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ORIGINAL ARTICLE

The effect of glenosphere size on functional outcome for reverse shoulder arthroplasty

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Abstract
Purpose Reverse shoulder arthroplasty (RSA) is an effective surgery for a variety of patients with difficult shoulder pathology. Since postsurgical outcomes are often variable, there has been great effort made to optimize the design and use of these implants. Previous studies demonstrated an association between increased glenosphere size and improved range of motion. The purpose of this study is to assess the relationship between glenosphere size, range of motion, and functional outcome scores.
Methods This is a retrospective cohort study of 140 patients (148 shoulders) undergoing reverse shoulder arthroplasty. All patients were assessed pre- and postoperatively for range of motion, Constant score, ASES score, and Subjective Shoulder Value. Improvements in these variables were compared for patients treated with three different glenosphere sizes (36, 40, 42 mm).
Results All groups had a mean improvement in range of motion and functional outcome scores, but there were no statistically significant differences between groups when controlling for preoperative differences.
Conclusions Our findings do not support a strong role for glenosphere size as a singular factor affecting range of motion or patient-reported outcome following RSA. These problems are most likely due to the multifactorial nature of shoulder dynamics. For this reason, assessing the effect a single surgical or biomechanical parameter on function has been challenging.

Keywords Reverse shoulder arthroplasty · Surgical outcomes · Glenosphere size · Prosthesis design · Shoulder range of motion

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Introduction

Reverse shoulder arthroplasty (RSA) is based on a semi-constrained design utilizing a spherical glenoid component that articulates with a concave humeral cup. This design aims to provide stability to the joint when the rotator cuff is deficient. Several clinical studies have demonstrated functional improvements and decreased pain following RSA in those with rotator cuff arthropathy [1–4]. Despite the relative success of this surgery, reported outcomes are often variable [5]. Active elevation and external rotation have been shown to range from 30° to 180° and 10° to 65° following RSA [2]. The inconsistency in range of motion may be due to variability in surgical technique, implant design, rotator cuff function, or etiology of disease [6]. Several studies have evaluated optimal positioning of glenoid implants and have suggested a relationship between glenosphere diameter and range of motion (ROM) using numerical models [6–8]. A study by Gutiérrez et al. showed that when the glenosphere was placed in a neutral position with no center-of-rotation offset, the average abduction ROM increased with increasing glenosphere size (30, 36, 42 mm) [6]. Although the relationship between glenosphere size and range of motion has been established in biomechanical and computational studies, few clinical correlations have been made. For example, a study by Randelli et al. examined dislocations rates following RSA and demonstrated that a 10° inferior tilt of the glenosphere is associated with a reduced risk of dislocation compared to a neutral tilt [9]. It is important to further study the clinical results of RSA because full shoulder range of motion is needed to perform many essential activities of daily living [10, 11]. The objective of this study was to evaluate the effect of different glenosphere sizes (36, 40, and 42 mm) on range of motion and patient-reported outcomes following RSA.

Materials and methods

This was an IRB-approved retrospective cohort study. Patients who were treated with a reverse shoulder arthroplasty between 2006 and 2010 were included in this study. All patients were treated by senior shoulder subspecialty surgeons (JPI, JMW, and VJS) and had a minimum of 11-month follow-up. This yielded a study cohort of 140 patients of which eight patients had bilateral RSA surgery (148 shoulders) with an average follow-up of 30.68 months (range 11–90 months).

All procedures were performed with the patient in the semi-beach-chair position using a standard deltopectoral approach. The glenoid was prepared with minimal reaming in order to preserve the subchondral bone. The glenoid base plate was positioned in the recommended inferior position to minimize notching and optimize functional outcomes [7, 12]. Patients were treated with a Grammont-style RSA prosthesis using standard manufacturer-recommended instrumentation [Delta Reverse (Depuy Orthopaedics, Warsaw, IN), Aequalis Reverse (Tornier, Edina, MN), and Zimmer Reverse system (Zimmer, Warsaw, IN)] [13]. Patients were excluded if any nonstandard techniques or components were used (constrained or high mobility liner, glenoid bone grafting). Component size was selected based on surgeon technique and experience with the goal of restoring proper shoulder kinematics. Size of the glenosphere component and manufacturer type were recorded for each patient.

Postoperatively, all patients were managed with a shoulder immobilizer with or without a pillow with the arm at the patient's side in internal rotation. Immediate passive mobilization was begun under the direction of physical therapists. Passive and active-assisted exercises were continued with a gradual progression to independent activities of daily living at 6 weeks.

All preoperative and postoperative clinical evaluations were performed by the operating surgeon or independent research nurse (JPI, JMW, or VJS). Forward elevation of the arm was measured as the humero-thoracic angle, external rotation was measured as degrees from a line parallel to the body, internal rotation was measured by having the patient reach up his/her back, and the highest level they could reach with the thumb was recorded. Internal rotation was scored according to the methods of the Constant–Murley score. The Constant–Murley score (CMS), American Shoulder and Elbow Surgeons (ASES) score, Subjective Shoulder Values (SSV), visual analogue scale for pain, range of movement, and strength were measured pre- and postoperatively. Case-specific complications were also recorded.

Preoperative measurements of forward flexion and external rotation were compared for the three groups to establish whether any differences existed at baseline for the groups. The improvements in the forward flexion, external rotation, internal rotation, and functional outcome scores were then assessed for the entire cohort. Differences between improvements in forward flexion, external rotation, internal rotation, and outcome scores between the three different-sized glenosphere groups were then assessed. Analysis of differences in forward flexion rotation improvements between the groups was performed controlling for differences in preoperative forward flexion.

Pre- and postoperative values for the entire groups were compared using independent sample *t* tests to assess whether improvements were significant. The different-sized glenosphere groups were compared using analysis of variance. Post hoc analysis was performed using the Bonferroni correction to further analyze differences between the individual groups. Analysis of covariance (ANCOVA) was used to control for preoperative differences between groups when assessing whether there were differences between the groups. Also the proportions of patients in each group experiencing dislocations postoperatively were compared using a Chi-squared test. A p value of less than 0.05 was considered statistically significant, and all statistics were performed using SPSS software (IBM SPSS Statistics for Windows, version 22.0. Armonk, NY: IBM Corp).

Results

Of the 148 shoulders included in our study, 52 were treated with a 36-mm glenosphere (group 1), 80 shoulders treated with a 40-mm glenosphere (group 2), and 16 shoulders treated with a size 42-mm glenosphere (group 3). Among all patients, 7 dislocations were reported. These dislocations occurred in 3.8 % of the 36-mm glenospheres ($n = 2$), 6.3 % of the 40-mm glenospheres ($n = 5$), and none of the 42-mm glenospheres. These proportions were not different when compared by Chi-squared test ($p = 0.523$).

There was a significant difference in preoperative forward flexion between the groups, and averages for group 1,

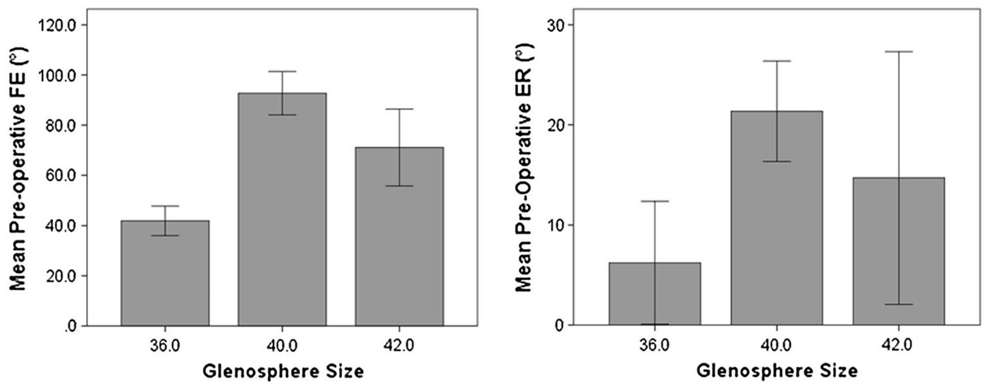

Fig. 1 Mean preoperative forward elevation (FE) and external rotation (ER) for different glenosphere size groups. *Error bars* represent 95 % confidence interval

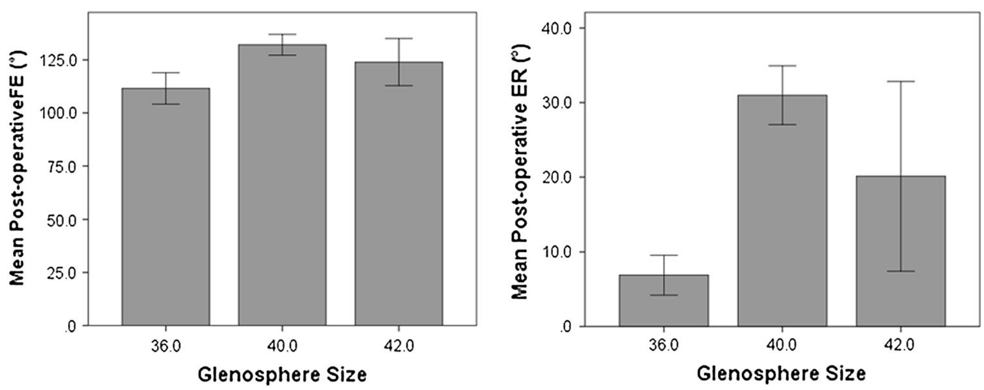

Fig. 2 Mean postoperative forward elevation (FE) and external rotation (ER) for different glenosphere size groups. *Error bars* represent 95 % confidence interval

2, and 3 were 41.9°, 92.7°, and 71.1°, respectively ($p < 0.001$) (Fig. 1). These differences were significant between all individual groups (groups 1–2 $p < 0.001$, groups 1–3 $p = 0.006$, groups 2–3 $p = 0.048$). Average preoperative external rotation was 6.2°, 21.4°, and 14.7° for groups 1, 2, and 3, respectively (Fig. 1), which was a statistically significant difference between groups ($p = 0.001$). However with post hoc analysis, the difference in external rotation was only significant between groups 1 and 2 ($p = 0.001$), and differences between groups 1 and 3 and 2 and 3 were not statistically significant ($p = 0.565$ and $p = 0.828$).

Postoperative forward flexion also differed between the three groups with groups 1, 2, and 3 having means of 111.6, 132.1, and 123.9 ($p < 0.001$) (Fig. 2). However, with post hoc analysis, this difference was only significant between groups 1 and 2 ($p < 0.001$), while the differences between groups 1 and 3 ($p = 0.209$) and 2 and 3 ($p = 0.627$) were not significant. There were also significant differences ($p < 0.001$) in postoperative external rotation, with group 2 having the most motion on average (31.0°), followed by group 3 (20.1°) and group 1 (6.9°) (Fig. 2). These differences were significant between all individual groups (1–2 $p < 0.001$. 1–3 $p = 0.015$, 2–3 $p = 0.047$).

Overall there was a significant improvement in preoperative to postoperative forward flexion for the entire cohort with an average preoperative forward flexion of 72.6° and a postoperative average of 124.4° ($p < 0.001$). There also was a significant improvement in external rotation from a preoperative average of 15.5° to a postoperative average of 21.4° ($p < 0.001$).

The pre- to postoperative improvement in forward flexion was greatest in group 1 (70.4°) followed by group 3 (52.9°) then group 2 (40.2°) ($p \leq 0.001$) (Fig. 3). When analyzing differences between the individual groups, only the difference between groups 1 and 2 was significant ($p < 0.001$), and differences between groups 1 and 3, and 2 and 3 were not ($p = 0.221$ and $p = 0.531$, respectively). Using ANCOVA to account for preoperative variations in range of motion demonstrated no significant differences between the improvement in forward flexion ($p = 0.089$) between the different-sized glenosphere groups. There was no difference in average improvement (pre to postoperative) of external rotation among group 1 (0.29°), group 2 (9.6°), or group 3 (5.44°) ($p = 0.700$) (Fig. 3). There were also no significant differences seen in average improvements in internal rotation scores of 1.7, 1.2, 0.6 for groups 1, 2, and 3, respectively ($p = 0.518$).

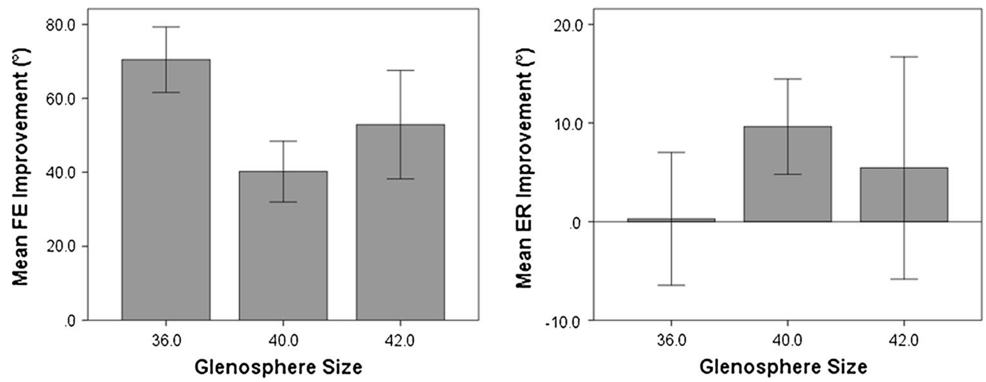

Fig. 3 Mean improvements in forward elevation (FE) and external rotation (ER) for different glenosphere size groups. *Error bars* represent 95 % confidence interval

Table 1 Pre- to postoperative changes in outcome scores following RSA

	Preoperative mean	Postoperative mean	Mean improvement	p value
ASES	33.5	78.5	45.2	0.007
SSV	22.7	77.8	55.2	0.025
CS	24.5	58.0	40.1	0.001

p value represents differences in pre- and postoperative scores

ASES American Shoulder and Elbow Surgeons score, *SSV* Subjective Shoulder Value, *CS* Constant score

Table 2 Comparison of mean improvements in outcome scores between different glenosphere size groups

	Average improvement			p
	36 mm	40 mm	42 mm	
ASES	44.1	38.2	32.6	0.122
SSV	61.0	50.7	58.1	0.102
CS	44.7	46.9	38.9	0.459

p value represents comparison of differences between the three glenosphere size groups

ASES American Shoulder and Elbow Surgeons score, *SSV* Subjective Shoulder Value, *CS* Constant score

The mean preoperative Constant score, ASES score, and SSV were 26.6, 33.0, and 22.7, respectively, for the entire cohort. There were significant differences in the Constant, ASES, and SSV preoperative scores when comparing the different-sized glenosphere groups ($p < 0.001$, $p = 0.04$, and $p < 0.001$). There were significant pre- to postoperative improvements in the Constant (40.1), ASES (45.2), and SSV (55.2) scores for the entire cohort ($p = 0.001$, $p = 0.007$, and $p = 0.025$) (Table 1). There were no significant differences in improvements in the three outcome scores between the different-sized glenosphere groups (Table 2). When controlling for differences in preoperative scores as a covariate, the differences in improvement of the CS, ASES score, and SSV were also not significant ($p = 0.102$, $p = 0.153$, 0.137).

Discussion

Rotator cuff arthropathy is one of the most common causes of shoulder disability in the elderly population [6, 14]. Reverse shoulder arthroplasty (RSA) has emerged as an effective treatment in dealing with this difficult problem. Multiple studies have demonstrated that reverse shoulder arthroplasty is capable of addressing pain and improving functionality [1–4, 15]. Despite the success that RSA has achieved, there are still needed improvements in the design and use of these implants in order to optimize outcomes.

Several surgical factors have already been shown to influence postoperative outcome [12, 16, 17]. For instance, it has been shown that an eccentrically placed glenosphere can reduce the risk of scapular notching, a common complication of RSA [18, 19]. The center-of-rotation offset relative to the glenoid has been determined to correlate with abduction range of motion [6]. Appropriate deltoid tensioning and role of subscapularis have both been shown to contribute to shoulder range of motion as well [20–23]. The purpose of this study is to evaluate the singular effect of glenosphere size on postoperative range of motion and ultimately the outcomes associated with this procedure.

Computer modeling has demonstrated that increased glenosphere size may decrease bony impingement at extremes of range of motion [6, 8]. This impingement is important not only because of limitations in motion but also because impingement between the humeral component and the inferior lateral scapula (inferior impingement) is thought to contribute to scapular notching and ultimately implant loosening [12]. Furthermore, internal and external rotation ranges of motion were also shown to increase with increasing glenosphere size when implanted in cadaveric models [24]. A recent study involving implantation of a customized system for measuring joint loads at variable glenosphere diameters found increased joint loads, decreased internal rotation, and increased abduction/adduction range of motion associated with increased glenosphere size [25]. In one biomechanical study, it was shown that increased glenosphere size was a contributor to improved stability and fewer dislocations [26].

As expected, the results of our study demonstrated significant improvements in both range of motion and functional outcome scores following RSA. Our results were consistent with the previously reported improvements seen for RSA with a mean improvement of 52° in forward flexion, and 6° in external rotation [27–31], in Constant scores between 15 and 50 points [30, 32–34], and ASES score between 20 and 40 points [30, 33, 35]. These similarities between improvements between our patients in our study and those in the literature presumably support the accuracy and validity of our measurements.

However, the expected correlation between these improvements and varying glenosphere size was not reflected in these results. On initial analysis, our results demonstrated that the smallest glenosphere diameter implants had greater improvements in forward flexion. When controlling for these preoperative differences as covariates, there were no significant differences in improvement of range of motion between the groups. In addition, there were a higher number of outliers or patients who had a decline in postoperative forward flexion in the 40 mm group compared with the 36 and 42 mm groups. This result may reflect suboptimal improvement in this group in particular, or may be related to a technical factor in surgery, such as joint overstuffing. This concept was observed in a cadaveric study, where specimens were found to have decreased internal rotation with increasing glenosphere size as a result of excessive soft tissue tension created by the size of the implant [25].

Range of motion in internal and external rotation was similarly unrelated to glenosphere size. This may be attributed to the large initial variations in internal and external rotation motions, the overall small incremental improvements seen for all groups.

Although previous literature has indicated that larger glenospheres ought to be more stable, our results were mixed regarding joint stability. The most dislocations occurred in the 40-mm glenospheres, followed by the 36 mm group. None were observed in the 42 mm group. This variability may be attributed to intra-group factors. While these differences were not statistically significant, the lack of dislocations in the 16 shoulders treated with a 42-mm glenosphere could be reflective of the increased stability associated with this design.

There were several limitations to our study. Using measures of range of motion as the gold standard of functional outcomes following RSA does not provide a complete picture of outcomes following this surgery, and measurements can be subject to evaluator variations. In addition, although we attempted to account for demographic variations and variations in preoperative function to truly evaluate the effect of glenosphere size, functional and patient-reported outcomes are complex and multifactorial. Other factors may confound the influence of glenosphere size, such as glenosphere thickness and the ratio between glenosphere and humeral liner curvature arches. The largest diameter glenosphere group (42 mm) had fewer patients than the other groups. Although we attempted to standardize surgical technique by only including surgical patients from three senior surgeons who utilize the same surgical guidelines, there can still be variations in glenosphere placement which may indirectly contribute to changes in functional outcomes.

In conclusion, our study does not support a strong role for glenosphere size as a singular independent factor affecting functional or patient-reported outcome following RSA. This may in part be due to a poor correlation between overall shoulder function following arthroplasty and range of motion or objective scoring systems [36]. These problems are likely due to the multifactorial nature of shoulder dynamics. For this reason, assessing the effect of a single surgical or biomechanical parameter on function has been challenging. Future evaluations should focus on the combination of multiple design factors and outcomes in RSA so that we may continue to improve design and utilization of these implants in order to optimize postoperative function and patient satisfaction.

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Compliance with ethical standards

Conflict of interest JM Wiater is a paid consultant for Zimmer-Biomet and Depuy-Synthes, outside the submitted work. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript.

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