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Post-operative Baseplate Radiographic Evaluation Using Routine pre-Operative CT

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Abstract

Background: There is limited data evaluating post-operative component position and fixation in reverse shoulder arthroplasty (RSA). Therefore, the purpose of this study was to evaluate baseplate position and fixation using routine pre-operative CT and post-operative radiographs.

Methods: A retrospective analysis of a series consecutive patient who underwent primary RSA was performed. Pre-operative and post-operative glenoid retroversion and inclination were measured using radiographs aligned with projection silhouettes of 3D scapula models in Mimics software. Baseplate retroversion and inclination were measured followed by evaluating for the presence of radiolucent lines (RLLs).

Results: Twenty-four patients met inclusion criteria. The average age was 73.4 ± 10.7 years (range, 45-89 years). Radiographic follow-up was 3.4 ± 1.3 years. Post-operative glenoid baseplate retroversion was 2 ± 10 degrees (range, 30 to −9). Post-operative glenoid baseplate inclination was 3.8 ± 9.1 (range, −13 to 19). Five (21%) RSAs had baseplate retroversion >10 degrees. Follow-up radiographs revealed no RLLs around the baseplate, central post, or peripheral screws in any patient.

Conclusions: Pre-operative CT imaging enabled evaluation of baseplate component placement and fixation on post-operative radiographs. Baseplate version was within 10 degrees of neutral in 79% (19/24) of patients. No RLLs or loss of fixation were found in any cases.

Level of Evidence: Level IV: Diagnostic Study.

Keywords

baseplate, reverse shoulder arthroplasty, mimcs, 3D CT, retroversion, radiolucent lines

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Introduction

Indications for reverse shoulder arthroplasty (RSA) have broadened since its initial usage for elderly patients with rotator cuff deficiency. Common indications for RSA now include trauma,[1-3] sequelae of trauma,[4-10] osteoarthritis with bone loss,[11] revision arthroplasty,[12] and tumor resection.[13,14] This array of complex pathologies can present challenges to surgeons seeking to decrease complications and improve outcomes. Therefore, pre-operative planning of RSA has become increasingly utilized to optimize component sizing, placement, and fixation.[15,16]

Computer-aided virtual planning software helps surgeons visualize of bony deformities, understand pathoanatomy, and provide automated values for glenoid inclination and retroversion.[15] Implant seating and impingement-free range of motion can also be determined.[15] Consequently, virtual planning software has enabled surgeons to better plan for challenging cases involving glenoid deformity or bone loss. In addition, patient-specific instrumentation and navigation have also been developed to more accurately implement pre-operative plans.[17] However, there are limited studies evaluating the success of implementing pre-operative plans by the way of post-operative component

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position and fixation over longer follow-up periods. Moreover, multiple studies have shown the measurements on radiographs can be unreliable pre-operatively and post-operatively.[18,19]

Mehta et al described a novel method of determining post-operative glenoid component position after anatomic total shoulder arthroplasty.[20] The method used routine pre-operative CT scans and post-operative radiographs coupled with Mimics software.[20] The authors found their method was accurate and strongly correlated with CT controls.[20] To our knowledge, no such study has been performed using this method to evaluate RSA baseplates. Therefore, the purpose of this study was to apply a previously validated method using routine pre-operative CT imaging to evaluate RSA baseplate position and fixation with post-operative radiographs.

Materials and Methods

Study Cohort

This was a retrospective analysis of a consecutive series of patients from our institutional shoulder arthroplasty database who underwent primary RSA for cuff tear arthropathy. Patients were included if they had a pre-operative CT scan and post-operative AP and axillary radiographs at least 2 years from time of surgery. All patients had the same implant which was comprised of an ingrowth baseplate with a central post (Zimmer Trabecular Metal Reverse Shoulder System, Zimmer, Warsaw, IN, USA). Two fellowship-trained shoulder surgeons performed all surgical procedures. Surgery was performed through a deltopectoral approach using a subscapularis peel or tenotomy which was repaired at the conclusion of the case.

Mimics 3D Scapula Model Building

Pre-operative CT scans were imported into Mimics Research 20.0 software (Materialise, Leuven, Belgium). Segmentation of the scapula was performed by selecting all pixels representing bone with a radiodensity greater than 226 Hounsfield units. The region-growing tool was then used to select pixels contiguous to an arbitrary point within the scapula. Inclusion of only the scapula was manually confirmed. A 3D object was calculated from this selection and refined using wrapping (0.8 mm smallest detail, 8 mm gap closing distance) and smoothing (1 iteration, 0.8 smooth factor) tools.

Pre-Operative 3D CT Assessment

The coronal scapular plane, defined by the inferior scapula tip, medial pole, and glenoid center, was defined in 3-matic 12.0 software (Materialise, Leuven, Belgium). The transverse scapular plane was defined as that containing the medial scapula pole and glenoid center as well as being perpendicular to the coronal scapular plane. The Mimics reslice tool was used to reslice the CT scan in the transverse scapular plane, and version was measured on the mid-glenoid slice using the technique described by Friedman (Figure 1).[21] Results from this method were considered the standard control for pre-operative glenoid version measurements,

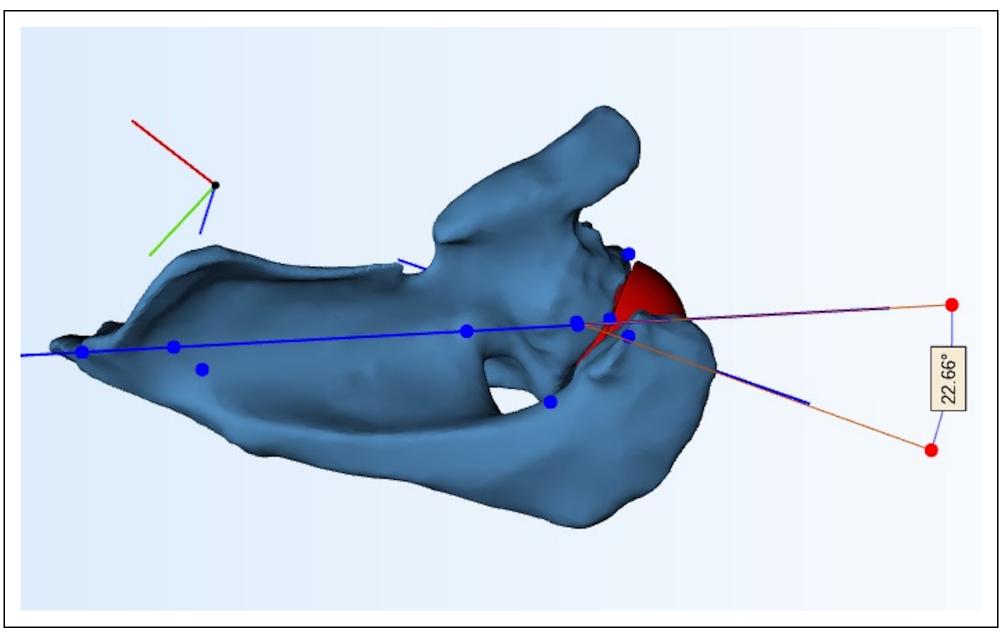

Figure 1. Baseplate version. Measurement of baseplate retroversion (22.6 deg) within the scapular coordinate system of the 3D CT of scapula.

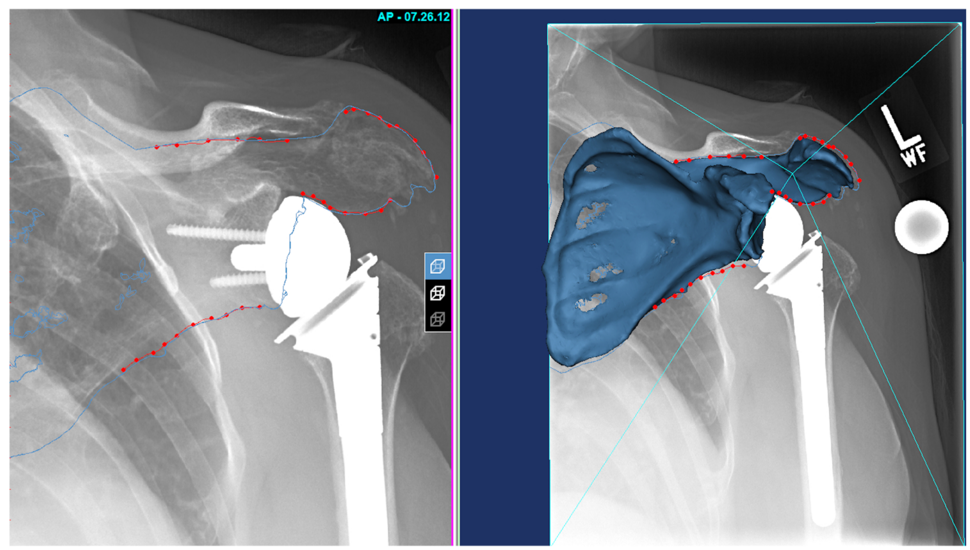

Figure 2. Radiograph registration to 3D CT. Radiographs were registered to calculate post-operative position of glenoid baseplate within pre-operative 3D CT of scapula.

similar to the methods used by Budge et al.[22] In addition, glenoid inclination was also measured using Glenosys 10.0.0 (Imascap, Plouzane, France), a commercially available 3D modeling software.

Post-Operative Radiograph Assessment

Glenoid component version and inclination measurements were made utilizing the orientation and position of the known glenoid baseplate and glenosphere complex of the Zimmer Trabecular Metal Reverse Shoulder System (Zimmer, Warsaw, IN, USA) relative to the 3D scapula model. To achieve this, AP and axillary radiographs were each aligned with the projection silhouettes of the 3D scapula model in Mimics software.

The external contours of the scapula were then defined on the post-operative AP and axillary radiographs. These contours consisted of the lateral scapula border, scapular spine, coracoid, and acromion on the AP view and the acromion, glenoid vault, and coracoid on the axillary view. Manual registration and a contour-based optimization algorithm were used to position the radiographs so that the 3D scapula model matched the AP and axillary radiographs (Figure 2).

Next, a 3D-model of the glenoid baseplate was aligned to create a projection silhouette that matched that of the glenoid baseplate on the post-operative AP and axillary radiographs (Figure 2). After the alignment process was completed for both the scapula and baseplate component, these models were exported to create a scapular coordinate system. The coordinate system had axes aligned with the transverse scapular plane, such that the x-axis (medial-lateral) lay on the line from the scapula's medial pole to the glenoid center, the z-axis (superior-inferior) lay on the line from the inferior glenoid tip to the glenoid center, and the y-axis (anterior-posterior) lay orthogonal to both. This enabled baseplate version and inclination to be measured on the post-operative radiographs.

Post-operative baseplate fixation was evaluated by two fellowship-trained shoulder and elbow surgeons for radiolucent lines (RLLs) assessed on AP and axillary radiographs according to the method described by Melis et al.[23] RLLs around the baseplate, screws, or central post were classified according to the RLL width ($<$2 mm or $\geq$2 mm). Loosening was considered to be present if the baseplate component migrated, as demonstrated by a shift, tilt, or subsidence, or if complete radiolucency $\geq$2 mm was present.[23]

Statistical Methods

Radiograph measurements were reported as means with standard deviations and ranges. Calculations were performed with MATLAB R2017a (MathWorks, Natick, MA).

Results

A total of 24 patients met inclusion criteria. The average age at the time of surgery was 73.4 ± 10.7 years (range, 45-89 years). Mean post-operative follow-up was 3.4 years (range, 2-7.3 years).

The mean pre-operative glenoid version was 6 ± 10 degrees, and the mean post-operative baseplate version was 2 ± 10 degrees (Table 1). The average correction of glenoid version was 4 ± 6 degrees. In other words, retroversion was

Table 1. Radiographic Assessment Values.

	Pre-operative[a]	Post-operative[a]
Glenoid retroversion[b]	5.9 (9.6; −17.3-30.2)	2.1 (10.4; −9.1-29.7)
Glenoid inclination[b]	2.9 (6.2; −9.0-15.5)	3.8 (9.1; −12.5-19.0)

[a]Mean pre-operative value (STD; range).
[b]Values in degrees (°).

Table 2. Baseplate retroversion >10°.

Patient	Pre-operative retroversion[a]	Post-operative retroversion[a]	Follow-up[b]	RLL[c] score
#1	27.4	29.7	3.6	0
#2	8.8	11.0	2.1	0
#3	11.1	10.6	3.5	0
#4	16.5	19.5	7.3	0
#5	30.2	22.7	2.2	0

Abbreviation: RLL, radiolucent line.
[a]Values in degrees (°).
[b]Values in years.
[c]Radiolucent line score according to Melis et al.[23]

decreased on average post-operatively. Pre-operative native glenoid inclination was 2.9 ± 6.2 (range, −9 to 16) and post-operative glenoid baseplate inclination was 3.8 ± 9.1 (range, −13 to 19). In other words, glenoid inferior inclination was increased on average post-operatively. There were five patients with baseplate retroversion over 10 degrees (Table 2) (range, 11-30 degrees).

There was no evidence of loosening or loss of fixation on post-operative radiographs in any patient. Furthermore, patients with baseplate retroversion >10 degrees had no difference in RLL score (average score 0) than patients with baseplate retroversion <10 degrees (average score 0). In addition, no radiographic abnormalities were appreciated in any patient with superior baseplate inclination.

Discussion

Optimization of glenoid baseplate position is an important factor in planning RSA. Accurate pre-operative and post-operative glenoid baseplate evaluation enables meaningful analysis of surgical planning and execution. The present study used a previously validated method to evaluate baseplate position and fixation using post-operative radiographs at mid-term follow-up.[20] Baseplate version was within 10 degrees of neutral in the majority of patients. No RLLsor loss of fixation were found in any cases at mid-term follow-up.

Although multiple studies have evaluated the implant position after shoulder arthroplasty, many of these studies have used 2D CT scans.[22] Budge et al found that glenoid version measured on 2D CT scans had differences between 10 and 15 degrees in 12% of patients compared to a 3D CT glenoid version measurement.[22] In addition, the authors also found intraobserver and interobserver reliability was more reliable and reproducible when using 3D CT.[22] Another study by Boileau et al investigated an automated image analysis software's ability to measure glenoid version and inclination.[24] The software (Imascap, Plouzané, France) provided 3D reconstruction of the scapula and humerus in addition to automated measurements of glenoid orientation. The authors found that the image analysis software showed a mean difference of 1.5 degrees compared to the corrected Friedman method for glenoid version and a mean difference of 0.2 degrees compared the Maurer method for glenoid inclination.[24] The present study similarly used a 3D scapula and implant model to analyze baseplate component position on post-operative radiographs.

Glenoid component RLLs have been reported despite the improved fixation in RSA. In a long-term follow-up study of 122 Grammont style RSAs, Melis et al showed a 16% rate of RLLs around the glenoid component which was more common with scapular notching.[23] However, the authors did not measure glenoid component orientation but suggested that higher rates of RLLs and notching were possibly secondary to superior inclination of the baseplate due to use of a superolateral approach.[23] Frankle et al found an 8% rate of RLLs around the reverse glenoid component in 60 patients at an average of 3.3 years follow-up.[25] However, no mention of glenoid component baseplate position was mentioned by the authors.[25] The present study found no RLLs or loss of fixation in any cases regardless of baseplate component position.

More recently, Elmallah et al evaluated clinical outcomes and radiographic findings of RSA patients with a mean follow-up of at least 2-years.[26] The authors used post-operative radiographs evaluated in isolation to determine baseplate component position. Two groups of patients were analyzed based on post-operative retroversion. Group A retroversion was less than 15 degrees and group B retroversion was greater than 15 degrees. The mean pre-operative retroversion for group A was 9 degrees and 19 degrees for group B. The mean change in pre-operative retroversion in groups A and B was 1 degree and 4 degrees, respectively. One radiolucency was noted in group A and two radiolucencies were noted in group B. No significant differences in outcomes were found between the two groups.[26] These findings are similar to the present study in that baseplate component retroversion had no apparent effect on outcome.

Baseplate inclination has been shown to be an important factor in early failure of RSA.[27-29] Superior inclination of the baseplate is considered a risk factor for baseplate loosening.[28,30,31] This has led many authors to advocate for slight inferior inclination in order to improve clinical and radiographic outcomes.[27-29] However, some authors have demonstrated inferior inclination does not affect clinic or radiographic outcomes.[32] Overall, the present study found no evidence of untoward radiographic outcomes despite some baseplates having some degree of superior inclination. This finding may be the result of only mid-term follow-up which averaged 3.4 years. Thus, it is possible that longer term follow-up would have demonstrated abnormal radiographic findings. Another possible explanation may be the rigid fixation imparted by the ingrowth baseplate and central post prevented any RLLs or loss of fixation. If no early abnormal motion of the baseplate occurred, rigid boney ingrowth likely ensued thus preventing any radiographic compromise.

Accurate pre-operative and post-operative glenoid baseplate evaluation enables meaningful analysis of pre-operative planning and surgical execution. Post-operative evaluation of glenoid components has been imprecise without post-operative CT scans.[20] However, routine post-operative CT scans expose patients to significant amounts of radiation and are considered beyond the standard of care for many surgeons.[20] The method used in the present study enabled the evaluation of baseplate position and fixation with routine imaging studies for RSA. The method employed 3D-modeling software to evaluate the glenoid baseplate relative to the pre-operative CT and post-operative radiographs. In addition, the method is less sensitive to the quality and projection of radiographs. Further development and application of this method will enable evaluation of optimal baseplate positioning and may help to improve clinical outcomes.

There are multiple limitations to the present study beyond those inherent to retrospective study designs. Some of these limitations include the image analysis method used in the assessment of post-operative radiographs. First, the method requires proficiency in specialized software which requires purchase (Materialise, Leuven, Belgium). Second, the method was somewhat time consuming and required approximately 30 minutes per case due to the lack of an automated analysis protocol. Programed automation would likely improve adoption and use in clinical practice. Another limitation of the study is the relatively small sample size and lack of clinical results. Finally, the present study only evaluated patients with a diagnosis of rotator cuff tear arthropathy. It is possible that differing indications or variations of glenoid morphology would have affected the results.

In conclusion, the use of routine pre-operative CT imaging enabled evaluation of baseplate component placement and fixation on post-operative radiographs using specialized software. Baseplate version was within 10 degrees of neutral in 79% (19/24) of patients. No RLLs or loss of fixation were found in any cases at mid-term follow-up. Future application of this method is likely to help improve glenoid baseplate position optimization and clinical outcomes.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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