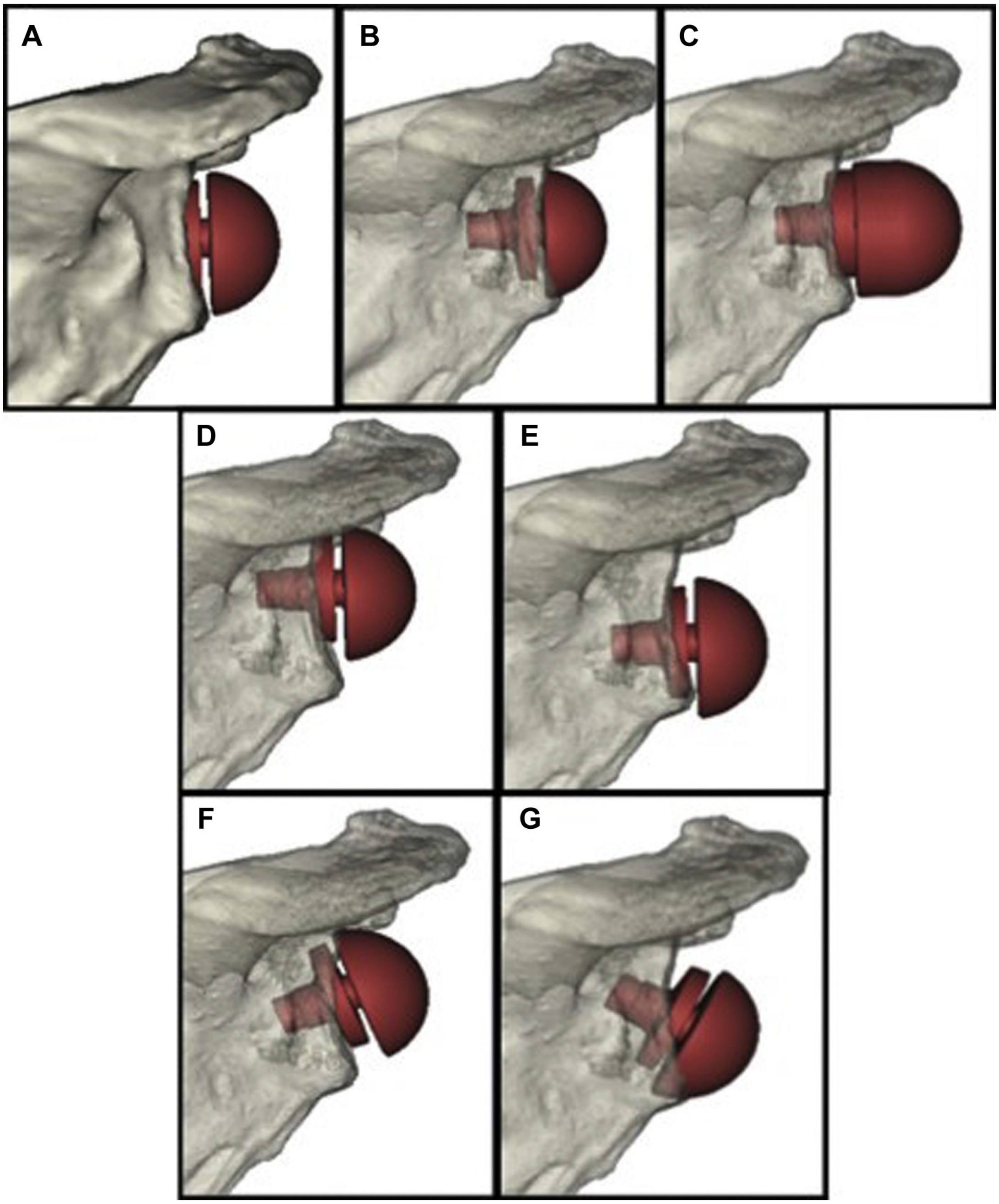

Figure 5 Glenosphere position resultant of the resting face of the glenoid in (**A**) neutral position, (**B**) medialized position, (**C**) lateralized position at 10 mm, (**D**) superiorly translated +6 mm, (**E**) inferiorly translated −6 mm, (**F**) 10° superior inclination, (**G**) 10° inferior inclination. (Reproduced with permission, from Li X, Knutson Z, Choi D, et al. Effects of glenosphere positioning on impingement-free internal and external rotation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22(6):807-813. https://doi.org/10.1016/j.jse.2012.07.013.)

technical challenges pose by baseplate augmentation, bone grafting, and/or alternate centerline positions[26] (Fig. 5).

In a virtual model examining glenoid version rotational ROM in patients with mild, moderate, and severe glenoid retroversion, Budge et al noted significant differences in IR when controlling for glenoid version and width. Specifically, when stratifying groups based on glenoid version (neutral version (10° to −10°), moderate retroversion (−10 to −25°), and severe retroversion (<−25°), the authors noted the greatest degree of achievable IR (at 60° arm abduction) with a native retroversion of 10° to −10° ($P < .001$).[9] In another virtual ROM study, Keener et al found increasing IR with greater degrees of glenoid retroversion. Assessed independently alongside lateralizing the glenoid, Keener et al observed a significant increase in IR with 20° retroversion compared with neutral positioning of 0° at 84° ± 9.0 ($P < .001$). Furthermore, a correlational analysis between studies examining the independent effects of glenoid component version noted a significant Pearson correlation relating to IR (0.239, $P < .001$). It should be noted independent analysis conferred a negative Pearson coefficient in every other plane—albeit abduction.[24] Together, these findings illustrate mixed results and warrant further investigation.

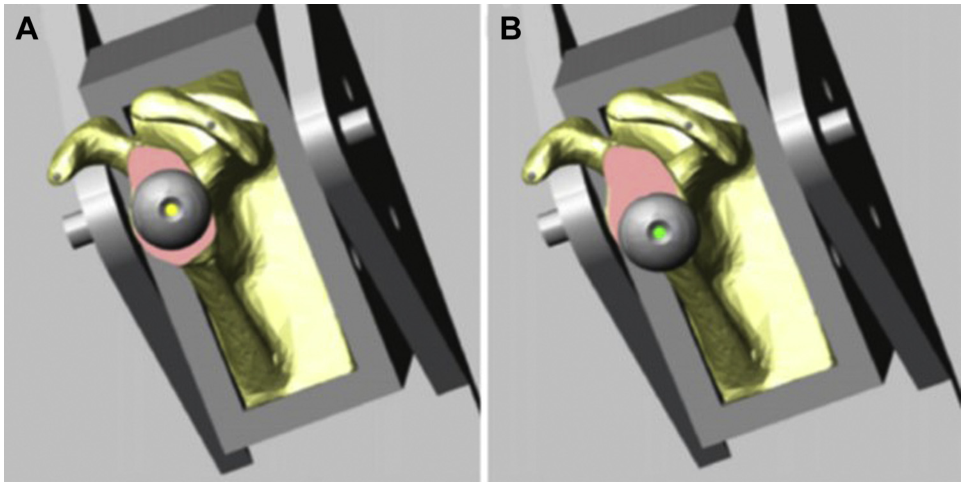

Figure 6 Glenosphere position relative to the glenoid placement (**A**) in native configuration (center of the glenoid), (**B**) inferior offset (1 cm inferior to center of glenoid). (Reproduced with permission, from Virani NA, Cabezas A, Gutiérrez S, Santoni BG, Otto R, Frankle M. Reverse shoulder arthroplasty components and surgical techniques that restore glenohumeral motion. J Shoulder Elbow Surg. 2013;22(2):179-187. https://doi.org/10.1016/j.jse.2012.02.004.)

Baseplate position

Proposed as a means of limiting inferior scapular notching, inferior/superior baseplate translation has been proposed as a means of increasing functional ROM[20,40,47] (Fig. 6).

In a virtual ROM study examining the differing effects of glenoid positioning, Li et al noted that no IR was achievable at 0° or 20° of scaption with 6-mm superior translation of the glenoid secondary to impingement of the implant on the acromion at the starting position. The greatest degree of IR was achieved with 6-mm of inferior translation 161.7 ± 30.2° of IR at 60° of scaption. Furthermore, the authors went on to state that inferior translation at 6 mm had the greatest improvement on impingement-free IR and ER as a function of different degrees of scaption.[33] Similarly, Werner et al in another virtual ROM model noted the greatest degree of functional IR at 0° of abduction (93.4° ± 8.5°) was with a 2 mm inferior eccentric glenoid offset.[51]

However, inferior position of the baseplate is not without risks. Increased postoperative acromiohumeral distances have been demonstrated to increase the risks of nerve injury or scapular spine fracture.[29] Although the current literature suggests that a superiorly positioned baseplate should be avoided, the ideal amount of glenosphere overhang has yet to be defined.[29,33] In addition to the aforementioned risks, the relationship between both humeral component design and position with distalization further complicates the conclusions of the study as well. Thus, the tolerable amount of distalization may be different based on prosthesis type and/or placement.

Baseplate tilt

Theorized to improve impingement-free adduction, ROM, equal force distribution at the baseplate interface, and decrease scapular notching, baseplate tilt has become a point of debate regarding improving IR.[11,14,19,25] In a virtual ROM model, Li et al compared IR at variable scaption with differing degrees of baseplate tilt. IR was most improved with 30° of inferior tilt with 1.0° ± 1.6° at 0° scaption, 35.9° ± 17.3° at 20° scaption, 71.6 ± 18.4° at 40° scaption, and 122.9° ± 29.9° at 60° scaption.[33] In a cadaveric investigation, Berhouet et al observed that IR/ER with a 36 mm glenosphere improved from 31.1° ± 10.2° with neutral positioning to 51.3 ± 11.2 with 10° of inferior tilt.[3] Contrary to these findings, a virtual ROM analysis by Werner et al found almost no influence of 10° of inferior tilt on IR; with IR only improving by 1° compared with neutral inclination.[51]

Clinical studies have not yet proven the benefit of baseplate tilt in the improvement of IR. In a prospective randomized trial of 52 RSA's with a 155° NSA comparing 10° of inferior baseplate tilt to neutral inclination, Edwards et al noted a larger percentage of patients with 10° of inferior baseplate tilt were able to achieve IR greater than the lumbosacral junction, but the difference did not reach statistical significance (77.3% vs. 60.0%; $P = .381$).[11] As such, inferior baseplate tilt may confer additional consequences when compared with neutral positioning. In a force distribution analysis comparing varying degrees of glenoid tilt and position with concentric glenospheres, Gutierrez et al noted the most uniform force distribution occurred when the baseplate was positioned with 15° inferior tilt. On the other hand, when the baseplate was positioned with superior tilt, the greatest discrepancy in force distribution was noted, which may, in turn, lead to earlier clinical failure.[19] Furthermore, scapular notching has been shown to be decreased with inferior tilt, although this may not be clinically valid when the length of follow-up is controlled.[11,14,25,37]

Subscapularis repair

Subscapularis repair after RSA remains a controversial topic in the literature. Advocates for subscapularis repair argue that subscapularis repair improves component stability and IR.[49] The data are often difficult to interpret based on the use of different prosthetic designs and lack of postoperative healing data. Friedman et al compared 341 patients who had a subscapularis repair to 251 patients who did not have a repair with the same onlay 145° prosthesis at 24-month follow-up. The investigators reported an improvement in postoperative IR to L1-L3 spinal levels when the subscapularis was repaired in comparison to L4-L5 spinal levels postoperatively when not repaired (5.1 ± 1.3SL vs. 4.4 ± 1.6SL; $P < .0001$). After controlling for body mass index across 4 categories (normal, overweight, obese, and morbidly obese), Eichinger et al reported significant improvement in IR after RSA using a 145° prosthesis when the subscapularis was repaired intraoperatively ($P < .001$).[12] In a retrospective cohort study of 86 patients with attempted subscapularis repair using a Grammont-style (155° neck shaft angle) reverse prosthesis (Aequalis Reversed II;

Tornier−Wright Medical, Bloomington, MN, USA), Collin et al noted significantly better mean constant IR in the intact repair group versus failed repair group (6.6 points vs. 4.8 points; $P = .0058$).[10] In contrast, Vourazeris et al found no significant difference in IR between 86 patients who underwent RSA using a 145° prosthesis with subscapularis repair and 116 patients who underwent RSA with tenotomy of the subscapularis ($P = .967$).[46] Furthermore, Oh et al noted no significant difference in IR between 40 patients who underwent RSA using a 145° prosthesis with subscapularis repair in comparison to 12 cases without repair ($P = .678$).[38] After RSA using a 145° prosthesis, Boulahia et al reported that lack of subscapularis repair did not affect IR; however, the investigators found that the presence of a subscapularis tear was associated with improved active ER ($P = .0234$).[8] Furthermore, Werner et al found that subscapularis repair in the setting of RSA using a 147° prosthesis with a lateralized glenosphere did not result in a significant change in American Shoulder and Elbow Surgeons scores in comparison to RSA without subscapularis repair ($P = .660$).[49]

Although improvement in IR was noted by Friedman et al, the onlay prosthesis used in this study distalizes the arm and may alter the vector of the subscapularis as well as the ability to successfully repair the subscapularis.[15] A confounding factor could be the sparsity of data regarding subscapularis healing outcomes after RSA, as low healing rates have been reported.[5,7] Boileau et al found that 10 patients who underwent RSA using a 155° prosthesis with an intact subscapularis preoperatively had a positive belly press test at follow-up, indicating subscapularis insufficiency. He postulated that these outcomes were because of poor healing of the subscapularis or displacement of the humerus inferiorly relative to the scapula secondary to the Grammont prosthesis, increasing the tension on the repaired subscapularis tendon.[6] De Boer et al reported only 40% of patients who underwent RSA with subscapularis repair were found to have an intact subscapularis by ultrasound.[5] With these findings in mind, the evidence in the current literature points toward negligible outcomes in preserving or increasing active IR in the setting of RSA with subscapularis repair; however, further investigation into subscapularis healing outcomes after RSA is warranted.

Conclusion

Overall, the available data suggest that postoperative IR is improved with a lower humeral NSA and lateralization of the glenoid. Decreasing humeral retroversion to 20° or less improves IR at the cost of decreasing active ER. The impact of glenosphere size improves IR as glenosphere diameter increases but often within the setting of additional variables. The association between subscapularis repair is less clear but overall suggests that IR is improved postoperatively when it is repaired.

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