Original Article
Clinics in Orthopedic Surgery 2023;15:135-144 • https://doi.org/10.4055/cios22084

Comparison of Clinical Performance of Inlay versus Onlay Humerus Implants in Reverse Total Shoulder Arthroplasty

Hyo-Jin Lee, MD, Chi-Young Yoon, MD, Yang-Soo Kim, MD

Department of Orthopedic Surgery, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

Background: Reverse total shoulder arthroplasty (RTSA) has become the treatment of choice for the management of massive rotator cuff tears combined with cuff tear arthropathy, and many novel designs have been proposed to overcome the shortcomings of classic RTSA. This study sought to evaluate and compare RTSA outcomes among patients with cuff tear arthropathy treated by a medialized inlay humerus implant with a neck shaft angle of 155° or a lateralized onlay implant with a neck shaft angle of 145°.

Methods: A retrospective review of 32 inlay implants and 32 onlay implants was performed. The active range of motion (ROM), visual analog scale (VAS) for pain, motor power for elevation and external rotation, and functional scores including the American Shoulder and Elbow Surgeons score, Constant score, and Korean Shoulder Scoring system were assessed before surgery, at 3, 6, and 12 months after surgery, and at the last follow-up at least 24 months after surgery. Scapular notching, lateral humeral offset, and deltoid wrapping offset were assessed for radiographic evaluation.

Results: The preoperative demographic data of both groups showed no significant differences ($p > 0.05$). The mean follow-up period was 24.9 months. Significant improvements in forward flexion, functional scores, and pain VAS score were observed in both groups at the last follow-up. No significant differences in ROM or functional scores were found between two groups at each time point, except that the onlay implant group exhibited a significantly greater range of external rotation at 3 and 12 months after surgery and at the last follow-up. The rate of scapular notching and the final power improvement did not show significant differences between the groups.

Conclusions: Primary RTSA using inlay or onlay humerus implants was associated with recovery from pseudoparalysis and good clinical outcomes. However, RTSA with onlay humerus implantation led to clinically superior results in terms of external rotation.

Keywords: *Rotator cuff tear arthropathy, Replacement arthroplasty, Shoulder*

For many years, patients with massive irreparable rotator cuff tears and cuff tear arthropathy (CTA) have been treated by reverse total shoulder arthroplasty (RTSA) owing to the predictable improvements in pain relief and shoulder motion.[1,2] There have been many changes in the design of RTSA over the years to overcome the identified problems, with lateralization being one of the most representative changes that have been made to the implant design.[3] Lateralization can be achieved by increasing the offset intrinsic to either the glenoid or humerus. Lateralization has a reliable theoretical background of increasing the tension to the anterior and posterior muscles of both the deltoid and rotator cuffs in a manner that adds stability to the joint and benefits rotations.[4-6]

However, there remains some level of concern regarding the substantial benefit of applying the concept

Received March 7, 2022; Revised July 11, 2022;
Accepted July 31, 2022
Correspondence to: Yang-Soo Kim, MD
Department of Orthopedic Surgery, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, 222 Banpo-daero, Seocho-gu, Seoul 06591, Korea
Tel: +82-2-2258-6350, Fax: +82-2-535-9834
E-mail: kysoos@catholic.ac.kr

of implant lateralization, wherein somewhat diluting the basic principle of classic RTSA leads to reduced medialization and distalization and an increase in shear force on the glenosphere and baseplate, which can enhance the risk for component loosening.[7] In this regard, there is controversy about the ideal location of lateralization, as well as how much lateralization should be achieved. Despite numerous modifications to RTSA, with more than 30 different designs introduced so far, the basic concept of medializing and distalizing the center of rotation (COR) by RTSA has not been altered, and products that are faithful to the classic concept are still clinically in use with only slight modifications made to their design or fixation method in order to overcome the known problems.[8,9]

Until now, many studies have compared various types of lateralized RTSA products to the original Grammont-style prosthesis, and the vast majority of lateralized prostheses used for the analysis consist of lateralization achieved by both increasing the offset on the glenoid and decreasing the neck shaft angle of the humerus. In this particular study, a comparison was made on the two different products with similar amounts of glenoid offset, but a primary difference in the humeral inclination. The purpose of this study was to evaluate RTSA outcomes, including the overall range of motion (ROM) and functional scores, among patients with CTA treated using either a classic medialized inlay implant with a neck shaft angle of 155° or a lateralized onlay implant with a neck shaft angle of 145°. The hypothesis of this study was that the performance of a lateralized onlay implant would exceed that of a medialized inlay implant in the aspects of ROM and functional scores with a lower incidence of scapular notching.

METHODS

This study was approved by the Institutional Review Board of Seoul St. Mary's Hospital, the Catholic University of Korea (No. KC17OESI0118). As a retrospective review study, informed consent was waived.

Prospectively collected data of RTSA procedures performed by a single surgeon (YSK) from May 2015 to September 2019 were retrospectively reviewed to compare medialized RTSA performed with an inlay humeral implant and lateralized RTSA performed with an onlay humeral implant. Inclusion criteria were a primary RTSA under the diagnosis of a massive tear of supraspinatus with CTA. Patients with ipsilateral pseudoparalysis of ipsilateral shoulder but with well-preserved active elevation of the contralateral shoulder were enrolled. The minimum required follow-up period was 24 months. Patients with irreparable subscapularis and functional deficit in external/internal rotational movement were excluded. To clarify the benefit of lateralization in patients with a functional teres minor, those with fatty infiltration of the teres minor of grade 3 or greater were excluded from the evaluation. Finally, patients with fracture sequelae (a history of infection or trauma, the presence of neurologic problems, or previous shoulder surgery, including arthroscopic rotator cuff repair) were excluded. The total number of enrolled patients was 64 with 32 patients in each group.

Implant

Shoulders were grouped based on the implant design: medialized COR with a 155° polyethylene inlay humerus (inlay group) (SMR; Lima Corporate, San Daniele del Friuli, Italy) and medialized COR with a 145° polyethylene onlay humerus (onlay group) (Equinoxe Reverse System; Exactech, Gainesville, FL, USA). The implant of the inlay group had a specific eccentric design that allows for the glenosphere to extend in a lower position with respect to the inferior glenoid rim (Fig. 1).[10] According to the classification introduced by Hamilton et al.,[11] the implant of the inlay group belongs to the medialized glenoid/medialized humerus category, whereas the implant of the onlay group belongs to the medialized glenoid/lateralized humerus category.[12] Within the study time frame, a Grammont-style inlay implant was used from 2015 to 2017 and a lateralized onlay implant was used for the rest of the study period. All RTSAs were performed through a deltopectoral approach and other aspects of the surgeon's protocol, including the

Fig. 1. The SMR reverse system with an eccentric glenoid design and extended overhang.

use of non-cement, press-fit stems, and the peel and repair of the subscapularis, remained consistent.

Rehabilitation

The same standardized home-based rehabilitation protocols were adopted by both groups postoperatively. An abduction brace was applied for 4 weeks after the operation and during this period, no active forward flexion or rotation beyond neutral was allowed. After discontinuation of brace-wearing at 4 weeks postoperatively, pulley exercises were prescribed to increase forward flexion, and external rotation and behind-the back ROM exercises were allowed. No limit was imposed on the use of the treated shoulder within a tolerable extent.

Clinical Outcome Assessment

Patients completed preoperative and 2-year follow-up evaluations of active ROM, visual analog scale (VAS) score for pain, and clinical scoring, including the American Shoulder and Elbow Surgeons (ASES) score, Constant score, and Korean Shoulder Scoring system. Outcomes were evaluated before surgery, at 3, 6, and 12 months after surgery, and at the final follow-up. For measuring ROM, forward flexion and external rotation were evaluated with a goniometer when patients were in the supine position, excluding the scapulohumeral motion. Internal rotation, which was measured with patients in the seated position, was evaluated with the tip of the thumb reaching the vertebral level. Internal rotation up to the level of the sacrum was designated as 0 point, and 1 point was added for each level up. All assessment data were collected by a clinical researcher who was not otherwise involved in the current study.

Elevation and external rotation motor power were evaluated at each visit by using a digital force myometer and compared with measurements of the contralateral unaffected arm. The compact force gauge transducer used in this study was certified for "force and torque measurement application" by Mecmesin Ltd., U.K., to conform to an operational accuracy of ± 0.5% for any measurement within the working range.[13] Strength index, defined as the strength of the affected arm divided by the strength of the contralateral arm, was used instead of the absolute value of the muscle.[14,15] As normal muscle strength varies between individuals, comparison of the absolute values is not objective. The strength of the affected shoulder was divided by the strength of the contralateral side.

Radiographic Assessment

Standardized true anteroposterior and axial radiographic evaluations were conducted preoperatively, at 3, 6, and 12 months postoperatively, and at the last follow-up. All radiographic measurements were performed on a true anteroposterior view of each patient. The severity of scapular notching was graded according to the Sirveaux classification, with grade 1 notches involving only the scapular bone, grade 2 notches reaching the inferior screw of the base plate, grade 3 notches extending to the superior aspect of the inferior screw, and grade 4 notches extending

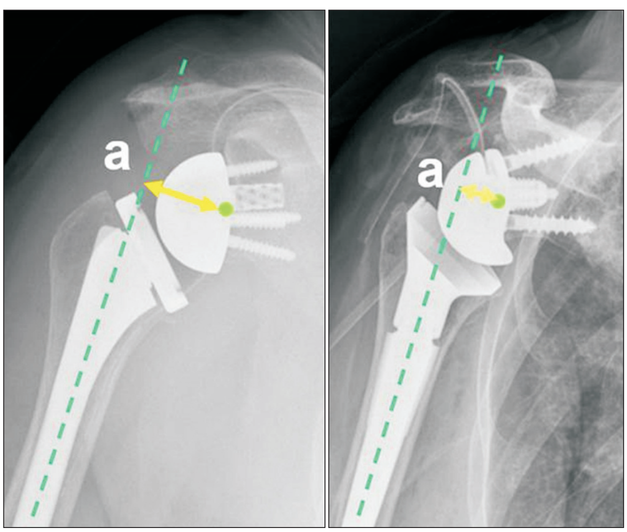

Fig. 2. Lateral humeral offset (a), which is the perpendicular distance from the center of rotation of the glenosphere (green dots) to the line that passes along the center of the proximal humerus.

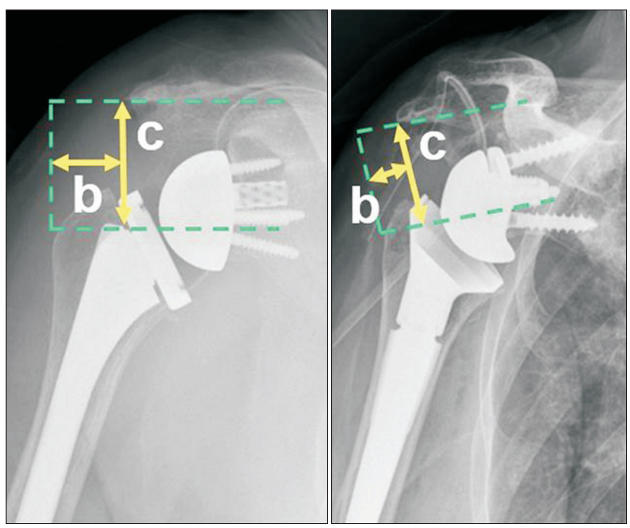

Fig. 3. Deltoid-wrapping offset (b), which is the perpendicular distance from the greater tuberosity to the line along the acromial undersurface and acromiohumeral distance (c), i.e., perpendicular distance from the acromial undersurface to the parallel line, passing the greater tuberosity.

superior to the inferior screw and including area under the baseplate.[16] Radiographic assessment was performed to identify changes in the lateral humeral offset, which is the perpendicular distance from the COR of the glenosphere to the line that passes along the center of the proximal humerus (Fig. 2);[3] the deltoid-wrapping offset, which is the perpendicular distance from the greater tuberosity to the line along the acromial undersurface; and the acromiohumeral distance, which is the perpendicular distance from the acromial undersurface to the parallel line passing the greater tuberosity (Fig. 3).

Table 1. Demographic Data

Variable	Inlay group (n = 32)	Onlay group (n = 32)	*p*-value
Age (yr)	75.5	74.78	0.64
Sex (male : female)	12 : 20	6 : 26	0.98
Body mass index (kg/m^2)	25.01	25.96	0.24
Follow-up period (mo)	25.22	24.58	0.93
Preoperative			
Critical shoulder angle (°)	31.9	31.3	0.84
Deltoid wrapping offset (mm)	26.1	27.4	0.14
Acromiohumeral distance (mm)	5.91	6.21	0.64

Statistical Analysis

The Wilcoxon signed-rank test was used for comparison of the preoperative and final postoperative measurements of each group. The Kruskal-Wallis test was used to compare the data between the groups at each time point. The significance level was set at 0.05 with associated 95% confidence intervals. The SPSS software ver. 19 (IBM Corp., Armonk, NY, USA) was used for statistical analysis.

RESULTS

Demographic data including age, sex, body mass index, mean follow-up period, and preoperative critical shoulder angle, deltoid-wrapping offset, and acromiohumeral distance showed no significant difference between groups ($p > 0.05$) (Table 1). The average follow-up period was 24.9 months. Both groups demonstrated improvements in active forward flexion at the final follow-up relative to the preoperative pseudoparalytic state (active forward flexion < 90°). Compared to the inlay implant group, the onlay implant group achieved greater improvements in external rotation at the last follow-up despite the well-preserved preoperative external

Table 2. Comparison of Pre- and Postoperative Range of Motion

Measure	Active range of motion		*p*-value
	Initial	Last follow-up	
Forward flexion			
Inlay group	78.00 ± 13.58	133.57 ± 17.70	0.02
Onlay group	75.23 ± 12.35	139.29 ± 8.98	0.02
External rotation with 90° abduction			
Inlay group	73.45 ± 22.72	73.85 ± 21.03	0.51
Onlay group	74.29 ± 13.99	84.29 ± 6.76	0.02
External rotation at side			
Inlay group	70.34 ± 22.28	74.62 ± 15.61	0.33
Onlay group	70.71 ± 15.62	82.86 ± 7.84	0.01
Internal rotation			
Inlay group	6.83 ± 3.97	7.79 ± 3.77	0.07
Onlay group	6.70 ± 3.50	7.71 ± 1.79	0.06

Values are presented as mean ± standard deviation.

Table 3. Comparison of Pre- and Postoperative Functional Scores

Measure	Range of motion		p-value
	Preoperative	Last follow-up	
Visual analog scale for pain			
Inlay group	4.86 ± 1.68	3.61 ± 2.72	0.03
Onlay group	5.30 ± 1.89	2.26 ± 1.98	0.01
American Shoulder and Elbow Society score			
Inlay group	45.60 ± 18.36	63.43 ± 22.54	0.03
Onlay group	39.95 ± 18.95	66.38 ± 22.86	0.02
Constant score			
Inlay group	53.82 ± 16.66	75.07 ± 16.48	0.04
Onlay group	45.87 ± 16.38	72.59 ± 21.15	0.03
Korean Shoulder Society score			
Inlay group	50.00 ± 13.50	72.36 ± 20.07	0.04
Onlay group	44.16 ± 12.27	71.77 ± 22.09	0.02

Values are presented as mean ± standard deviation.

rotation (Table 2). Both groups obtained significant improvements in all functional scores, including a reduction in pain VAS score at the last follow-up (Table 3).

The range of external rotation with 90° abduction was significantly greater during the recovery time at postoperative 3 and 12 months in the onlay group. The onlay group also showed superior results with external rotation at side at postoperative 3 and 12 months and at the last follow-up. The inlay implant group experienced a slight decrease in both the external and internal rotation ranges postoperatively, but all ranges were fully recovered at the last follow-up (Table 4). No significant differences were found in pain VAS and clinical scores between the two groups at the last follow-up (Table 5).

The motor grade of external rotation showed no significant difference between the groups. However, the inlay group experienced greater elevation power at 3 months (3.93 ± 0.56 vs. 3.12 ± 0.21, $p = 0.02$) and 6 months (4.53 ± 0.11 vs. 3.89 ± 0.32, $p = 0.03$) postoperatively. Meanwhile, the overall power did not show a significant difference between the groups at the last follow-up (Fig. 4).

Regarding the radiographic assessment, all three parameters showed significant differences between the groups. Lateral humeral offset and deltoid wrapping offset were significantly larger in the lateralized group, whereas the medialized group showed more distalization with the increase in acromiohumeral distance. Overall scapular notching was 17.2% with no significant difference between the two groups ($p = 0.826$) (Table 6).

As mentioned by Poon et al.,[10] the implant used for the inlay group boasted an additional 4-mm positioning achieved by an off-center attachment in the glenosphere. In the case of the implant used for the onlay group, the average distance from the scapular neck to the inferior glenosphere rim was 3.8 mm. In a study by Werthel et al.,[12] the global lateral offset was 17.0 mm for the inlay implant and 26.4 mm for the onlay implant. There were no reported complications during the surgical procedures, and no shoulders included in this study developed dislocation or infection or required repeat surgery.

DISCUSSION

In this study, both medialized inlay and lateralized onlay implants showed effective recovery of pseudoparalysis and pain reduction. Overall, active external rotation movement was better in those who received lateralized onlay implants, whereas inlay implants facilitated stronger elevation power during the early postoperative period. There are numerous studies that have compared the clinical outcomes of the classic medialized inlay and lateralized onlay prostheses of RTSA and a majority of them showed superior results with lateralization in certain aspects. In fact, these results are somehow predictable as the purpose

Table 4. Postoperative Changes in Active Range of Motion

Active range of motion		Inlay group	Onlay group	p-value
Forward flexion	Initial	78.00 ± 13.58	75.23 ± 12.35	0.70
	3 mo	100.96 ± 16.61	108.20 ± 14.26	0.31
	6 mo	130.58 ± 14.44	131.92 ± 11.50	0.71
	12 mo	138.67 ± 15.52	139.05 ± 6.82	0.45
	Last	133.57 ± 17.70	139.29 ± 8.98	0.22
External rotation with 90° abduction	Initial	73.45 ± 22.72	74.29 ± 13.99	0.87
	3 mo	59.62 ± 24.41	73.93 ± 13.99	0.01
	6 mo	72.69 ± 18.45	80.37 ± 10.18	0.07
	12 mo	71.33 ± 17.27	85.71 ± 5.07	0.01
	Last	73.85 ± 21.03	84.29 ± 6.76	0.11
External rotation at side	Initial	70.34 ± 22.28	70.71 ± 15.62	0.94
	3 mo	58.08 ± 20.40	68.96 ± 15.24	0.03
	6 mo	70.00 ± 16.97	75.19 ± 11.56	0.20
	12 mo	72.00 ± 16.56	80.95 ± 6.25	0.03
	Last	74.62 ± 15.61	82.86 ± 7.84	0.03
Internal rotation	Initial	6.83 ± 3.97	6.70 ± 3.50	0.37
	3 mo	6.54 ± 3.17	6.55 ± 3.38	0.23
	6 mo	5.88 ± 3.33	7.73 ± 3.17	0.12
	12 mo	7.33 ± 3.11	8.67 ± 2.58	0.06
	Last	7.79 ± 3.75	7.71 ± 1.79	0.09

Values are presented as mean ± standard deviation.

of developing a lateralized system was mainly to overcome the drawbacks of the classic inlay prosthesis. Similar results were reported by Streit et al.[17] In the study, a greater range of forward flexion was achieved with Grammont-style prosthesis, whereas greater external rotation was achieved by a lateralized prosthesis, but these results were without statistical significance. In contrast to our findings, lateralization was achieved both on the humerus and glenoid side. According to a systematic review by Erickson et al,[18] patients with 135° cup inclination had significantly greater improvement in external rotation than patients with 155° cup inclination, but the focus of the study was on the humeral inclination and the status of glenoid offset was not under consideration.

The overall incidence rate of scapular notching was less than 20%, without significant differences in grade distribution between the groups. A lower incidence of scapular notching is one of the many advantages of glenoid lateralization, but the lateralized implant we evaluated in this study was an onlay prosthesis, in which lateralization was mainly made on the humeral side without further modification to the medialized COR. The lateral offset of the glenoid for the onlay implant was 12.9 mm, whereas the inlay implant showed a lateral offset of 14 mm; thus, both groups belonged to the medial glenoid category.[12] With this degree of glenoid offset, a relatively low incidence of scapular notching in this study cannot be explained as an advantage adopted from the lateral offset of the glenoid. Instead, we can offer a few possible reasons for the relatively low incidence of notching in both groups.

The specific medialized inlay implant that we used in this study has a unique feature of having an eccentric glenosphere with inferior overhang. The presence of inferior overhang is considered to allow for a greater adduc-

Table 5. Postoperative Changes in Functional Scores

Functional score		Inlay group	Onlay group	*p*-value
Visual analog scale for pain	Initial	4.86 ± 1.68	5.30 ± 1.89	0.34
	3 mo	4.29 ± 2.48	3.76 ± 2.19	0.44
	6 mo	3.81 ± 2.43	2.91 ± 2.07	0.16
	12 mo	4.30 ± 2.19	2.56 ± 1.69	0.01
	Last	3.61 ± 2.72	2.25 ± 1.98	0.12
American Shoulder and Elbow Surgeons score	Initial	45.60 ± 18.36	39.95 ± 18.95	0.24
	3 mo	48.80 ± 19.72	53.65 ± 19.49	0.40
	6 mo	57.77 ± 25.18	63.86 ± 18.72	0.33
	12 mo	52.33 ± 20.07	67.95 ± 17.68	0.02
	Last	63.43 ± 22.54	66.38 ± 22.86	0.71
Constant score	Initial	53.82 ± 16.66	45.87 ± 16.38	0.06
	3 mo	55.88 ± 18.83	63.36 ± 15.29	0.13
	6 mo	58.61 ± 18.50	65.50 ± 14.67	0.11
	12 mo	61.80 ± 21.25	69.30 ± 18.82	0.28
	Last	75.07 ± 16.48	72.59 ± 21.15	0.71
Korean Shoulder Scoring system	Initial	50.00 ± 13.50	44.16 ± 12.27	0.08
	3 mo	51.20 ± 17.41	59.6 ± 13.03	0.06
	6 mo	57.89 ± 20.00	62.35 ± 13.94	0.07
	12 mo	61.60 ± 15.81	70.65 ± 14.95	0.09
	Last	72.36 ± 20.07	71.77 ± 22.09	0.94

Values are presented as mean ± standard deviation.

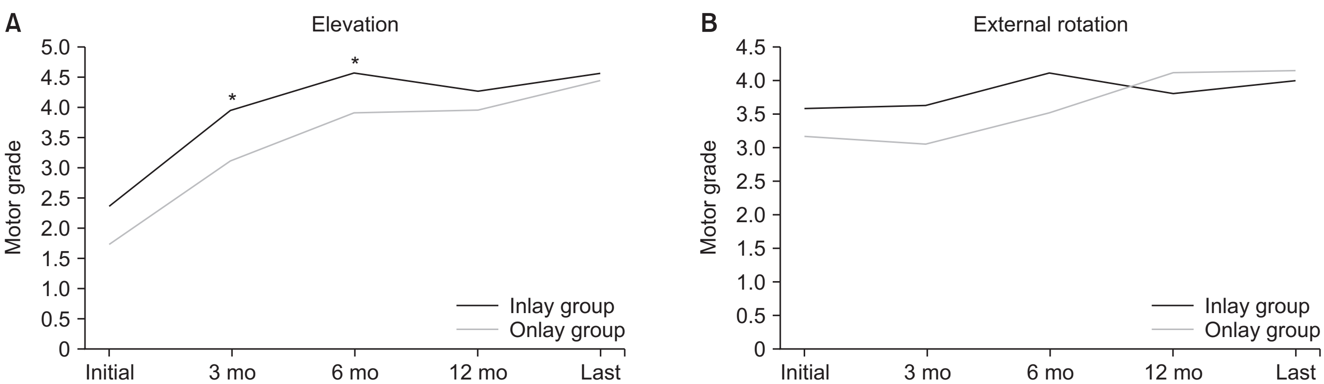

Fig. 4. Motor grade for elevation (A) and external rotation (B). *$p < 0.05$.

tion before impingement of the humerus to the inferior scapula, which can lead to scapular notching.[19-21] In the case of the lateralized onlay implant, the baseplate design has a built-in offset, which distally shifts the glenosphere to a position that may prevent humeral liner impingement on the inferior glenoid from occurring.[10,22] It is likely that this offset negates the need for additional lateralization on the glenoid side to avoid scapular notching together with a

Table 6. Postoperative Radiographic Changes

Variable	Inlay implant	Onlay implant	*p*-value
Lateral humeral offset (mm)	15.90	28.62	0.001
Deltoid wrapping offset (mm)	19.03	26.94	0.001
Acromiohumeral distance (mm)	34.60	30.36	0.025
Scapular notching, n (%)	6/32 (18.8)	5/32 (15.6)	0.826
Scapular notching grade (I : II : III : IV)	3 : 2 : 1 : 0	3 : 1 : 1 : 0	0.901

reduced neck shaft angle.

According to the electromyographic result reported by Pelletier-Roy et al.,[23] RTSA intervenes in cuff-defect shoulders by modifying the scapulothoracic sequence. Further lengthening of the distance between the medial border of the scapula and the glenohumeral joint by lateralization not only affects the tension of rotators, but also the scapulothoracic muscles, especially the upper trapezius and latissimus dorsi, which are known to be the main activator muscles in RTSA shoulders.[23] However, this theory only can be applied in the setting of implants with increased offset on the glenoid side. So far, numerous clinical studies have compared two or three different products that represent either medialized or lateralized RTSA systems. However, as lateralization is completed in a variety of ways among different manufacturers, few studies have compared the pure effect of lateralization on the humeral side only. Humeral offset can be modified by either inlay or onlay implantation, which would eventually lead to different neck shaft angles. Still, most of the studies that have compared the clinical results of different neck shaft angles of RTSA were not successful in achieving identical or at least similar conditions or offset degrees of glenoid components. According to recent studies conducted by Nelson et al.[24] and Zitkovsky et al.,[25] lateralized prostheses with a 135° neck shaft angle showed superior results relative to Grammont-style prostheses with s 155° neck shaft angle; however, lateralization of the offset was not established solely on the humerus side, but instead on both the glenoid and humerus sides. A systematic review of 65 studies comparing the ROM of RTSA humeral components with cup inclinations of 135° and 155° also showed significantly greater external rotation with the 135° humeral cup inclination.[18] However, as clearly stated in the limitations, glenosphere sizes were not reliably specified in most of the included studies and outcomes based on this variable could not be evaluated. Even though two different implants from two different manufacturers were compared in our study, these implants had only 1.1-mm offset difference on the glenoid side, with the majority of differences existing on the humeral side. This condition enabled a more objective analysis of the effect of humeral lateralization with different neck shaft angles.

Apart from the theoretic expectation that lateralization would always lead to rotational superiority due to increased tension on the anterior and posterior deltoid and rotator cuffs, the postoperative rotational movement of the shoulder can be affected by the positioning of the arm. According to a biomechanical study that evaluated the effect of lateralization on humeral components, it only affected the posterior cuff torque at 0° abduction.[4] The results of our study were in line with those of this biomechanical study, indicating the significant superiority of external rotation with the arm at the side (0° abduction) at the last follow-up. Still, during the recovery period, the lateralized implant group had higher ranges of external rotation relative to the medialized implant group at each time point. Moreover, significant postoperative improvement was apparent in external rotation ROM with the lateralized implant.

Meanwhile, different from external rotation, the range of internal rotation did not show significant differences between the two groups at each time point. According to Ackland et al.,[26] the posterior deltoid loses its function as an external rotator and somehow it may work as an internal rotator in the setting of medialized classic RTSA. However, lateralization may mitigate this change to some extent by allowing posterior deltoid to recover its own function of external rotation. It may explain why the recovery of internal rotation with lateralization was not as efficient as that of external rotation.

The aim of this study was to assess patients who underwent RTSA due to pseudoparalysis caused by a massive tear on the supraspinatus but had well-preserved anterior and posterior cuffs. Without apparent preoperative lesions or functional deficits in the external rotators, postoperative rotational function was not actually hampered by the medialized prosthesis that is known to decrease the tension of the anterior and posterior cuffs. Even though a certain amount of decrease in external rotation was shown during the early postoperative period, probably due to insufficient recovery, the range of external rotation eventually fully recovered to that in the preoperative period.

Meanwhile, regarding the results of this study, we came up with a few reasons why the classic medialized Grammont-style prosthesis is still clinically valid and should not be unconditionally ostracized or replaced by lateralized prostheses. First, the concept of a medialized prosthesis is rather loyal to the principle of RTSA, and elongation of the deltoid arm actually led to better elevation power during the recovery time than the lateralized prosthesis did. This classic implant is capable of not only helping patients recover from pseudoparalysis, but also improving overall clinical parameters, without falling behind the lateralized implant in this regard. Second, with only minor changes to the design and the positioning of the glenoid, scapular notching, which is one of the most common problems that come to the fore with RTSA, can be sufficiently resolved. In this particular study, the similarity of offsets between the groups enabled the objective analysis of the influence of inferior overhang on the prevention of scapular notching. Lastly, under the circumstances of there being no preoperative rotational deficit in pseudoparalytic patients, the use of a medialized implant does not necessarily lead to reductions in rotational functions. Still, it cannot be denied that lateralized implants, which were developed to compensate for the shortcomings of a nonlateralized Grammont design, have clearly shown superiority in rotational movement.

This study has several limitations, including its retrospective nature and lack of randomization. First, the analysis was influenced by the relatively small population evaluated in the present study (n = 32 for each group). Also, the assessment of clinical outcomes was limited to 24 months of follow-up. We were not able to evaluate further heterotopic ossification, osteolysis, or loosening among groups, which may occur in the longer term. Second, the results were limited to the difference in humeral inclination and cannot be interpreted as global lateralization. Also, the patient enrollment was limited to those with the existence of preoperative functional rotation movement and practically candidates for RTSA often also have problems in anterior and posterior cuffs with or without functional deficit. In these cases, we cannot guarantee not only the postoperative preservation or improvement of rotational movement by inlay implants but also the overall rotational improvement by lateralized implants. Third, even if two implants have similar offsets on the glenoid side, all the conditions except the neck shaft angle of the humerus cannot be identical. In fact, the use of an eccentric glenosphere for inlay group further enhances distalization of the humerus in relation to the acromion and may add further bias to the entire study as the purposed difference was the neck angle of either 145° or 155°. Fourth, some values were not consistent enough to induce a solid conclusion. Contrary to the rest of the postoperative results regarding the external rotation at side, we were not able to explain why the difference at postoperative 6 months was not statistically significant. Still, despite the lack of statistical significance, the fact that the value of the onlay group was numerically higher at postoperative 6 months is in line with the results.

Primary RTSA using inlay or onlay humerus implants was associated with recovery from pseudoparalysis and good clinical outcomes. However, RTSA with onlay humerus implantation led to clinically superior results in external rotation.

CONFLICT OF INTEREST

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

ORCID

Hyo-Jin Lee https://orcid.org/0000-0002-7708-4754
Chi-Young Yoon https://orcid.org/0000-0001-7137-5609
Yang-Soo Kim https://orcid.org/0000-0003-4267-7880

REFERENCES

1. Jarrett CD, Brown BT, Schmidt CC. Reverse shoulder arthroplasty. Orthop Clin North Am. 2013;44(3):389-408.
2. Wall B, Nove-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am. 2007; 89(7):1476-85.
3. Cho NS, Nam JH, Hong SJ, et al. Radiologic comparison of humeral position according to the implant designs following reverse shoulder arthroplasty: analysis between medial glenoid/medial humerus, lateral glenoid/medial humerus, and medial glenoid/lateral humerus designs. Clin Shoulder Elb. 2018;21(4):192-9.

4. Chan K, Langohr GD, Mahaffy M, Johnson JA, Athwal GS. Does humeral component lateralization in reverse shoulder arthroplasty affect rotator cuff torque?: evaluation in a cadaver model. Clin Orthop Relat Res. 2017;475(10):2564-71.

5. Greiner S, Schmidt C, Herrmann S, Pauly S, Perka C. Clinical performance of lateralized versus non-lateralized reverse shoulder arthroplasty: a prospective randomized study. J Shoulder Elbow Surg. 2015;24(9):1397-404.

6. Helmkamp JK, Bullock GS, Amilo NR, et al. The clinical and radiographic impact of center of rotation lateralization in reverse shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg. 2018;27(11):2099-107.

7. Harman M, Frankle M, Vasey M, Banks S. Initial glenoid component fixation in "reverse" total shoulder arthroplasty: a biomechanical evaluation. J Shoulder Elbow Surg. 2005; 14(1 Suppl S):162S-167S.

8. Young SW, Everts NM, Ball CM, Astley TM, Poon PC. The SMR reverse shoulder prosthesis in the treatment of cuff-deficient shoulder conditions. J Shoulder Elbow Surg. 2009; 18(4):622-6.

9. Beltrame A, Di Benedetto P, Salviato D, et al. The SMR reverse shoulder arthroplasty in rotator cuff arthropathy management. Acta Biomed. 2017;88(4S):81-9.

10. Poon PC, Chou J, Young SW, Astley T. A comparison of concentric and eccentric glenospheres in reverse shoulder arthroplasty: a randomized controlled trial. J Bone Joint Surg Am. 2014;96(16):e138.

11. Hamilton MA, Diep P, Roche C, et al. Effect of reverse shoulder design philosophy on muscle moment arms. J Orthop Res. 2015;33(4):605-13.

12. Werthel JD, Walch G, Vegehan E, Deransart P, Sanchez-Sotelo J, Valenti P. Lateralization in reverse shoulder arthroplasty: a descriptive analysis of different implants in current practice. Int Orthop. 2019;43(10):2349-60.

13. Kumar MS, Thombare RU. A comparative analysis of the effect of various denture adhesives available in market on the retentive ability of the maxillary denture: an in vivo study. J Indian Prosthodont Soc. 2011;11(2):82-8.

14. Zhang Q, Zhou J, Ge H, Cheng B. Tenotomy or tenodesis for long head biceps lesions in shoulders with reparable rotator cuff tears: a prospective randomised trial. Knee Surg Sports Traumatol Arthrosc. 2015;23(2):464-9.

15. Park JY, Lhee SH, Choi JH, Park HK, Yu JW, Seo JB. Comparison of the clinical outcomes of single- and double-row repairs in rotator cuff tears. Am J Sports Med. 2008;36(7): 1310-6.

16. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff: results of a multicentre study of 80 shoulders. J Bone Joint Surg Br. 2004;86(3):388-95.

17. Streit JJ, Shishani Y, Gobezie R. Medialized versus lateralized center of rotation in reverse shoulder arthroplasty. Orthopedics. 2015;38(12):e1098-103.

18. Erickson BJ, Harris JD, Romeo AA. The effect of humeral inclination on range of motion in reverse total shoulder arthroplasty: a systematic review. Am J Orthop (Belle Mead NJ). 2016;45(4):E174-9.

19. Nyffeler RW, Werner CM, Simmen BR, Gerber C. Analysis of a retrieved delta III total shoulder prosthesis. J Bone Joint Surg Br. 2004;86(8):1187-91.

20. Bloch HR, Budassi P, Bischof A, et al. Influence of glenosphere design and material on clinical outcomes of reverse total shoulder arthroplasty. Shoulder Elbow. 2014;6(3):156-64.

21. Chou J, Malak SF, Anderson IA, Astley T, Poon PC. Biomechanical evaluation of different designs of glenospheres in the SMR reverse total shoulder prosthesis: range of motion and risk of scapular notching. J Shoulder Elbow Surg. 2009; 18(3):354-9.

22. Oh JH, Lee S, Rhee SM, Jeong HJ, Yoo JC. Rationale for Small glenoid baseplate: position of central cage within glenoid vault (Exactech® Equinoxe® Reverse System). Clin Shoulder Elb. 2019;22(1):24-8.

23. Pelletier-Roy R, Ratté-Larouche M, Laurendeau S, Pelet S. Electromyographic and kinematic study of reverse total shoulder arthroplasty: an observational prospective cohort study. J Shoulder Elbow Surg. 2021;30(1):165-71.

24. Nelson R, Lowe JT, Lawler SM, Fitzgerald M, Mantell MT, Jawa A. Lateralized center of rotation and lower neck-shaft angle are associated with lower rates of scapular notching and heterotopic ossification and improved pain for reverse shoulder arthroplasty at 1 year. Orthopedics. 2018;41(4): 230-6.

25. Zitkovsky HS, Carducci MP, Mahendraraj KA, Grubhofer F, Jawa A. Lateralization and decreased neck-shaft angle reduces scapular notching and heterotopic ossification. J Am Acad Orthop Surg. 2020;28(23):e1073-80.

26. Ackland DC, Roshan-Zamir S, Richardson M, Pandy MG. Moment arms of the shoulder musculature after reverse total shoulder arthroplasty. J Bone Joint Surg Am. 2010;92(5): 1221-30.