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# Optimal glenosphere size cannot be determined by patient height

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**Background:** Glenosphere size remains 1 surgeon-controlled variable that can affect patient outcomes following reverse shoulder arthroplasty (RSA). There remains no objective criterion to guide surgeons in choosing glenosphere size. This study's purpose was to evaluate range of motion (ROM) as a function of patient height and glenosphere size to determine the optimal glenosphere size based on patient height.
**Methods:** We retrospectively reviewed 589 primary RSAs from a multicenter shoulder arthroplasty database of a single RSA system with multiple glenosphere sizes. Shoulders were separated into groups based on glenosphere size (38 or 42 mm). Predictive accuracy was calculated in relation to height and sex for predicting glenosphere size. Improvements in active ROM and patient-reported outcome measures (PROMs) were compared based on glenosphere size as a function of height.
**Results:** Logistic regression analysis demonstrated a strong association of height and sex with surgeon selection of glenosphere size, with shorter heights preferentially treated with 38-mm glenospheres and taller heights with 42-mm glenospheres. There were no statistically significant interaction effects of glenosphere size and height on improvements in ROM or PROMs. These results indicate that for a given glenosphere size, there is not an optimal height range to maximize improvements in postoperative outcome measures.
**Discussion:** Height and sex are highly correlated with a surgeon's choice of glenosphere size. However, on the basis of improvements in ROM and PROMs, no recommendation can be made for surgeons to select a particular glenosphere size based on a patient's height. Surgeons should consider other variables when selecting a glenosphere size.
**Level of evidence:** Level III; Retrospective Cohort Design; Treatment Study


**Keywords:** Reverse shoulder arthroplasty; glenosphere size; range of motion; outcomes; glenosphere; sex; optimal; height

Institutional review board approval was received for this study (WIRB study no. 1112376).

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Reverse shoulder arthroplasty (RSA) is a reliable operation to decrease pain and improve function in patients with end-stage glenohumeral arthritis and rotator cuff deficiency.[2,14] Early use of RSA resulted in a high rate of complications, which have improved over time with surgical technique and design changes.[1,6,13,24,31] Despite these advancements, up to 9% of shoulders will fail to achieve improvements above the minimal clinically important difference (MCID) for patient-reported outcomes following surgery.[29] Modifiable risk factors for poor outcomes include the following: superior placement of the glenosphere, superior baseplate tilt, a medialized center of rotation, arm lengthening, and the superior approach.[1,7,11,13,15] Biomechanical studies have demonstrated that larger glenospheres lead to greater impingement-free range of motion (ROM), although scapular mobilization and soft tissues have not been evaluated.[15,32] However, few clinical studies have demonstrated this difference in vivo.[3,4,9,16,21,22,32] More recently, Matsuki et al[19] showed that patients at the extreme ends of the growth curve (short and tall) achieved smaller gains in ROM compared with patients of average stature. One of the only modifiable parameters for the surgeon to address these size differences is to modify the glenosphere size; therefore, Matsuki et al suggested that larger glenosphere sizes may not be optimal for all patients, especially those on the lower end of the growth curve. In addition, this indicates that there may be an optimal glenosphere size for a given patient height. There remains no definable reference for choosing the size of a glenosphere for an individual patient. Factors affecting surgeon selection include exposure, patient size and sex,[22] and intraoperative stability. Some surgeons may choose to place the smallest glenosphere available, which minimizes difficulty with insertion. Others may choose to systematically try to implant the largest glenosphere possible to reduce dislocation risk. There remain no objective criteria to guide surgeons in choosing a glenosphere size for an individual patient, which remains 1 of the few surgeon-modifiable risk factors for RSA outcomes. The purpose of this study was to evaluate ROM as a function of patient height and glenosphere size to determine the optimal glenosphere size based on objective patient height.

## Materials and methods

A retrospective review of all primary RSAs between 2007 and 2015 was performed using a multicenter shoulder arthroplasty database. Patients were prospectively enrolled and followed up at regular time points. Only shoulders with a minimum of 2 years' follow-up were included. Shoulders with a preoperative diagnosis of cuff tear arthroplasty, primary osteoarthritis, and rotator cuff insufficiency were included. Shoulders with a preoperative diagnosis of post-traumatic arthritis (n = 28), acute fracture (n = 2), tumor (n = 1), or nerve injury (n = 1) were excluded. Patients with a history of post-traumatic arthritis and acute fracture were excluded because of prior reports documenting poorer clinical performance in this population.[10,23,28] Shoulders undergoing revision surgery (n = 20) were also excluded because of our desire to evaluate a well-functioning population to develop clinical recommendations to optimize RSA outcomes. Two additional patients without recorded heights were excluded. This left 612 shoulders meeting the inclusion criteria.

All shoulders were treated using a single arthroplasty system (Equinoxe; Exactech, Gainesville, FL, USA). This system comprises a lateralized humeral stem, tray, and liner with a 145° neck-shaft angle. The glenoid is a medialized design, with 2 mm of lateral offset for all standard glenosphere sizes. Three glenosphere options are available (38, 42, and 46 mm). Eighteen senior shoulder surgeons performed the operations evaluated in this study. Glenosphere size was chosen intraoperatively based on surgeon preference. No single glenosphere size is officially recommended based on any patient characteristics.

The database was queried for patient demographic information including age, sex, hand dominance, and preoperative diagnosis. Clinical outcomes were assessed at the time of latest follow-up. ROM measurements included forward elevation, abduction, and external rotation measured in degrees. Internal rotation was assessed as the most cephalad vertebral body reached by the thumb behind the back. Postoperative patient-reported outcome measures (PROMs) included the American Shoulder and Elbow Surgeons (ASES) score, Constant score, Simple Shoulder Test (SST) score, and University of California at Los Angeles (UCLA) score.

### Statistical analysis

All analyses were performed with JMP Pro software (version 14.0; SAS Institute, Cary, NC, USA). Continuous measures were summarized by means and standard deviations, and categorical measures were summarized by percentages. We used $\chi^2$ analysis to assess the relationship between glenosphere size and sex. The *t* test was used to evaluate mean differences in height across glenosphere sizes. By use of logistic regression, predicted probabilities for each glenosphere size and the overall predictive accuracy of height and sex for predicting patient glenosphere size were evaluated. This information was used to empirically assess height cutoffs regarding use of different glenosphere sizes. Finally, regression analyses were used to assess if there were significant interaction effects between glenosphere size and height in relation to change in shoulder outcomes (from preoperative evaluation to 2-year follow-up). To estimate the change in outcomes, these models included preoperative scores as an independent variable and follow-up scores as a dependent variable to create a ‘‘residual change score’’ for each shoulder outcome. Including preoperative scores in the model thereby controlled for any baseline differences between groups. A significant interaction between glenosphere size and height would indicate that the association between height and change in shoulder outcomes is dependent on glenosphere size. These analyses also accounted for sex and included both height and glenosphere size as main effects. Secondary analyses were repeated for body mass index (BMI). $P < .05$ was considered statistically significant, following correction for multiple testing using the false-discovery-rate approach.[30]

**Table I** Comparison of demographic characteristics and preoperative and postoperative measures in 38-and 42-mm glenosphere groups

| | 38 mm | 42 mm | *P* value |
|---|---|---|---|
| Demographic characteristic | | | |
| Age, yr | 72.9 ± 8.0 | 72.0 ± 7.1 | .191 |
| % Female sex | 88.7 | 26.5 | <.001 |
| Height | 160.8 ± 8.4 cm | 170.9 ± 9.1 cm | <.001 |
| Weight | 48.1 ± 18.2 kg | 87.5 ± 19.7 kg | <.001 |
| BMI | 28.0 ± 6.4 | 30.0 ± 6.8 | <.001 |
| Prior surgery, % | 27.3 | 20.6 | .064 |
| Injection, % | 40.5 | 42.0 | .726 |
| Follow-up, mo | 30.8 ± 9.1 | 30.6 ± 8.9 | .813 |
| Preoperative measure | | | |
| Abduction, ° | 78 ± 32.6 | 76 ± 32.7 | .444 |
| Forward elevation, ° | 95 ± 38.7 | 90 ± 33.6 | .134 |
| Internal rotation | Sacrum ± 4.2 | L5 ± 4.0 | .012 |
| External rotation, ° | 19 ± 22.0 | 16 ± 21.2 | .280 |
| SST score | 2.8 ± 2.5 | 4.1 ± 2.6 | <.001 |
| Constant score | 35.0 ± 14.0 | 37.0 ± 13.3 | .109 |
| ASES score | 35.1 ± 15.8 | 41.0 ± 15.5 | <.001 |
| UCLA shoulder score | 13.1 ± 4.0 | 13.9 ± 3.9 | .027 |
| Postoperative measure | | | |
| Abduction, ° | 120 ± 30 | 119 ± 31 | .704 |
| Forward elevation, ° | 142 ± 26 | 142 ± 26 | .916 |
| Internal rotation | L2 ± 5 | L3 ± 4 | .223 |
| External rotation, ° | 38 ± 17 | 37 ± 20 | .440 |
| SST score | 10.0 ± 2.5 | 10.3 ± 2.5 | .156 |
| Constant score | 68.7 ± 13.9 | 72.7 ± 14.5 | .001 |
| ASES score | 83.1 ± 17.3 | 85.2 ± 18.3 | .162 |
| UCLA shoulder score | 30.1 ± 4.9 | 30.4 ± 5.2 | .475 |

*BMI*, body mass index; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *UCLA*, University of California at Los Angeles.
Data are presented as mean ± standard deviation unless otherwise indicated.

## Results

### Study population

A total of 612 primary RSAs were evaluated at a mean follow-up of 31.2 months (range, 24-60 months). Because of low use rates of 46-mm glenospheres (n = 25), our analyses focused on patients receiving either 38- or 42-mm glenospheres (589 shoulders). Size 38-mm glenospheres were used in 370 shoulders (62.8%), and 42-mm glenospheres were used in 219 shoulders (37.2%). The study population included 203 men (34.5%) and 386 women (65.5%). The mean age at the time of surgery was 72.6 years (standard deviation, 7.7 years; range, 38-90 years). Heights ranged from 54 to 75 inches (1.37-1.91 m). Full demographic information is shown in Table I. Preoperative measures demonstrated significantly greater internal rotation in shoulders receiving a 38-mm glenosphere. However, the clinical significance may be questioned, as this represented only 1 vertebral level. Preoperative SST, ASES, and UCLA scores were also significantly greater in shoulders treated with a 38-mm glenosphere, but all of these remained below the MCID as described by Simovitch et al.[29] Because of preoperative differences, subsequent statistical analyses controlled for baseline differences.

### Influence of sex

A relationship was observed between sex and glenosphere size ($\chi^2 = 243.2$, $df = 1$, $P < .001$) for shoulders treated with 38- and 42-mm glenospheres. The majority of female patients (328 of 386, 85%) received 38-mm glenospheres, whereas the majority of male patients (161 of 203, 79%) received 42-mm glenospheres.

### Influence of surgeon

When we evaluated glenosphere size by surgeon, 4 surgeons used only 38-mm glenospheres. However, 3 of these surgeons had fewer than 5 patients included in the study. The fourth surgeon had performed 12 included shoulder procedures, all treated with a 38-mm glenosphere. The remaining surgeons used multiple glenosphere sizes.

## Influence of height and BMI on glenosphere selection

Between glenosphere sizes, there were significant mean differences in height ($t = 13.7$, $df = 584$, $P < .001$). Shorter heights were more preferentially treated with the 38-mm size, and taller heights were more likely to receive a 42-mm glenosphere (Table I). For the 38-mm size, heights ranged from 54 to 73 in (1.38-1.85 m), and for the 42-mm size, heights ranged from 58 to 75 in (1.47-1.91 m). Patients receiving 42-mm glenospheres had slightly higher BMI values (Table I).

## Predicting glenosphere size

Logistic regression analysis demonstrated that height alone had a predictive accuracy of 75.9% for glenosphere size used. With the addition of sex, the predictive accuracy increased to 82.9%. Figure 1 depicts the predicted probabilities for 38- and 42-mm sizes as a function of patient height. The intersection point (where the probabilities for both sizes were approximately 50%) occurred between 66 and 67 inches (1.68-1.70 m), suggesting that this may be a useful cutoff for height in relation to glenosphere size. In other words, patients shorter than 67 inches (1.70 m) have a higher likelihood of receiving the 38-mm size, whereas patients taller than 67 inches (1.70 m) have a higher likelihood of receiving the 42-mm size. Moreover, these probabilities increased for shorter and taller heights. The predicted probability of receiving the 38-mm size was greater than 90% for patients with a height of 58 inches (1.47 m) or shorter, and the predicted probability of receiving the 42-mm size was greater than 90% for patients with a height of 73 inches (1.85 m) or taller. Models with BMI alone had lower predictive accuracy (62.9%) than height alone, and the predictive accuracy of combined sex and BMI models (82.7%) was similar to that of sex and height.

## Clinical outcomes

Regression analyses were used to assess the combined effects of glenosphere size and height on improvements in ROM and PROMs. Figures 2 and 3 depict correlations between height and change in outcomes stratified by glenosphere size, with overall low to moderate correlations between height and change in outcomes for both glenosphere sizes. No statistically significant interaction effects (following correction for multiple comparisons) were found between height and glenosphere size for change in ASES score ($P = .854$), Constant score ($P = .854$), UCLA score ($P = .765$), active abduction ($P = .854$), active forward elevation ($P = .854$), active external rotation ($P = .364$), and active internal rotation ($P = .854$). In other words, the slopes of the lines for the relationship between heights and outcomes were not statistically different between glenosphere sizes, indicating that the correlations between height and improvement in shoulder outcomes were similar between glenosphere sizes. For the SST, although not statistically significant, shorter patients treated with a 42-mm glenosphere showed less improvement in the SST score than taller patients ($P = .299$). This is demonstrated in

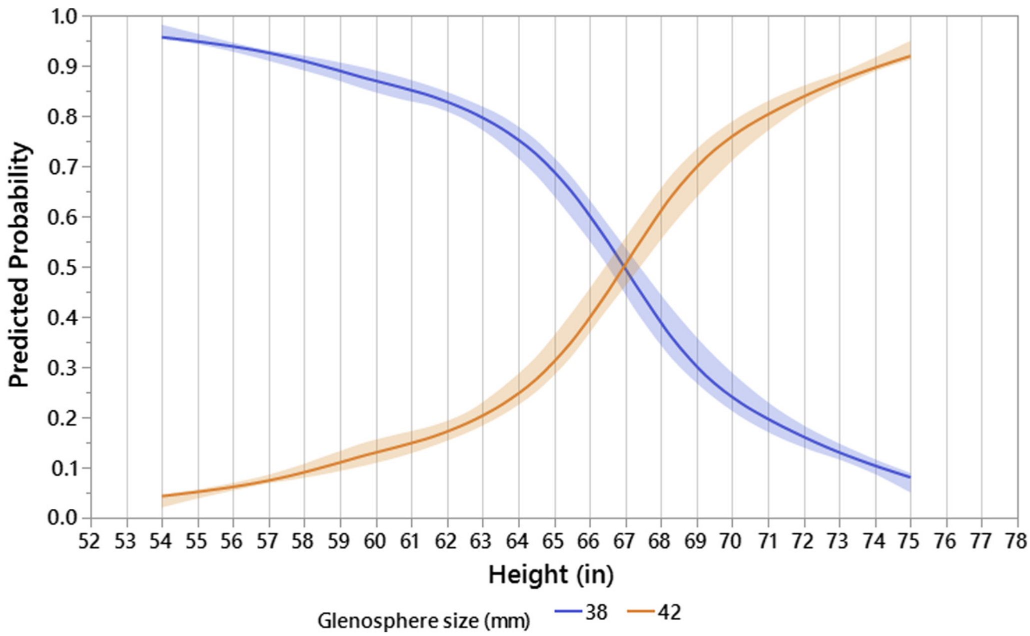


**Figure 1** Predicted probabilities for 38- and 42-mm glenosphere sizes across a range of heights (*shaded areas* represent 95% confidence regions). Heights below 67 inches (1.70 m) have a higher probability of receiving the 38-mm size, whereas heights above 67 inches (1.70 m) have a higher probability of receiving the 42-mm size.

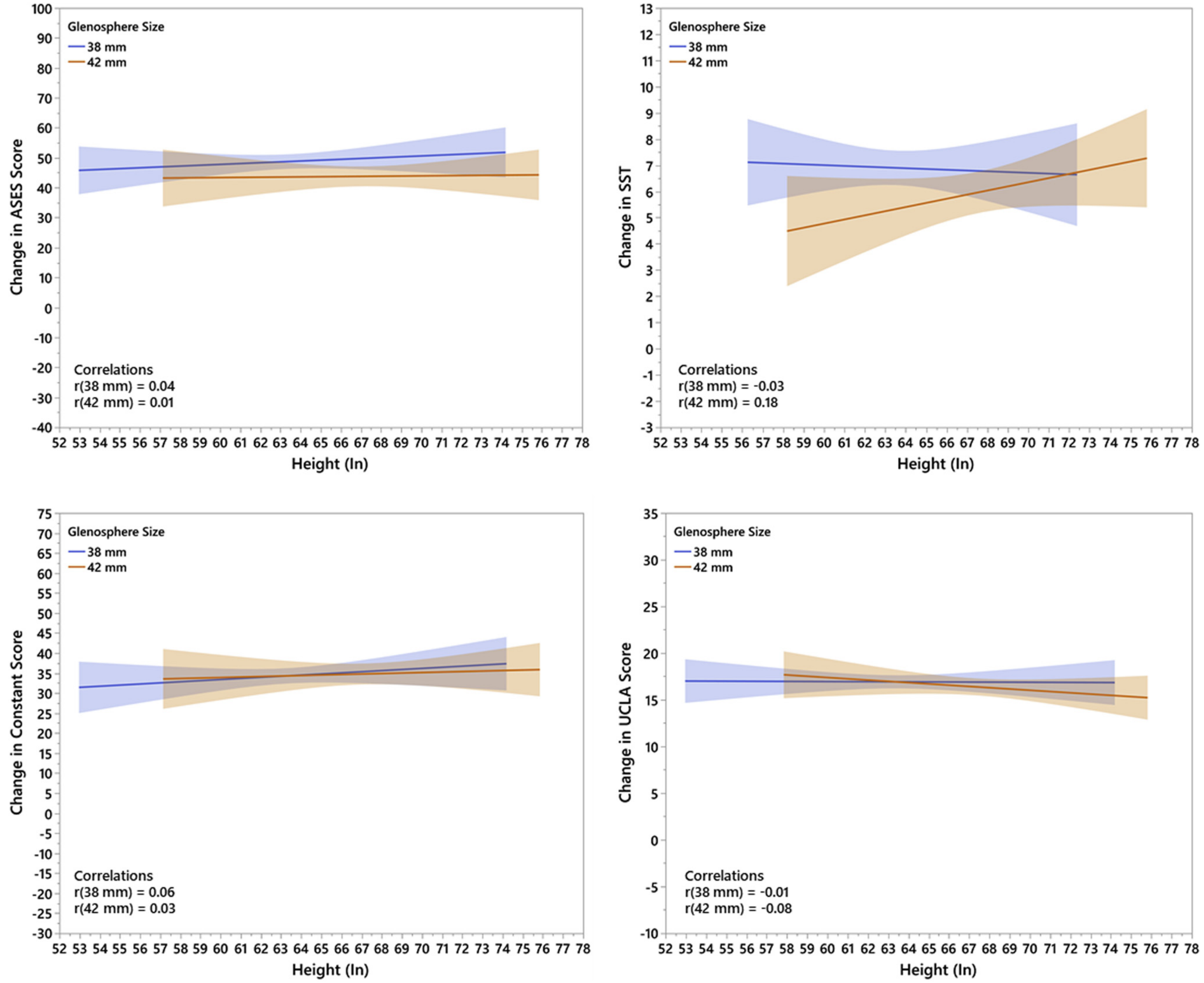


**Figure 2** Association between change in patient-reported outcome measures and height, stratified by glenosphere size (*shaded areas* represent 95% confidence regions). For all measures, correlations between height and improvement in shoulder outcomes were not statistically significantly different between glenosphere sizes. *ASES*, American Shoulder and Elbow Surgeons; *SST*, Simple Shoulder Test; *UCLA*, University of California at Los Angeles.

Figure 2 by the greater slope in the 42-mm SST trend line. Collectively, these results do not indicate that, for a given glenosphere size, there are optimal ranges of height that confer improved shoulder outcomes. Similar results were found for BMI, with nonsignificant interactions between BMI and glenosphere size.

## Discussion

Choosing a glenosphere size during RSA remains a surgeon's choice, with few clinical data to support choosing 1 size over another. One factor that affects the choice of glenosphere size is patient height.[22] However, scientific studies directing the choice of glenosphere size to optimize clinical outcomes remain lacking. Previous work has shown that patients at the extreme ends of the growth curve have lower improvements in ROM compared with average-sized patients.[19] Although our results confirm that surgeons who performed RSAs in this study chose glenosphere size based on patient height, no optimal glenosphere size could be identified based on patient height. Improvements in ROM and PROMs with 38- and 42-mm glenosphere sizes were similar across height ranges. This finding suggests that altering glenosphere size based only on patient height does not lead to superior patient outcomes.

Early computer-modeling studies evaluated the effect of glenosphere size on impingement-free ROM with RSA. Gutiérrez et al[15] and Roche et al[25] demonstrated greater impingement-free abduction and adduction with larger glenosphere sizes. The model of Gutiérrez et al also showed that impingement-free ROM was affected by inferior tilt

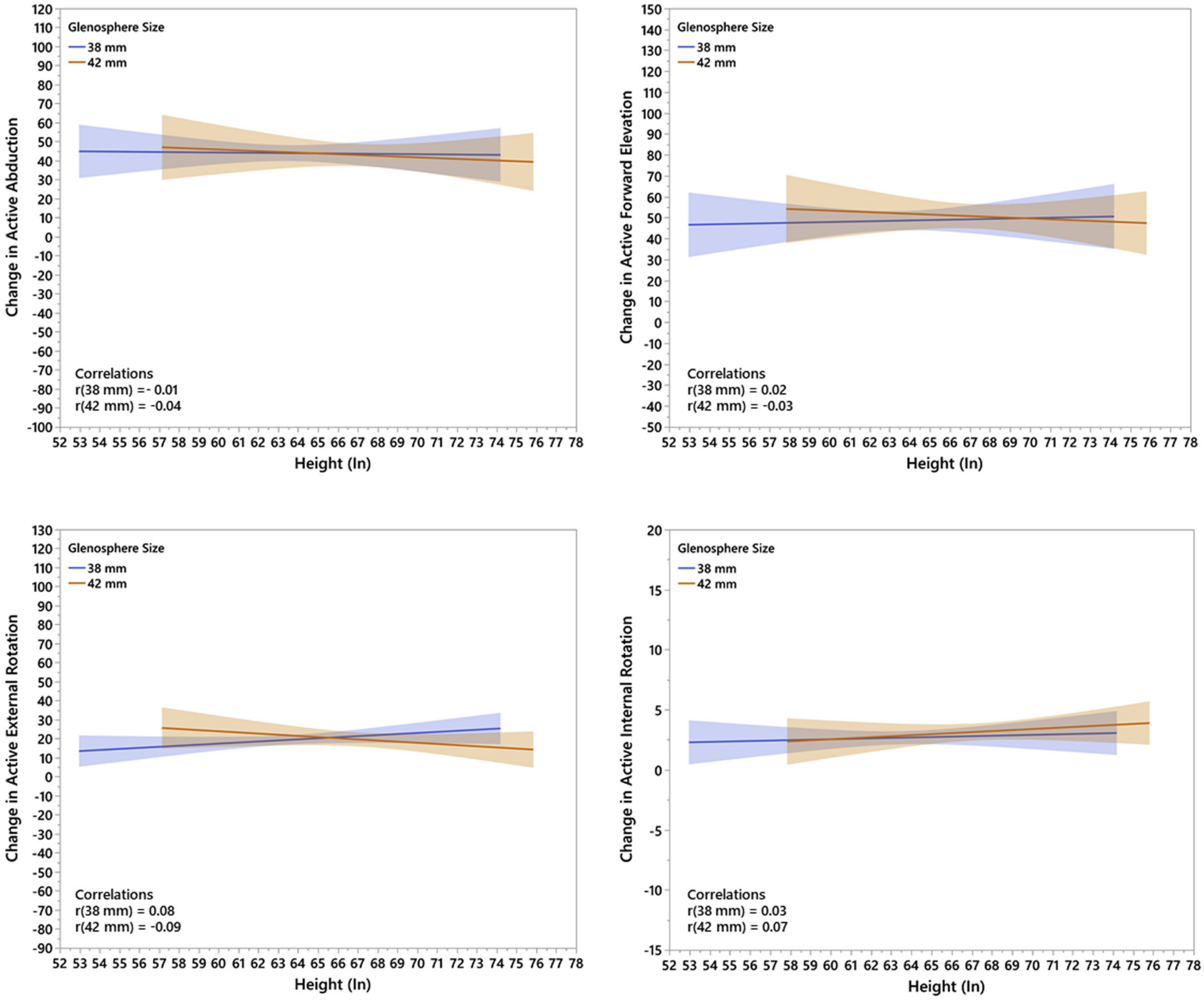


**Figure 3** Association between change in range-of-motion outcomes and height, stratified by glenosphere size (*shaded areas* represent 95% confidence regions). For all measures, correlations between height and improvement in shoulder outcomes were not statistically significantly different between glenosphere sizes. *Preop*, preoperative.

and inferior placement of the glenoid baseplate. In addition to adduction, external rotation is believed to play a role in scapular notching.[17] In a study of 40 cadaveric shoulders, Berhouet et al[4] found that a 7-mm glenoid lateralization on a 36-mm glenosphere led to a significant increase in impingement-free external and internal rotation in an experimental model. The increase was even greater when the glenosphere was changed from 36 mm in diameter to 42 mm. This finding suggests that the improvement in axial rotation is likely due to a 3-dimensional effect.[4]

In addition to decreasing impingement, increasing glenosphere size has been shown to improve clinical ROM. Bloch et al[5] reported on 133 RSAs treated with different sized glenospheres (36 centered, 36 eccentric, and 44 eccentric). Shoulders treated with a 44-mm glenosphere demonstrated significantly greater improvements in forward elevation; however, these remained below the MCID as described by Simovitch et al,[29] and this was not correlated with patients' height.[5] No difference was shown among glenosphere sizes for internal or external rotation. Mollon et al[21] also showed greater gains in forward elevation with a larger glenosphere size (42 mm vs. 38 mm), with the difference (15°) exceeding the MCID. In addition, improvements in external rotation were shown to be significantly greater with a 42-mm glenosphere (24° vs. 17°).[21] When performing regression analysis, we were unable to show a clinical benefit to using a larger glenosphere when evaluated as a function of patient height.

Our results are similar to those of Sabesan et al,[27] who demonstrated no difference in ROM or PROMs among 3 glenosphere sizes (36, 40, and 42 mm). However, similarly to other prior retrospective reviews, these studies are limited by the fact that patient height was not considered as a variable affecting outcomes. This may explain the contrasting literature on the effect of glenosphere size on patient ROM.[5,21] When evaluating outcomes as a function of height, this study again was unable to identify a glenosphere size to maximize improvements in postoperative ROM at a minimum 2-year follow-up.

The strength of this study is that it evaluated outcomes as a function of both height and glenosphere size, which previous studies have been unable to do. Over 500 RSAs were evaluated, which is nearly twice as many as in the largest clinical series evaluating the impact of glenosphere size on outcomes.[21] However, there remain multiple limitations in this study. First, the study was retrospective, with surgeons performing unblinded follow-up. In some cases, patients' heights may have been recorded based on self-reporting, which can lead to inaccurate recordings. In addition, multiple surgeons were included, leaving us unable to control for patient selection regarding glenosphere size. However, statistical analyses strongly suggested that the selected glenosphere size was strongly correlated with patient height, indicating that surgeons performing RSA in this series were using height as a factor in selecting glenosphere sizes. Furthermore, the failure to identify a height cutoff for each glenosphere size may be a result of the limited glenosphere size options. Boileau and Walch[8] have previously shown that the native humeral head diameter ranges from 37 to 54 mm in the general population. It remains possible that limiting glenosphere sizing to 38 and 42 mm does not allow for accurate assessment of size optimization based on a patient's native anatomy, thus explaining the lack of significant interactions shown in our study. In addition, the inclusion of multiple surgeons may have resulted in variability in the position of both the glenoid and humeral stem, which could theoretically affect postoperative ROM and PROMs.[12,18,26] The database used in this study did not allow us to assess postoperative radiographs primarily, and thus, we were unable to compare inferior glenosphere offset and superior inclination. Both of these variables are associated with notching, which can lead to inferior clinical outcomes.[12,20,26]

## Conclusion

Height and sex are highly correlated with a surgeon's choice of glenosphere size. However, on the basis of improvements in ROM and PROMs, no height cutoffs can be recommended for surgeons to select a particular glenosphere size. Surgeons should consider other variables when selecting a particular glenosphere size, as similar clinical improvements can be expected between 38- and 42-mm implants using a lateralized humeral RSA design.

## Disclaimer

Bradley Schoch is a paid consultant and receives royalties from Exactech.

Thomas Wright receives royalties from Exactech and Wolters Kluwer Health–Lippincott Williams & Wilkins and is a paid consultant for Exactech.

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