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Biomechanical Characteristics of Glenosphere Orientation Based on Tilting Angle and Overhang Changes in Reverse Shoulder Arthroplasty

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Background: Glenoid position and inclination are important factors in protecting against scapular notching, which is the most common complication that directly affects the longevity of reverse shoulder arthroplasty (RSA). This study aimed to investigate the biomechanical characteristics of glenosphere orientation, comparing neutral tilt, inferior overhang with an eccentric glenosphere at the same placement of baseplate, and inferior tilt after 10° inferior reaming in the lower part of the glenoid in RSA.

Methods: Nine cadaveric shoulders were tested with 5 combinations of customized glenoid components: a centric glenosphere was combined with a standard baseplate (group A); an eccentric glenosphere to provide 4-mm inferior overhang than the centric glenosphere was combined with a standard baseplate (group B); a centric glenosphere was combined with a wedge-shaped baseplate tilted inferiorly by 10° with the same center of rotation (group C); an eccentric glenosphere was attached to a wedge-shaped baseplate (group D); and 10° inferior reaming was performed on the lower part of the glenoid to apply 10° inferior tilt, with a centric glenosphere secured to the standard baseplate for simulation of clinical tilt (group E). Impingement-free angles for adduction, abduction, forward flexion, external rotation, and internal rotation were measured. The capability of the deltoid moment arm for abduction and forward flexion, deltoid length, and geometric analysis for adduction engagement were evaluated.

Results: Compared with neutral tilt, inferior tilt at the same position showed no significant difference in impingement-free angle, moment arm capability, and deltoid length. However, group D resulted in better biomechanical properties than a central position, regardless of inferior tilt. Group E demonstrated a greater range of adduction, internal and external rotation, and higher abduction and forward flexion capability with distalization, compared to corresponding parameters for inferior tilt with a customized wedge-shaped baseplate.

Conclusions: A 10° inferior tilt of the glenosphere, without changing the position of the baseplate, had no benefit in terms of the impingement-free angle and deltoid moment arm. However, an eccentric glenosphere had a significant advantage, regardless of inferior tilt. Inferior tilt through 10° inferior reaming showed better biomechanical results than neutral tilt due to the distalization effect.

Keywords: *Reverse shoulder arthroplasty, Rotator cuff tear, Cuff tear arthropathy, Notching, Inferior tilt*

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Recent designs of reverse shoulder arthroplasty (RSA) prostheses have been improved to overcome biomechanical disadvantages of the Grammont design prosthesis, mainly by using an increased lateral offset and steeper inclination of the humeral component. However, prosthesis-related complications, including scapular notching, instability, and incomplete restoration of shoulder function still occur.[1,2] Glenosphere variables, including lateral offset, position of the center of rotation (COR), and inclination are still recognized as alternative ways to improve clinical outcomes and reduce prosthesis-related complications.[3,4] The biomechanical properties of RSA related to the glenoid components can be controlled by creating an inferior overhang or inferior tilt during surgery.[4-6] Although there is no consensus on the degree of overhang that minimizes scapular notching, inferior glenosphere overhang has consistently demonstrated better active arm elevation and a lower incidence of scapular notching by moving the COR inferiorly.[6,7] Surgical methods used to achieve inferior glenosphere overhang are distal implantation of the baseplate, selection of a large glenosphere, or use of an eccentric glenosphere.[8-11]

Compared with the inferior overhang, the inferior tilt of the glenosphere provides a larger arc of rotation inferiorly to minimize scapular notching and has the biomechanical advantage of stronger resistance to vertical shearing forces due to the distalization effect of RSA.[12] However, there is a clinical concern that shortening of the scapular neck due to reaming for inferior tilt could lead to medialization of the COR, which could promote scapular notching.[4] Considering the importance of lateral offset of the glenoid component, the "pure inferior tilt" that provides inferior tilt with the same COR to preserve the lateral offset may have different biomechanical properties than the "clinical inferior tilt" that creates inferior tilt through reaming of the glenoid. There is a paucity of biomechanical data comparing the effects of "clinical inferior tilt" with "pure inferior tilt" of the glenosphere on the range of motion, deltoid force, and scapular notching.

The purpose of this study was to compare neutral tilt and inferior tilt without changing COR using a customized glenoid component that maintained lateral offset regardless of tilt and to analyze whether inferior tilt without changing COR differed from the inferior overhang. The differences between inferior tilt preserving the COR by customized glenoid and the inferior tilt in clinical practice performed by eccentric reaming for 10° inferior tilt were also compared. Our hypotheses were that inferior tilt has different biomechanical properties from inferior overhang with the same lateral offset and that clinical inferior tilt of the glenosphere through 10° inferior reaming might show different characteristics from pure inferior tilt.

METHODS

Since this research is a basic science study, Institutional Review Board or Institutional Animal Care and Use Committee approval was not obtained. Nine non-matched, fresh-frozen, cadaveric shoulder specimens (4 right and 5 left) were prepared for testing. The specimens were obtained from 7 males and 2 females, and the mean donor age was 67 years (range, 64–70 years). Specimens were stored frozen at −20 °C and completely thawed before dissection. Skin, subcutaneous tissues, and muscles were completely dissected from the humerus and scapula. In all specimens, approximately 2 cm of the humeral insertion of the subscapularis, teres minor, and deltoid were preserved. The glenohumeral joint was disarticulated for reverse implantation. Remarkable bony defects and deformities were not observed in any of the specimens. The tendinous insertions of subscapularis, teres minor, and the anterior, middle, and posterior deltoids were sutured with No. 2 FiberWire (Arthrex) using a modified Kessler stitch for physiologic muscle loading (Fig. 1A). Three markers on the lateral cortex of the proximal humerus, 3 at insertions of the anterior, middle, and posterior deltoid, 2 on the boundary of the acromion, and 1 on the coracoid were placed with unicortical screws to measure deltoid length and relative position of the humerus, using point digitiza-

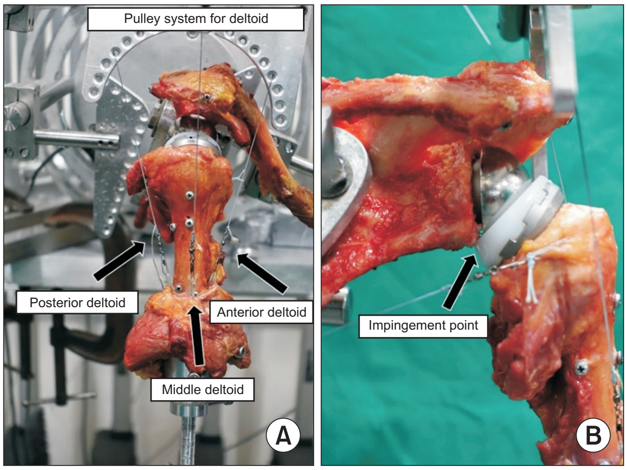

Fig. 1. Setting for biomechanical testing. (A) Each loading of 5 N was applied to the anterior, middle, and posterior deltoids, the subscapularis, and the teres minor muscles through a metal pulley frame. (B) The point at which the polyethylene liner and the scapular neck impinged during adduction in a neutral position was determined when 3 observers agreed.

tion with the MicroScribe 3DLX (Model G, Revware).

This experiment was performed with each shoulder specimen sequentially equipped with a combination of 5 glenoid components. Implantation was performed with a customized glenoid component, with a 3-mm inherent lateral offset in the humeral component of a Coralis reverse shoulder prosthesis (Corentec). In this study, 5 conditions were evaluated for inferior tilt and overhang of the glenoid component: a centric glenosphere was combined with a standard baseplate (group A); an eccentric glenosphere to provide 4-mm inferior overhang than the centric glenosphere was combined with a standard baseplate (group B); a centric glenosphere was combined with a wedge-shaped baseplate tilted inferiorly by 10° with the same COR (group C); an eccentric glenosphere was attached to a wedge-shaped baseplate (group D); and 10° inferior reaming was performed on the lower part of the glenoid to apply 10° inferior tilt, with a centric glenosphere secured to the standard baseplate for simulation of clinical tilt (group E) (Fig. 2). To implement "pure inferior tilt," a custom-made, wedge-shaped baseplate that could implement 10° inferior tilt with the same COR and that could be fixed with the standard glenosphere while maintaining the same central peg position was prepared (Fig. 3). For these 2 baseplate types, a glenosphere capable of providing 4 mm inferior overhang was also prepared.

For humeral stem insertion, humeral head resection was made at a fixed inclination of 135°, with an extramedullary guide and according to the anatomic retroversion of each specimen. Using the smallest reamer, a pilot hole in line with the humeral canal and at the apex of the resected surface was created. Then, while reaming with a larger reamer in sequence, the size to fit the cortical bone was determined. After inserting the same-sized humeral stem with the last reamer into the humerus and fastening the centric-type humeral tray, a standard polyethylene liner with 10° inclination was attached.

To prepare the glenoid component, after positioning the customized guide to the best fit, with the circle below the articular surface of the glenoid, a 2.0-mm Steinmann pin was inserted perpendicular to the articular surface and completely passed through the medial cortex of the scapula. After removing the previous pin, the 2.0-mm

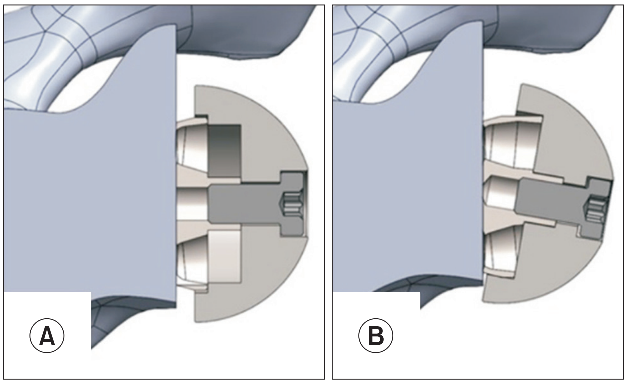

Fig. 3. (A, B) Schematic drawings of a custom-made baseplate and a glenosphere for a 10° inferior tilt without changing the center of rotation.

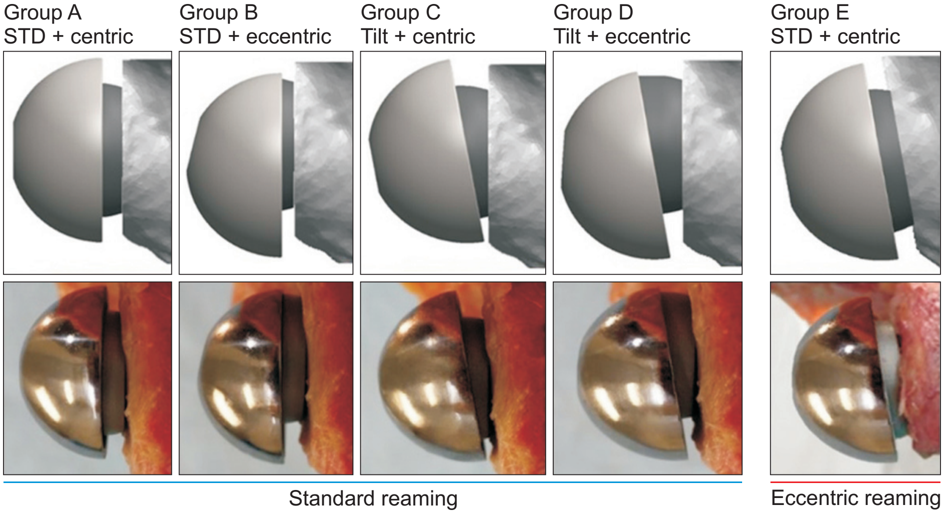

Fig. 2. A customized wedge-shaped baseplate for the inferior tilt of 10° and an eccentric glenosphere providing a 4-mm inferior overhang were used to achieve 5 different conditions in the glenoid component: combination of the standard baseplate (STD) and concentric glenosphere (group A); eccentric glenosphere fastened on the STD (group B); concentric glenosphere attached to a wedge-shaped baseplate to provide inferior tilt of 10°, without changing center of rotation (group C); eccentric glenosphere fixed on the wedge-shaped baseplate (group D); and concentric glenosphere on the STD implanted on the glenoid reamed eccentrically along the guide pin for the inferior tilt of 10° (group E).

Steinmann pin was again penetrated through the customized guide to have a 10° inferior tilt to the same point as the previous pin was inserted. Then, the position at which the pin passed through the inner cortex was marked and the pin was removed. For groups A to D, minimal reaming was performed so that the glenoid was flattened based on a pin perpendicular to the glenoid articular surface. The baseplate and glenosphere were also placed for each combination. To create a condition for "clinical inferior tilt" (group E), 10° inferior reaming was performed by reinserting the Steinmann pin into the path of the previously drilled pin by 10° inferior tilt after biomechanical measurement of the conditions for groups A to D had been completed. The amount of reaming was determined so that the baseplate was completely sitting on the inclined plane (Fig. 4).

After implanting an RSA prosthesis in each specimen, the scapula and humerus were set to a custom shoulder testing system used in a previous biomechanical test setting for RSA.[13)] The scapula was mounted with 3 screws to a metal bracket and positioned at 20° of anterior tilt in the sagittal plane. The intramedullary rod was inserted into the transected humerus and firmly secured with several unicortical screws. The rotational range of motion of the humerus was measured with a digital goniometer (M-D Building Products) at the distal end of the intramedullary rod. For measurement of internal and external rotation of the humerus, neutral rotation was defined when the glenosphere and humeral component were centered with each other, which could be visualized by aligning a marker on the lateralmost point of the humeral tray and the center of the glenoid peg. The degree of abduction was determined by manual measurement using a digital goniometer that was attached parallel to the humeral rod. The definition of shoulder abduction 0° was when the intramedullary rod inserted into the humerus was perpendicular to the horizon. Physiologic muscle force vectors were simulated using a semicircular metal plate with multiple holes and a cable pulley system. For the subscapularis, teres minor, and the anterior, middle, and posterior deltoid muscles, a 5 N weight was connected to the previously created suture loop with FiberWire, and loading was applied along the anatomic direction.

The impingement angles for abduction, forward flexion, adduction, and internal and external rotation with 5° and 30° abduction at the glenohumeral joint were measured for each condition of the glenoid component, and the impingement points were confirmed visually by 2 observers (JHA and SWJ). The impingement angle for adduction was defined as the point where the polyethylene liner and scapular neck impinged during adduction in a neutral rotation position (Fig. 1B). The point of impingement on the scapular neck was also digitized with the MicroScribe to compare the location of the impingement point. The impingement angle for abduction was determined when the lateral border of the acromion and the greater tuberosity or proximal part of the humeral stem contacted each other at 0° axial rotation. The impingement angle for forward flexion was measured when the proximal humerus and acromion contacted in elevation at 30°

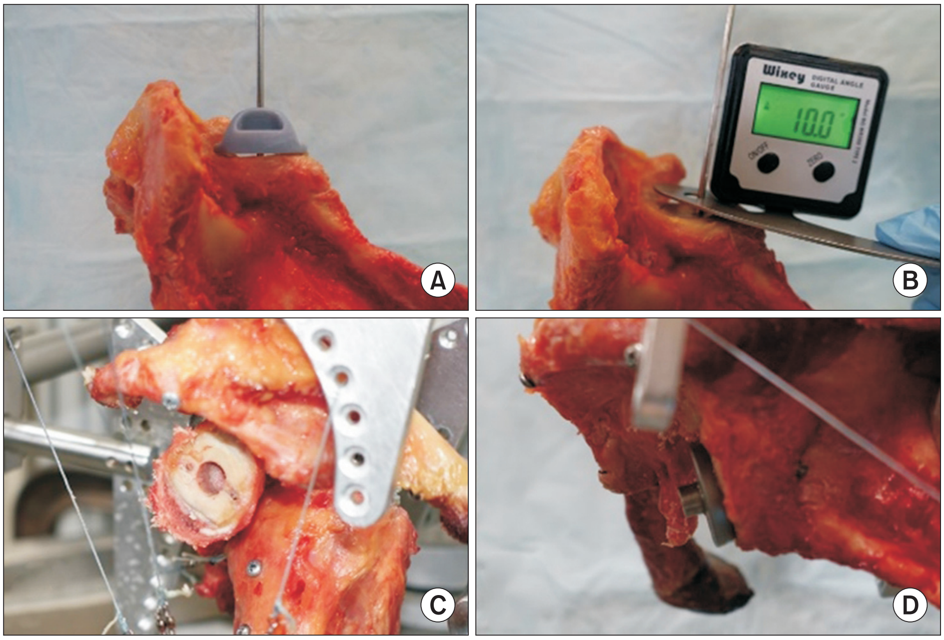

Fig. 4. In group E, the standard baseplate was inserted after eccentric reaming to the lower part of the glenoid. (A) Using a customized guide, a 2.0-mm Steinmann pin was inserted perpendicular to the articular surface at the position that best fits the lower side of the glenoid. (B) At the point where the first pin was penetrated, a new Steinmann pin was inserted to maintain the inferior tilt of 10°. (C) The central peg hole and the glenoid surface were displayed after additional reaming following the inferior 10° tilted guide pin. A significant amount of bone was removed at the lower side of the glenoid. (D) The standard baseplate was implanted on the glenoid after eccentric reaming.

external rotation to avoid the coracoid from impinging on the proximal humerus at 0° axial rotation. The impingement angles for internal and external rotation were measured at 5° and 30° of abduction, respectively.

While 5 N of loading was applied to the anterior, middle, and posterior deltoids to implement a physiological state, additional loading was gradually applied to insertion sites requiring additional loading to measure movement capability. To assess the abduction capability of the glenohumeral joint, depending on the condition of the glenoid component, the abduction angle reached was recorded, while the load on the middle deltoid was increased from 5 N to 15 N, in increments of 2.5 N, and with constant loads of 5 N applied to the subscapularis and teres minor. The amount of forward flexion was analyzed by sequentially increasing loading on the anterior and middle deltoids; 15 N was set as the final loading force to prevent mpingement in the abduction and forward flexion through pilot tests.

The length of the anterior, middle, and posterior deltoids at 30° abduction in neutral rotation for all groups and the impingement position between the inferior scapular neck and the polyethylene liner were measured. In each condition, the position of the center of the peg screw was also measured as the center of 4 points around the rim of the center peg hole in the glenosphere before the experiment. The amount of humeral distalization and medialization for each glenosphere configuration compared to group A was also measured using the MicroScribe 3DLX.

For each specimen, 2 trials with each combination were performed to ensure repeatability, and average values were included for statistical analysis. Data are presented as mean±standard error. Pairwise comparisons were made between groups using a linear mixed effects model, and significant differences were identified using the Tukey *post hoc* test. All statistical analyses were performed using IBM SPSS ver. 21.0 (IBM Corp.), and $p < 0.05$ indicated statistical significance.

RESULTS

In the neutral position, the adduction impingement angle was positive in groups A (3.9° ± 3.3°) and C (6.3° ± 3.5°) indicating for these implant configurations the impingement angle was in abduction of the arm, and there was no change with group C; however, in groups B (−15.9° ± 4.3°) and D (−13.8° ± 4.5°), the adduction impingement angle was negative and indicated significantly greater adduction. Group E (−8.4° ± 3.5°) also had a negative adduction impingement angle; however, the extent of adduction was significantly less than that of group B ($p < 0.01$) (Fig. 5A).

When the location of the impingement point at the inferior scapular border was measured based on the three-dimensional axis, it was confirmed that impingement occurred in all groups more posteriorly than group A in the anteroposterior axis. In the superior-inferior axis, similar results were observed with only a difference of about 1 mm between groups, but in the medial to lateral axis, point of impingement was located on the more medial side than group A in groups B, D, and E; however, group C had a more lateral notching position (Table 1).

The abduction impingement angle was similar in

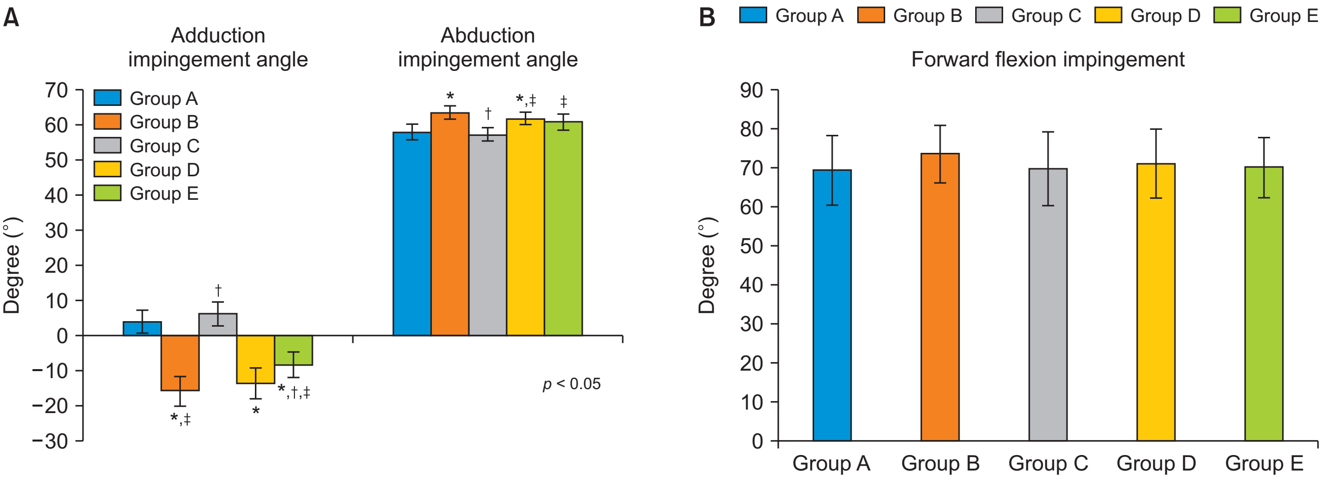

Fig. 5. The impingement-free angle at adduction and abduction (A) and forward flexion (B). Standard baseplate and centric glenosphere (group A); eccentric glenosphere and standard baseplate (group B); centric glenosphere attached to a wedge-shaped baseplate to provide inferior tilt of 10° (group C); eccentric glenosphere and the wedge-shaped baseplate (group D); and centric glenosphere on the baseplate on the glenoid reamed eccentrically for inferior tilt of 10° (group E). *vs. group A. †vs. group B. ‡vs. group C.

group A (57.9° ± 2.2°) and group C (57.3° ± 1.9°) ($p = 0.98$), whereas groups B (63.6° ± 1.8°) and D (61.7° ± 1.9°) had significantly better abduction impingement angles than group A (group B vs. group A, $p < 0.01$; group D vs. group A, $p < 0.01$). Group E (60.9° ± 2.2°) had a significantly better abduction impingement angle than group C ($p = 0.02$); however, there was no significant difference for group E versus other groups. No significant between-group differences were evident in the forward flexion impingement angle (Fig. 5B).

In 5° abduction, group B (69.3° ± 6.6°) had a significantly larger angle of internal rotation before impingement than groups A (51.7° ± 6.8°) and C (50.5° ± 6.1°) (group B vs. group A, $p = 0.019$; group B vs. group C, $p = 0.011$). In 30° abduction, group B (96.0° ± 8.7°) still maintained a significantly larger internal rotation impingement angle than groups A (59.8° ± 7.9°) and C (65.6° ± 9.9°) (both differences $p < 0.01$). Group D (91.5° ± 9.7°) also had a significantly larger angle than groups A and C (both differences $p < 0.01$). Group E (66.5° ± 11.3°) also had a significantly larger internal rotation impingement angle than group A ($p = 0.01$) (Fig. 6A).

Table 1. Change in Inferior Scapular Notching Position Relative to Group A (mm)

	Anterior (+) / posterior (–)	Superior (+)/ inferior (–)	Lateral (+) / medial (–)
Group B	–0.7 ± 1.3	–1.4 ± 0.8	–6.5 ± 0.6
Group C	–1.9 ± 1.1	0.4 ± 0.4	1.0 ± 1.0
Group D	–2.9 ± 1.3	–0.8 ± 0.5	–4.9 ± 0.9
Group E	–1.3 ± 1.4	–0.7 ± 0.4	–4.4 ± 0.9

Values are presented as mean ± standard error. Group A: centric glenosphere and standard baseplate, group B: eccentric glenosphere and standard baseplate, group C: centric glenosphere and the wedge-shaped baseplate, group D: eccentric glenosphere and the wedge-shaped baseplate, group E: centric glenosphere and the baseplate with inferior reaming.

Groups D (–19.9° ± 2.4°) and E (–20.1° ± 1.6°) had a significantly lower external rotation impingement angle than group A (–32.8° ± 3.1°) in 5° abduction (group D vs. group A, $p = 0.023$; group E vs group A, $p = 0.027$). In 30° abduction, group C (–56.3° ± 3.3°) had a significantly less external rotation impingement angle than group B (–70.6° ± 3.2°) ($p = 0.044$) and groups D (–70.7° ± 5.0°) and E (–63.7° ± 8.0°) (group C vs. group D, $p = 0.043$; group C vs. group E, $p = 0.034$) (Fig. 6B).

Groups B, D, and E had significantly greater abduction capability compared to groups A and C ($p < 0.01$). However, with loading of 12.5 N or more, group E had significantly lower abduction capability compared to group B (at 5 N, $p = 0.293$; at 7.5 N, $p = 0.535$; and at 10 N, $p = 0.973$) (Fig. 7A). Similar results were seen with forward flexion capability. Although group E always showed greater forward flexion capability compared to groups A and C, group E had significantly less capability than group B at all loads of 7.5 N and above ($p < 0.01$) (Fig. 7B).

For anterior deltoid length, groups B and D had longer deltoid lengths than group A, and group C had a significantly shorter deltoid length than groups B, D, and E. For middle deltoid length, groups A, B, C, and D showed the same results as for anterior deltoid length (groups B, D, and E vs group A, $p < 0.01$). Group E had a significantly longer middle deltoid length than groups A and C (both

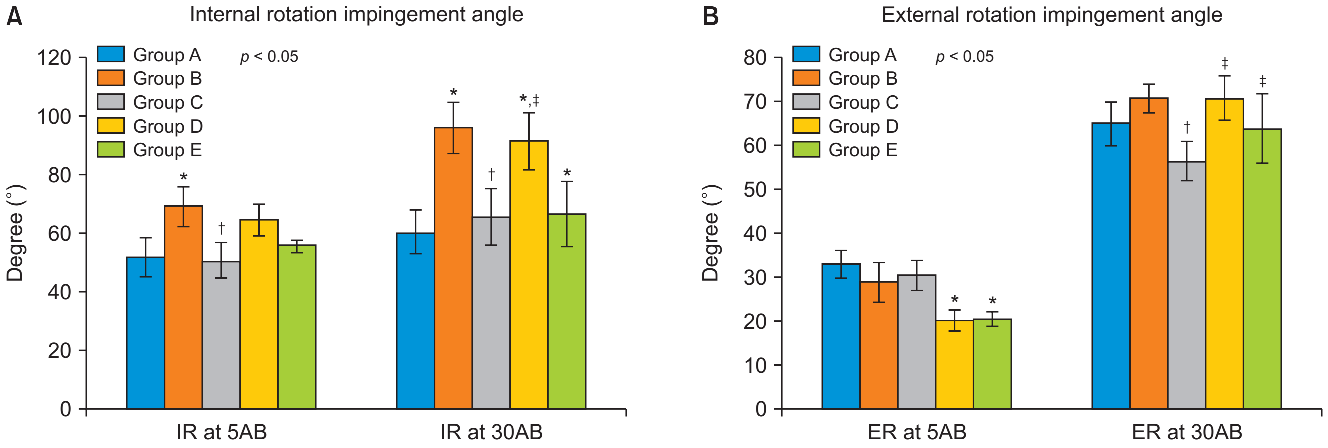

Fig. 6. The impingement-free angle during internal rotation (IR) at 5° abduction (5AB) and 30° abduction (30AB) (A) and external rotation (ER) at 5° abduction and 30° abduction (B). Standard baseplate and centric glenosphere (group A); eccentric glenosphere and standard baseplate (group B); centric glenosphere and the wedge-shaped baseplate (group C); eccentric glenosphere and the wedge-shaped baseplate (group D); and centric glenosphere and the baseplate with inferior reaming (group E). *vs. group A. †vs. group B. ‡vs. group C.

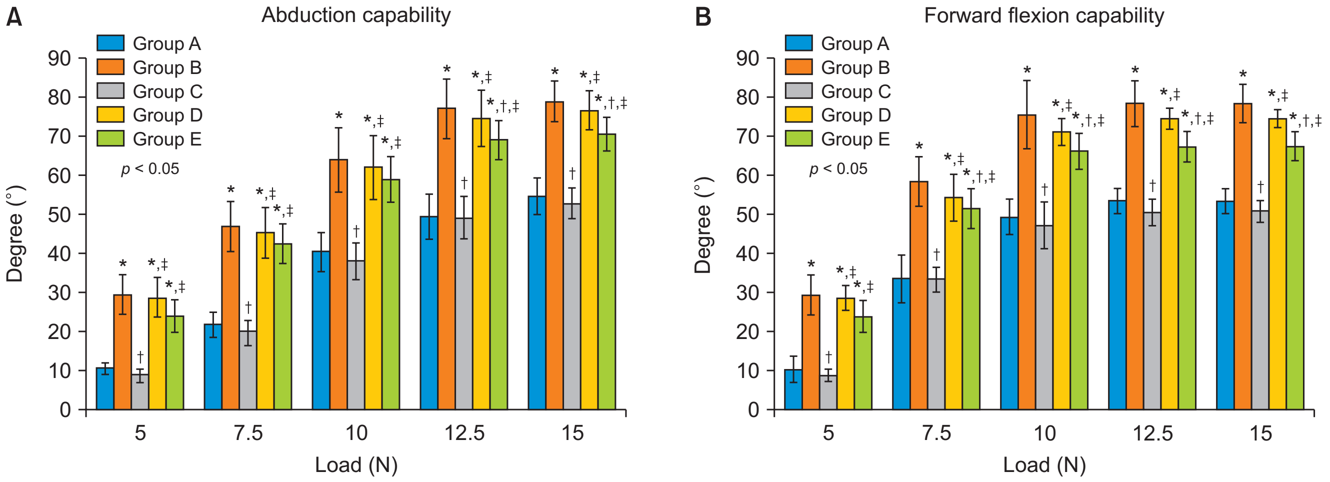

Fig. 7. The capability of the deltoid moment arm during sequential load increases: abduction (A) and forward flexion (B). Standard baseplate and centric glenosphere (group A); eccentric glenosphere and standard baseplate (group B); centric glenosphere and the wedge-shaped baseplate (group C); eccentric glenosphere and the wedge-shaped baseplate (group D); and centric glenosphere and the baseplate with inferior reaming (group E). *vs. group A. †vs. group B. ‡vs. group C.

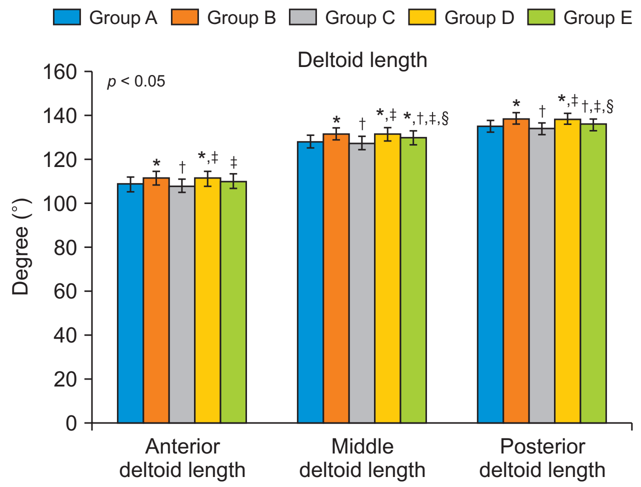

Fig. 8. The length of the anterior, middle, and posterior deltoids at 30° abduction. Standard baseplate and centric glenosphere (group A); eccentric glenosphere and standard baseplate (group B); centric glenosphere and the wedge-shaped baseplate (group C); eccentric glenosphere and the wedge-shaped baseplate (group D); and centric glenosphere and the baseplate with inferior reaming (group E). *vs. group A. †vs. group B. ‡vs. group C. §vs. group D.

Table 2. Change in Position of Implant Relative to Group A (mm)

	Anterior (+)/ posterior (–)	Superior (+)/ inferior (–)	Lateral (+)/ medial (–)
Group B	0.5 ± 0.6	–3.7 ± 0.3	–0.4 ± 0.4
Group C	–1.5 ± 0.6	0.5 ± 0.4	–0.8 ± 0.3
Group D	–0.5 ± 0.7	–3.3 ± 0.4	–0.8 ± 0.4
Group E	–1.3 ± 0.8	–1.9 ± 0.5	–0.8 ± 0.6

Values are presented as mean ± standard error. Group A: centric glenosphere and standard baseplate, group B: eccentric glenosphere and standard baseplate, group C: centric glenosphere and the wedge-shaped baseplate, group D: eccentric glenosphere and the wedge-shaped baseplate, group E: centric glenosphere and the baseplate with inferior reaming.

differences $p < 0.01$), although group E had a middle deltoid length that was shorter than that for groups B and D. Posterior deltoid length showed the same statistical results as middle deltoid length, except that there was no significant difference in posterior deltoid length between group A and group E ($p = 0.495$) (Fig. 8).

According to the analysis for the relative position of the humeral liner compared to the central peg hole relative to group A, group B was located anteriorly, all other groups were placed posteriorly, and all groups were located more medial. Group C showed a superior position than group A by 0.5 mm, and it was demonstrated that all other groups were more inferior than group A (Table 2).

DISCUSSION

In this study, an eccentric glenosphere with a 4-mm inferior overhang showed superior biomechanical results in the range of motion and movement capabilities of all directions, regardless of inferior tilt, compared to a concentric glenosphere. The implant designed for a pure inferior tilt of 10° had no significant difference from the glenosphere with a neutral tilt at the same location. However, the clinical inferior tilt showed better results than the pure inferior tilt, which were equivalent to results for the eccentric glenosphere. Deltoid lengthening associated with the clinical inferior tilt was smaller than that for the eccentric glenosphere; however, distalization was significantly greater than that for the pure inferior tilt, and the inferior scapular impingement during adduction was also more on the medial side with a wider range of adduction impingement-free angle.

Biomechanically, the inferior tilt of the glenosphere affords a greater impingement-free angle, with stronger resistance to upward vertical shearing forces due to arm distalization at the bone–glenoid interface.[12] The inferior tilted glenoid component that we customized has the advantage of being able to implement the inferior tilt of the glenosphere without initial bone loss due to inferior reaming of the glenoid. However, there are conflicting results as to whether this pure inferior tilt has beneficial effects in biomechanics and clinical practice.[5,12,14-16] In particular, there was a report that shortening of the scapular neck caused by 10° inferior tilt promoted impingement on the scapular neck during shoulder external rotation and adduction.[4] However, several biomechanical experiments that reported that inferior tilt prevented notching by providing an arc for greater motion in the inferior part did not completely control the COR position.[4,12,14] Clinical and experimental studies have also reported that COR movement in the glenoid, such as lateralization, has a critical influence on scapular notching or range of motion.[17,18] Therefore, considering the effect of COR of the glenoid in RSA, it is necessary to understand whether there is a similar effect for inferior tilt. In our study, compared with custom-made glenoid components, inferior tilt using 10° inferior reaming revealed comparable or similar biomechanical characteristics to inferior overhang with distalization of the COR. It is possible that 10° inferior reaming performed clinically to give inferior tilt has a better effect in preventing scapular notching and improving the range of motion because of moving the COR inferiorly and providing a wider arc due to the tilt of the glenosphere.

Placing the glenosphere with an inferior overhang has proved a reliable method to reduce scapular notching with minimal adverse effects in several biomechanical and clinical studies.[7,9,16,19] In our study, compared with the concentric glenosphere, the eccentric glenosphere not only showed a larger impingement angle for adduction, but also showed improvements in impingement angles for abduction and internal and external rotation and in deltoid abduction capability. In another biomechanical test, positioning the glenosphere with a larger inferior overhang resulted in better efficiency in deltoid force to abduct the arm due to the distalization effect.[3] Measurement of deltoid length and geometric analysis in our experiment also displayed the distalization effect of eccentric glenospheres. However, an improved range of motion was observed as the position of contact with the acromion and the proximal humerus or top of the humeral stem at the end of the abduction angle was changed. Deltoid load also decreased due to changes in the moment arm according to distalization. Clinically, an inferior overhang of the glenosphere was positively associated with restored arm elevation after RSA.[7] Based on our results, this is considered to result from an improved moment arm, due to better lengthening or recruiting of the deltoid. Further, there were changes in the contact point between the scapular neck and liner of the humeral stem at the angles of terminal abduction and internal and external rotation.

The most inferior boundary of the glenosphere can be made to pass over the inferior glenoid rim by implanting the baseplate as far down as possible or by fastening an eccentric glenosphere to the baseplate. Since fixing the central peg and peripheral screws in the optimal position and orientation is important for maximizing the stability of the glenoid component, inferior overhang using an eccentric glenosphere is biomechanically advantageous, rather than changing the position of the baseplate.[20,21] In a clinical series comparing a concentric with a 2-mm inferior eccentric glenosphere, over a minimum follow-up of 5 years, the eccentric glenosphere produced less notching and a similar rate of complications such as glenoid loosening.[9] However, the eccentric rather than concentric glenosphere has more concerns regarding uneven forces or micromotion at the baseplate bone interface.[12] A randomized controlled trial comparing concentric and eccentric glenospheres reported that an inferior glenoid overhang of more than 3.5 mm did not induce scapular notching; however, no optimal amount of inferior overhang was concluded to maximize postoperative outcomes.[22] Nonetheless, depending on patient stature or joint size, eccentric glenospheres with different amounts of inferior overhang may have different effects on arm lengthening, and excessive lengthening may be associated with worse outcomes, such as decreased arm elevation and nerve deficits.[23,24] Therefore, one method to maximize the fixation force of the baseplate, while maintaining inferior overhang appropriately and considering the anatomic size and characteristics of each patient, may be inferior tilt using 10° inferior reaming.

Advancements in RSA prostheses through lateralization designs by changing the humeral neck-shaft angle and COR of the glenoid have reduced scapular notching and have more biomechanically advantageous properties than the standard Grammont design. However, the reason for still considering inferior tilt clinically is to prevent superior tilt of the glenoid component, which is significantly associated with postoperative instability, and a biomechanical probability of exacerbated scapular notching.[25,26) Although meticulous evaluations for preoperative wear patterns, anatomic inclination, and glenoid version are performed, errors occur in the positioning and inclination of glenoid fixation for various reasons.[27,28) In our study, the humeral stem had a neck-shaft angle of 145°, adopting a lateralization design; however, inferior tilt through eccentric reaming showed better results in adduction angle and deltoid efficacy than neutral tilt. Therefore, even when using a prosthesis with a humeral lateralization design, inferior tilt through proper reaming prevents superior tilt and is more biomechanically advantageous than neutral tilt.

This study has several limitations. First, the glenosphere was limited to one size of 36 mm diameter. Several studies have already reported that a large glenosphere has biomechanical and clinical advantages; therefore, bias may have been introduced because a glenosphere of fixed diameter was used irrespective of cadaver size.[11,29) Second, the degree of variation in overhang and tilt of the glenoid component was limited, so more detailed biomechanical characteristics could not be analyzed. The effects of eccentric and concentric glenospheres could have been compared after inferior reaming of the glenoid for clinical inferior tilt, but additional analysis could not be performed due to the already large number of comparison groups. Since there was also a report that inferior overhang was effective in preventing scapular notching when the inferior overhang was at least 3.5 mm, more specific results could be obtained by comparing inferior overhang in various conditions.[22) Third, there were anatomic variations of the specimens due to the small number and differences in the size and length of the scapular neck of individual cadavers.

At the center of the glenoid, a 10° inferior tilt of the glenosphere without changing the COR had no benefit in terms of the impingement-free angle and deltoid moment arm. However, the eccentric glenoshere providing a 4-mm inferior overhang showed superior biomechanical properties than the central position in both neutral and 10° inferior tilt. Inferior tilt through 10° inferior reaming showed better biomechanical results than neutral tilt due to the distalization effect.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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