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Reverse total shoulder arthroplasty and resting radiographic scapular rotation

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Background: It remains unclear whether changes in scapular rotation influence the surgeon's ability to achieve resting radiographic neutral or inferior baseplate tilt at final follow-up. The purposes of this study were (1) to determine whether reverse total shoulder arthroplasty (RTSA) changes the resting scapular rotation, (2) to determine the association between glenoid inclination with respect to the scapula (β angle) and resting scapular rotation, and (3) to determine the β angle threshold that will most likely lead to resting radiographic neutral or inferior baseplate tilt relative to the thorax.

Methods: This was a retrospective radiographic study. Patients with adequate-quality standing anteroposterior and Grashey radiographs obtained preoperatively and after primary RTSA at a minimum of 1 year were included. Glenoid inclination (β angle) was measured between the supraspinatus fossa and the glenoid. Resting scapular rotation was measured between the supraspinatus fossa and a vertical line. Baseplate tilt was then calculated as the angle between the glenoid and a vertical line.

Results: The study included 74 patients with a mean follow-up period of 3 years (range, 1-9 years). Scapular rotation changed 2° ± 12° (mean ± standard deviation) into upward rotation ($P = .048$). No association was found between the β angle and scapular rotation. In 71% of patients with a neutral or inferior baseplate tilt, a postoperative β angle greater than 85° was found.

Conclusions: Resting radiographic scapular rotation changed 2° into upward rotation with RTSA and was not associated with the β angle. If the β angle is greater than 85°, resting radiographic baseplate tilt will most likely be inferior or neutral.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Reverse total shoulder arthroplasty; shoulder arthroplasty; shoulder replacement; scapulothoracic; glenoid inclination; scapular orientation

Reverse total shoulder arthroplasty (RTSA) has been shown to be an effective treatment that reduces pain and improves function in several conditions, including rotator cuff arthropathy, osteoarthritis with associated rotator cuff deficiency, and revision arthroplasty.[2-4,19,22,26] Over the past 2 decades, the use of RTSA has increased dramatically in the United States and worldwide.[1,8,9,17,20] Optimal component placement during RTSA has been a topic of continued debate. The goals of RTSA component positioning are to maximize functional mobility of the

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shoulder and to decrease implant-related complications such as instability, scapular notching, and component loosening. Previous research has demonstrated that optimizing glenoid component positioning likely plays a significant role in achieving these goals.[6,7,16,21]

Several studies have emphasized the importance of achieving a neutral to inferior tilt of the glenoid component of the RTSA.[5-7,12,14] Inferior baseplate tilt has been shown to decrease shear forces across the baseplate and theoretically decrease rates of glenoid component loosening.[5-7,12,14] Baseplate tilt may also alter component impingement on the lateral scapula with the arm in adduction. Because muscular forces within the shoulder work to counteract gravity's downward pull on the arm, the glenoid component's position in relation to the vertical, that is, the thorax, may be important. However, baseplate tilt relative to the thorax includes both the glenoid inclination with respect to the scapula, traditionally measured with the β angle, and scapular rotation relative to the thorax. Surgically, the surgeon only has control over the former. Previous research has focused solely on glenoid inclination relative to the scapula as it is more easily measured radiographically and altered intraoperatively. Maximizing compressive forces and minimizing shear forces on the baseplate while reducing adduction impingement may be dependent on inferior inclination of the baseplate relative to a vertical plumb line of the thorax as well.[7,16]

The effect of RTSA on overall resting radiographic scapular rotation is largely unknown. Although multiple studies have demonstrated that RTSA significantly alters scapular kinematics and scapulohumeral rhythm,[10,11,13,25] the effect of changing baseplate inclination on resting scapular rotation has not been studied. Given the nonanatomic nature of RTSA, there may be significant changes in resting radiographic scapular rotation following RTSA. These effects may dampen or enhance the surgeon's efforts to achieve the neutral or inferior baseplate tilt on a standing anteroposterior (AP) radiograph. Our overall aim with this study was to determine the influence of changes in scapular rotation in the coronal plane on the surgeon's ability to achieve resting radiographic neutral or inferior baseplate tilt at final follow-up.

The purposes of this study were (1) to determine whether RTSA changes the resting scapular rotation, (2) to determine the association between glenoid inclination with respect to the scapula (β angle) and resting scapular rotation, and (3) to determine the β angle threshold that will most likely lead to resting radiographic neutral or inferior baseplate tilt relative to the thorax.

Methods

This was a retrospective, comparative radiographic study. All patients treated with primary RTSA at a single institution from September 2007 to December 2015 were screened for glenoid inclination. All cases reviewed were performed by a single surgeon (R.Z.T.) during the aforementioned period with a consistent surgical philosophy and goals.

Patients were included in the study if they had standing radiographs obtained preoperatively, as well as at least 1 year postoperatively, that included standing true AP and Grashey views (ie, AP relative to the scapula) of the operative shoulder with the arm at the side. Patients were excluded if they had a non-native glenohumeral joint (ie, previous shoulder arthroplasty), underwent any concomitant tendon transfers, had a lack of adequate radiographs obtained preoperatively or at least 1 year after RTSA, or underwent any revision procedures within 1 year after primary RTSA. Radiographs were deemed inadequate if it was not possible to obtain the planned measurements, specifically those pertaining to glenoid and baseplate inclination, because the profile of the backside of the baseplate was not well visualized radiographically.

Our initial search using Current Procedural Terminology code 23472 revealed 488 shoulder arthroplasties; in 147 of these cases (30%), radiographs were performed at our institution at a minimum of 1 year postoperatively. Reverse arthroplasties comprised 101 (69%). Among these cases, there were 14 revision arthroplasties, 10 patients had inadequate radiographs, 1 patient underwent revision prior to 1 year of follow-up, and 2 patients were excluded as they underwent a tendon transfer concomitantly with RTSA, which was believed to potentially alter the scapulothoracic relationship, leaving 74 patients available for inclusion (Fig. 1).

For selection of radiographs, an attempt was made to always use the preoperative radiograph that was obtained closest in time to primary RTSA, as well as the postoperative radiograph with the greatest follow-up length after RTSA. The greatest length of follow-up was selected to provide the best representation of resting scapular rotation after re-equilibration of the periscapular musculature. The exception to this was when radiographs were inadequate in terms of quality for performing measurements because the profile of the backside of the baseplate was not well visualized. When this occurred, the next closest postoperative radiograph was used if adequate (excluding those radiographs obtained prior to the 1-year postoperative visit).

For measurements on preoperative radiographs, the β angle and resting scapular rotation were measured using a true AP radiograph of the operative shoulder. The β angle was measured as the angle between the line of the base of the supraspinatus fossa and a line from the superior-to-inferior glenoid rim (Fig. 2). Although several other methods of measuring glenoid inclination have been described, the β angle measurement has been shown to be the most reproducible and to have the least susceptibility to error with flexion or extension and internal or external rotation of the scapula during radiographic acquisition.[15] Larger β angles represented a more inferiorly oriented glenoid in which 90° was defined as neutral. The resting scapular rotation (ie, scapulothoracic rotation) was measured as the angle between the line of the base of the supraspinatus fossa and a vertical plumb line (Fig. 2). A larger resting scapular rotation measurement represented a more superiorly oriented glenoid with 90° defined as neutral. Resting glenoid tilt was then calculated from these 2 angles as the resting scapular rotation subtracted from the β angle, which was the same as the angle between a line from the superior-to-inferior glenoid rim and a vertical plumb line (Fig. 2). A larger resting tilt represented a more inferiorly orientated glenoid with 0° defined as neutral.

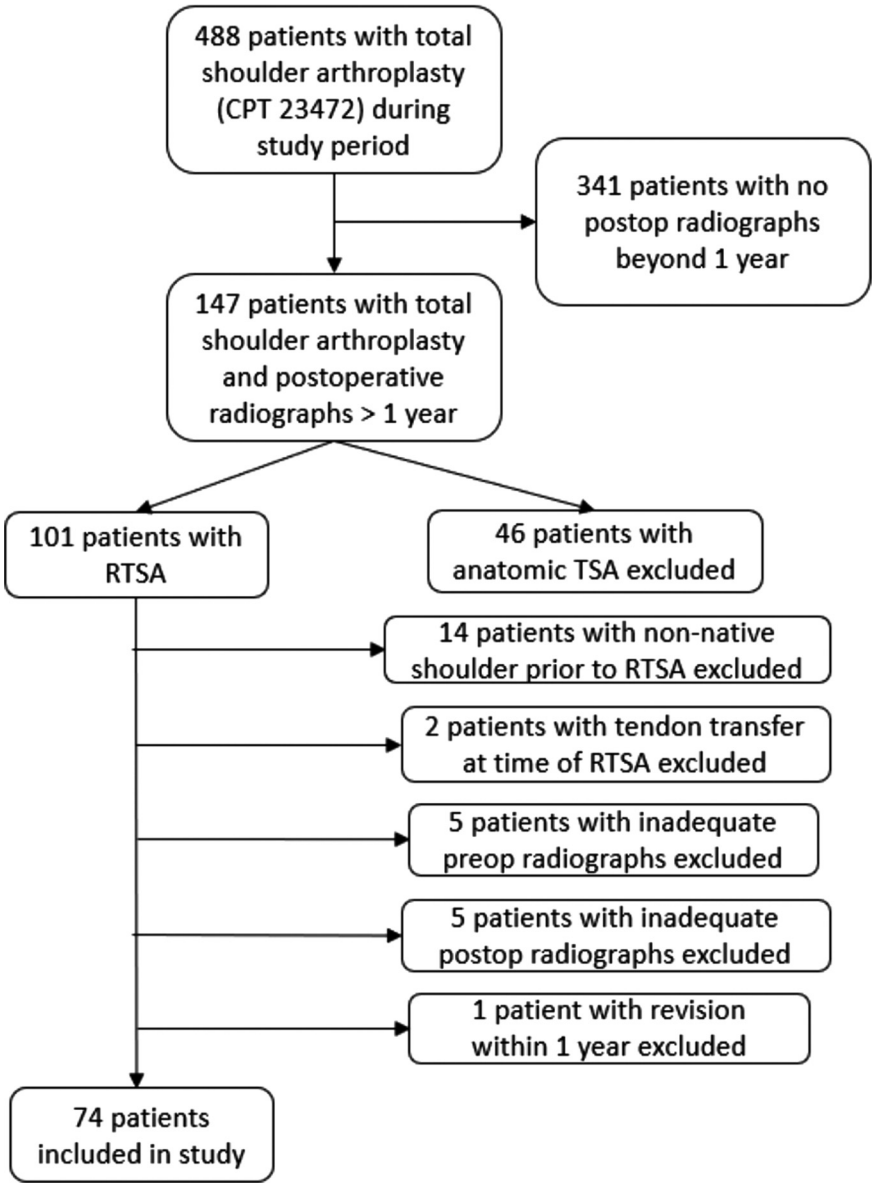

Figure 1 This flowchart demonstrates the creation of the study group through application of our inclusion and exclusion criteria. *CPT*, Current Procedural Terminology; *postop*, postoperative; *RTSA*, reverse total shoulder arthroplasty; *TSA*, total shoulder arthroplasty; *preop*, preoperative.

For measurements of postoperative radiographs, the β angle and resting scapular rotation were measured and resting tilt was calculated as described previously. Given the presence of the baseplate, the β angle was measured as the angle between the line of the base of the supraspinatus fossa and the most medial aspect of the glenoid baseplate (Fig. 2). The accuracy and reliability of this method of β angle measurement in this setting have been validated.[24] All radiographic measurements were performed using an IntelliSpace PACS Radiology system (Philips North America, Andover, MA, USA).

Statistical analysis

An a priori power analysis was performed assuming a non-normal distribution, with a significance level of .05, a standard deviation of 10°, a paired analysis, and a difference in scapular rotation of 5°, which was considered clinically significant. This analysis suggested that 47 subjects would be necessary to achieve 90% power in a preoperative vs. postoperative paired analysis. Data were first assessed for normality using a Kolmogorov-Smirnov test, and parametric and nonparametric tests were used as appropriate. To address purpose 1, preoperative and postoperative resting scapular rotation was compared using the Mann-Whitney *U* test. To address purpose 2, Spearman correlation coefficients were calculated between the preoperative and postoperative β angle and scapular rotation and the change in the β angle and scapular rotation. To address purpose 3, patients were divided into 2 groups: those with neutral to inferior tilt and those with superior tilt. After patients were divided into these 2 groups, the postoperative β angle was compared between groups using the Mann-Whitney *U* test. In all tests, the threshold for significance

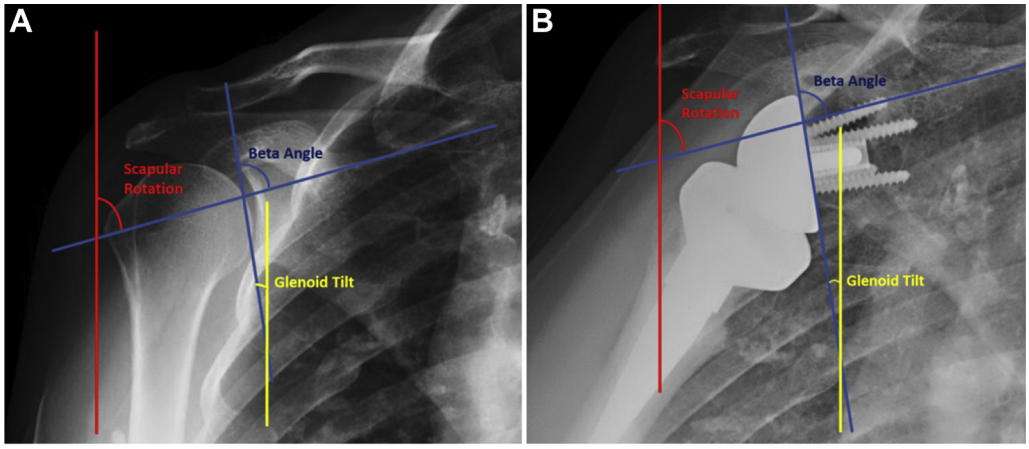

Figure 2 Preoperative and postoperative radiographs with representative measurements. **(A)** On this preoperative radiograph, the β angle and scapular rotation are measured using the supraspinatus fossa as a reference line. Glenoid tilt is measured as the angle between a line from the superior-to-inferior glenoid and a vertical plumb line. **(B)** Postoperative radiograph with similar measurements.

was set at .05. Statistical analysis was performed using SPSS Statistics software (version 25; IBM, Armonk, NY, USA).

Results

The average age of the 74 patients included in the study was 69 ± 8 years (mean ± standard deviation; range, 52-89 years). Rotator cuff arthropathy was the most common preoperative diagnosis and indication for RTSA (61% of patients). The mean follow-up period was 3 ± 2 years (range, 1-9 years; Table I). The β angle changed by 9° ± 10° into inferior inclination ($P < .001$), from 79° ± 8° (range, 51°-101°) to 88° ± 7° (range, 74°-117°). Resting scapular rotation changed by 2° ± 12° into superior rotation (range, –25° to 43°, $P = .048$), from 79° ± 11° (range, 48°-101°) to 77° ± 11° (range, 54°-101°).

The preoperative and postoperative β angles were not associated with preoperative ($\rho = 0.186$, $P = .353$) and postoperative ($\rho = 0.140$, $P = .352$) resting scapular rotation, respectively. The change in β angle from preoperatively to postoperatively was not correlated with the change in scapular rotation ($\rho = 0.139$, $P = .218$).

Patients were divided into those with a neutral or inferior postoperative resting glenoid tilt (62 patients, 84%) and those with a superior postoperative glenoid tilt (12 patients, 16%). Of the patients with a neutral or inferior glenoid tilt at final follow-up, 71% (44 of 62) had a postoperative β angle greater than 85°.

Discussion

Maximizing compressive forces and minimizing shear forces on the baseplate while reducing adduction impingement may be dependent on inferior inclination of the baseplate relative to the thorax.[7,16] To accomplish this goal, many surgeons are preferentially reaming inferiorly, using asymmetrical bone grafts, or using augmented components to increase inferior baseplate inclination. Very limited data exist on how these efforts affect the relationship between the scapula and the thorax, as well as which is more important: glenoid inclination with respect to the scapula or thorax. Within this study, resting scapular rotation basically showed no change, and it was not associated with the β angle, suggesting that resting scapular rotation does not change after RTSA and has a lower potential impact than glenoid inclination relative to the scapula, which can be modified during surgery. Our results also suggest that if the surgeon desires to obtain a postoperative radiograph with neutral to inferior tilt of the glenoid baseplate relative to the vertical, this can usually be achieved with a β angle greater than 85°.

Within our study, a statistically significant change into upward resting scapular rotation of 2° was found. We considered this change to be clinically insignificant as alignment changes of this magnitude cannot be achieved with human hands in the operating room. In addition, no association between the β angle and resting scapular rotation was observed. This finding suggests, regarding the radiographic outcome, that surgeons can proceed with inclination correction relative to the scapula rather than with respect to scapular rotation relative to the thorax. Prior studies have analyzed the effect of RTSA on scapular kinematics and scapulohumeral rhythm[10,11,13,25] and have found multiple changes; however, none have specifically analyzed resting rotation and the relationship to the β angle.

Within our study, most patients (71%) with postoperative neutral to inferior resting radiographic baseplate tilt had a β angle greater than 85°. Multiple studies have demonstrated that neutral or inferior glenoid inclination may help to reduce instability and loosening and may be preferable biomechanically.[7,18,21,23] Thus, achieving more inferior inclination has been a continued topic of interest during the evolution of RTSA techniques and prosthesis design.[21]

Table I Patient characteristics

	Data
Age, yr	69 ± 8
Sex: male, %	21 (28)
Laterality: right, %	50 (68)
Time from preoperative radiograph to surgery, d	139 ± 187
Time from surgery to postoperative radiograph, yr	3 ± 2 (SD, 2)
Diagnosis, %	
Rotator cuff arthropathy	45 (61)
Irreparable rotator cuff tear with pseudoparalysis	3 (4)
Osteoarthritis with rotator cuff insufficiency	12 (16)
Failed rotator cuff repair	5 (7)
Proximal humeral fracture sequelae	3 (4)
Other	6 (8)
Type of implant, %	
Tornier Aequelis (Tornier, Edina, MN, USA)	48 (65)
Tornier Ascend Flex	1 (1)
Tornier Fracture Specific Aequelis	1 (1)
Zimmer Trabecular Metal (Zimmer, Warsaw, IN, USA)	23 (31)

SD, standard deviation.
Continuous variables are displayed as mean ± standard deviation, and discrete variables are displayed as number (percentage).

Nyffeler et al[16] demonstrated that an inferiorly placed glenoid component, which extends inferiorly to the native glenoid rim, improves adduction range of motion, theoretically decreasing impingement and subsequent notching. Simovitch et al[21] similarly found that glenoid position and the angle of the glenoid component with the scapular neck were correlated with both inferior notching and midterm patient outcomes. Gutierrez et al[6] performed a biomechanical study demonstrating decreased micromotion and tensile forces with an inferiorly tilted glenoid component (15°). On the basis of these studies, baseplate inclination may be clinically important. Thus, our guidelines for achieving neutral to inferior tilt by achieving a β angle greater than 85° could be clinically useful to surgeons.

There are several limitations of this study. First, our study design relies on the assumption that the resting scapular rotation obtained radiographically represents the average resting scapular position for the patient. As scapular positioning can obviously be dynamic, the position at the time of radiography may not be a true reflection of resting position. Second, the position of the scapula in space could be affected by other patient-specific factors, such as patient posture, spine alignment, arm abduction angle, or lower-limb length discrepancies. Third, the retrospective nature of the study, loss to follow-up, and exclusion criteria could create a selection bias. Fourth, our relatively small sample size may be underpowered for some clinical comparisons. Fifth, there was variability in the length of follow-up. Sixth, scapular position is a 3-dimensional phenomenon affected by version and rotational factors that was measured within our study on 2-dimensional images, which may not capture the full extent of changes in scapular position. Our aim in the study was not to fully describe scapular position but instead was to determine how surgeons can best achieve the goal of a final radiograph with a neutral or inferiorly tilted baseplate.

Conclusion

Resting radiographic scapular rotation did not significantly change with RTSA and was not associated with the β angle. If the β angle is greater than 85°, resting radiographic baseplate tilt will most likely be inferior or neutral.

Disclaimer

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