



# Reverse total shoulder arthroplasty for acute proximal humeral fracture: comparison to open reduction–internal fixation and hemiarthroplasty

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**Background:** Significant controversy surrounds optimal treatment of displaced 4-part proximal humeral fractures. Reverse total shoulder arthroplasty (RTSA) has recently been proposed as an alternative to hemiarthroplasty (HA) and open reduction–internal fixation (ORIF). Several authors have questioned the additional implant cost for RTSA. The purpose of this study was to compare outcomes and cost of RTSA, HA, and ORIF.

**Materials and methods:** We prospectively evaluated patients who underwent RTSA for displaced 3- and 4-part proximal humeral fractures and then retrospectively developed age- and sex-matched control groups with 3- and 4-part proximal humeral fractures who underwent HA and ORIF. Range of motion including active forward elevation and external rotation and time to achieve active forward elevation >90° were recorded. American Shoulder and Elbow Surgeons (ASES), Short-Form 12-item (SF-12), and Simple Shoulder Test (SST) scores were recorded. In addition, treatment cost was assessed by Medicare data and implant list prices.

**Results:** This study enrolled 27 patients; 9 underwent RTSA, 9 HA, and 9 ORIF. Minimum follow-up was 1 year. No significant differences were seen in SST, ASES, or SF-12 scores. Significantly more patients achieved >90° of active forward elevation after RTSA ( $P = .012$ ). RTSA provided significant cost savings to Medicare compared with HA and ORIF ( $P = .002$ ).

**Conclusion:** In this case-control study, RTSA appears to provide superior range of motion earlier and more predictably than HA and ORIF, with significant cost savings to Medicare.

**Level of evidence:** Level III, Retrospective Cohort Study, Treatment Study.

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**Keywords:** Shoulder arthroplasty; reverse shoulder arthroplasty; hemiarthroplasty; proximal humeral fracture; shoulder fracture; open reduction and internal fixation

Institutional review board approval was obtained for this study under protocol # 11120602.

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Proximal humeral fractures cause substantial pain, loss of function, and loss of independence in performance of activities of daily living.<sup>15,24,36,45</sup> A wide variety of treatment options exist for these injuries, including nonoperative treatment with a brief period of sling use followed by early

mobilization,<sup>20,36,51</sup> closed reduction and percutaneous pin fixation,<sup>35</sup> open reduction and internal fixation (ORIF) with a tension band,<sup>21,51</sup> ORIF with a locking periarticular plate or suture fixation,<sup>3,28,37,43,45</sup> open reduction and external fixation,<sup>50</sup> hemiarthroplasty (HA),<sup>2,6,10,18,22,25,26,32,33,38,39,44,52</sup> total shoulder arthroplasty,<sup>44</sup> and, recently, reverse total shoulder arthroplasty (RTSA).<sup>9,11,12,14,24,29,31</sup> The management of displaced 3- and 4-part<sup>33</sup> proximal humeral fractures remains controversial.<sup>10,20,27,35,46</sup> Substantial geographic variation exists, suggesting lack of agreement between surgeons regarding the optimal treatment of these injuries and a need for further research or better treatment options.<sup>5</sup>

For proximal humerus fractures of 3- and 4-part severity, the treatment options available have advantages and disadvantages.<sup>10,20,27,35,46</sup> Whereas ORIF offers anatomic reconstruction with preservation of bone stock and without concern for prosthetic glenoid wear or loosening, complications include arthrofibrosis,<sup>37,43,45</sup> fracture displacement,<sup>37,43,45</sup> screw cutout in 16% to 67% of cases,<sup>37,43,45</sup> intra-articular migration of screws,<sup>37,43,45</sup> and avascular necrosis of the humeral head in 4% to 55% of cases.<sup>37,43,45</sup> Although HA avoids displacement or necrosis of the humeral head, this technique is particularly challenging with respect to the tuberosities, providing a poor healing environment. HA can thus be complicated by displacement and osteolysis of the tuberosities and subsequent loss of function.<sup>2,6,10,18,22,25,26,32,33,38,39,44,52</sup> Recently, RTSA has been proposed for treatment of proximal humeral fractures.<sup>1,17,41,46</sup> Theoretical advantages include relative independence from relying on a functioning supraspinatus muscle-tendon unit for active elevation, potential rapid recovery, and reduced need for postoperative rehabilitation.<sup>17</sup> Studies to date have demonstrated that RTSA provides predictable pain relief with reliable functional gains, especially with tuberosity healing. However, complication rates up to 50% to 68% have been reported, including hematoma formation, scapular notching, loosening of the glenoid component, instability, and component dissociation.<sup>1,9,11,12,14,24,29,31</sup>

Previous studies have reported on outcomes from each of these treatments individually or compared one treatment with another,<sup>3,7,8,15,20,36,41,43,51</sup> but no single study has attempted to compare outcomes from all three techniques from a single surgeon. In addition, the cost of reverse total shoulder implants has been previously reported as a public health concern should these implants become widely used for this indication.<sup>5,16</sup> The purpose of this study was to describe outcomes from a single surgeon, at a single center, with all three techniques. In addition, cost was estimated for each technique by several methods. We hypothesized that RTSA would lead to equivalent or superior outcomes at a lower overall cost.

## Materials and methods

This was a retrospective case-control study. Because of the inconsistent results that we had obtained with either ORIF or HA for severe proximal humerus fractures, we began using RTSA in

2010 as an option for the treatment of severe 3- and 4- part fractures in patients older than 65 years while still performing ORIF and HA in patients with appropriate indications. Criteria for inclusion in the study were age older than 65 years, preoperative radiographs demonstrating a 3- or 4-part proximal humeral fracture or fracture-dislocation by Neer's classification system,<sup>33</sup> functioning deltoid muscle on physical examination, ability to attend follow-up visits, and surgical treatment of the fracture with RTSA. The first 9 RTSAs for proximal humerus fractures were observed prospectively. We then compared these patients with age- and gender-matched cohorts of patients who underwent ORIF and HA for fracture from the author's practice. Patients were excluded from the study if they had an active infection, a nonfunctional deltoid muscle, a neurologic condition or movement disorder such as Parkinson's disease, a mental condition that might interfere with the ability to appropriately consent for the study or to follow postoperative protocols or data collection, a known metal allergy, or a length of follow-up of less than 1 year. The risks and benefits of this particular prosthetic reconstruction were discussed at length with the patient, and only patients who consented to undergo RTSA were included in this cohort.

Demographic data from these patients were then used to perform a retrospective review of prospectively collected data from the patient database of the senior author to collect age- and sex-matched controls who underwent acute HA and ORIF for proximal humeral fractures. Control patients were contacted and returned for repeated evaluation.

The following data were collected for all patients: age, duration between injury and operative fixation, hand dominance, side of injury, intraoperative findings, preoperative radiographic or clinical findings consistent with rotator cuff disease, complications, time necessary postoperatively to achieve 90° of active forward elevation (AFE), and number of physical therapy sessions attended. The following data were collected both preoperatively and at the time of final follow-up: anteroposterior, scapular Y lateral, and axillary lateral radiographs; visual analogue scale for pain (VAS), Simple Shoulder Test (SST),<sup>4,23</sup> American Shoulder and Elbow Surgeons (ASES),<sup>23</sup> and Short-Form 12-item (SF-12) quality of life scale scores<sup>42</sup>; and range of motion, including AFE in the plane of the scapula, active external rotation with the arm at the side, and active internal rotation in adduction. All examinations were performed in unblinded fashion by a trained research associate. Because these patients presented with acute fractures, it was not possible to determine preinjury function or range of motion. Radiographs were evaluated for any radiolucency surrounding the glenoid baseplate or screws, migration of the glenoid component or breakage in the screws, and scapular notching as graded by Nérot's system.<sup>40</sup>

## Cost analysis

Two cost analyses were performed: (1) societal costs as determined by Medicare reimbursement data and (2) individual costs as determined by list prices. Given that almost all variation between treatments arises from implant costs and physical therapy costs, these 2 variables combined were used to estimate total cost differences. Operative reports were reviewed to confirm the implants used. Physical therapy reports were reviewed to determine the number of sessions attended between the operation and release from physical therapy. The vendors for each of the implants used in this study were contacted and provided the list

price for these implants. The physical therapy facility most frequently used for rehabilitation after ORIF, HA, and RTSA was contacted to determine the typical cost of a treatment session after one of these operations as well as the average reimbursement provided by Medicare for a single postoperative physical therapy session. Publicly available data provided by the Centers for Medicare and Medicaid Services website (year 2012B, locality 0095216) using the fourth edition *Current Procedural Terminology* codes for each procedure were queried to complete the cost analysis.

## Surgical technique

All patients were positioned in the beach chair position. A deltopectoral approach was used for all procedures. ORIF<sup>28,48</sup> and HA<sup>10,35,46</sup> were performed by previously described techniques with a focus on tuberosity reduction and fixation with sutures. In ORIF, fixation was achieved with an anatomically contoured locking proximal humeral plate (Synthes, West Chester, PA, USA). HA was performed with a prosthesis with ingrowth material on the proximal aspect of the stem (Trabecular Metal; Zimmer, Warsaw, IN, USA), with supplementary distal cementation. All RTSAs were performed with a prosthetic stem that had the same bone ingrowth material on the reverse humeral stem (Trabecular Metal reverse; Zimmer, Warsaw, IN, USA), with the same supplementary distal cementation technique as for the humeral stem in HA. Whereas no specific, documented a priori criteria were used in treatment selection, patients generally underwent RTSA for fractures not amenable to ORIF because of head vascularity, bone quality, head-splitting nature of the fracture, severity of the fracture pattern, preoperative or intraoperative evidence of significant rotator cuff disease, or glenohumeral arthritis.

## Postoperative rehabilitation

Aftercare for HA and ORIF consisted of sling immobilization for 4 weeks, with pendulums and passive range of motion beginning on the first postoperative day. At 6 weeks, progression to active-assisted and then active motion was started. All patients who underwent HA or ORIF were prescribed formal physical therapy. Although the authors are not aware of any evidence comparing an unsupervised home exercise program with a supervised physiotherapy program for either of these indications, the majority of previous studies have employed formal physical therapy after HA<sup>2,6,18,22,32,39</sup> and ORIF.<sup>28,37,43</sup> We have not used formal outpatient physical therapy for RTSA performed for other causes and did not use it for a fracture. For RTSA, no pendulums or passive range of motion was allowed until 4 weeks. A sling was worn, and patients were allowed to perform activities of daily living in the sling. At 4 weeks, pendulums were begun and instruction in closed chain deltoid and "hitchhiker" teres minor exercises was given (Fig. 1). Patients were instructed to perform 3 sets of 10 repetitions of each exercise twice daily. The sling was discontinued at 4 weeks and active use for daily activity encouraged.

## Data analysis

Data were organized in Excel (Microsoft, Redmond, WA, USA). Analyses were performed in SPSS (IBM, Armonk, NY, USA). After creation of descriptive statistics with means and standard

deviations, the data were evaluated with the Kolmogorov-Smirnov test and found to be non-normally distributed. All further analyses were therefore performed with nonparametric independent samples Kruskal-Wallis tests. An a priori decision was made to divide patients into those who achieved 90° of AFE and those who did not as this was necessary to achieve a satisfactory result in Neer's initial evaluation system.<sup>34</sup> An a priori decision was also made to divide patients into those who had achieved 30° of external rotation and those who had not; we have clinically noted this degree of external rotation to be a functional threshold for patients with respect to activities of daily living. A *P* value < .05 was considered to be significant.

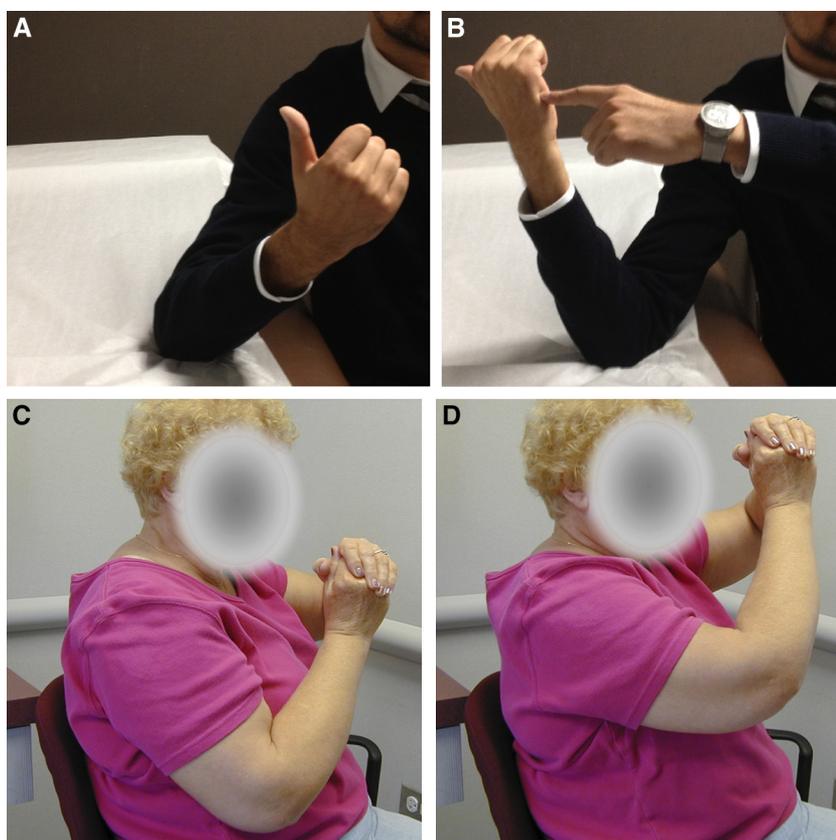
## Results

### Demographics

For the RTSA group, 9 patients met the inclusion criteria: 4 were 3-part displaced fractures, 3 were 4-part fractures, and 2 were anterior dislocations with associated 3- or 4-part fractures. Mean follow-up was  $1.2 \pm 0.5$  years. Age- and sex-matched groups of HA and ORIF patients were selected. The mechanism of injury in all patients in all groups was a ground-level fall. Among the patients who underwent HA, 5 had suffered head-splitting fractures and 4 had suffered 4-part proximal humeral fractures in which the vascularity of the humeral head was thought to be in question. Two were noted intraoperatively to have rotator cuff tears. Mean follow-up was  $4.9 \pm 1.2$  years. Among the patients who underwent ORIF, all suffered comminuted and displaced 3- and 4-part fractures. One patient suffered a concomitant anterior dislocation. Two patients were noted intraoperatively to have rotator cuff tears, which were repaired. Mean follow-up was  $3.0 \pm 1.5$  years. There were no significant differences in demographics between groups, which are shown in Table I.

### Outcomes

Significantly more patients in the RTSA group reached 90° of AFE (9 of 9) than in the HA or ORIF groups (*P* = .019; Fig. 2 and Table II). Significantly more patients in the RTSA group reached 30° of external rotation than in the HA or ORIF groups (*P* = .047 based on  $\chi^2$  likelihood ratio; Fig. 2 and Table II). There were no significant differences in quantitative outcome scores, which are shown in Table III. There were significantly higher physical therapy costs in the HA and ORIF groups compared with the RTSA group (Fig. 3; *P* = .002). Patients status post HA underwent  $5.6 \pm 2.9$  (mean  $\pm$  standard deviation) months of therapy with  $47.7 \pm 18.1$  sessions, and patients status post ORIF underwent  $5.4 \pm 2.3$  months of therapy with  $43.6 \pm 20.0$  sessions. Only a single patient status post RTSA required supervised physical therapy for delayed return of range of motion because of complex regional pain syndrome, which resolved with therapy and pain management intervention



**Figure 1** Home exercise program prescribed to patients after reverse total shoulder arthroplasty. (A, B) “Hitchhiker” external rotation exercises. Patients are instructed to place the affected elbow on an armrest, to supinate the arm, and to externally rotate at the shoulder for 3 sets of 10. (C, D) Closed chain deltoid exercises. Patients are instructed to make a fist with the affected arm, to place the contralateral hand onto that fist, and then to “punch toward the ceiling” for 3 sets of 10.

**Table I** Demographic details for each cohort

Group	Age (y)	% Female	% Affecting the dominant extremity	Time between injury and surgery in weeks
RTSA	77 ± 6	78	56	3.6 ± 3.6
HA	72 ± 7	75	71	2.2 ± 1.3
ORIF	71 ± 7	75	29	1.7 ± 0.8

RTSA, reverse total shoulder arthroplasty; HA, hemiarthroplasty; ORIF, open reduction and internal fixation.

When appropriate, data are reported as arithmetic means ± standard deviation. No significant differences were seen with independent samples Kruskal-Wallis testing.

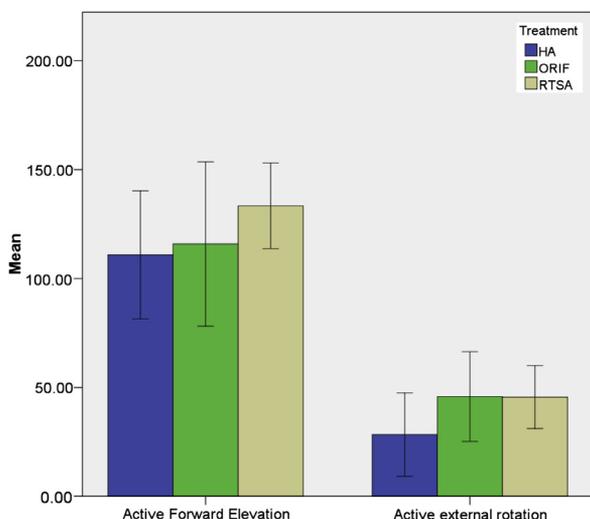
with two stellate ganglion block; thus, as a cohort, these patients underwent  $2.2 \pm 6.7$  sessions, with 8 of the 9 patients undergoing only a home exercise program with no cost.

The time to achieve AFE  $>90^\circ$  was also recorded. All RTSA cases achieved AFE  $>90^\circ$ . Only 4 of 9 in the HA group and 4 of 9 in the ORIF group ever achieved AFE  $>90^\circ$ . The time to achieve this was rapid with RTSA. One

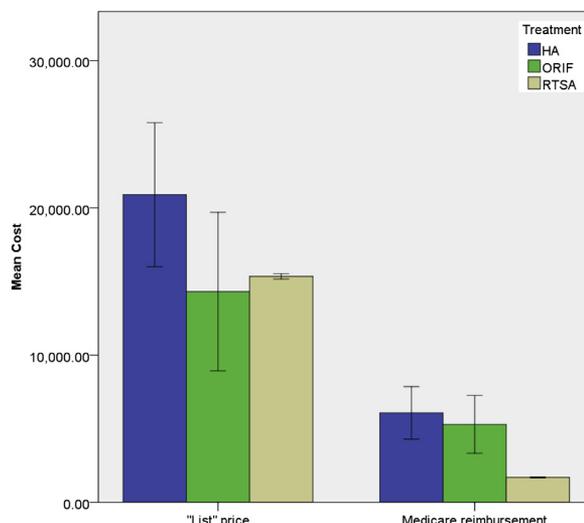
patient in the RTSA group took 14 months to achieve  $90^\circ$  of elevation. If this patient is treated as an outlier in the RTSA group, the other 8 cases achieved the AFE of  $90^\circ$  within an average of 4.2 months. Among the patients who underwent HA, the mean time to achieve  $90^\circ$  of AFE was 6.9 months; and among those who underwent ORIF, the mean time to achieve  $90^\circ$  of AFE was 3.8 months. These data are difficult to interpret because the majority of both the ORIF and HA cohorts did not achieve this goal, and thus no statistical comparison was conducted for this variable.

### Cost analysis

With use of publically available Medicare reimbursement data, when physical therapy and operative reimbursement data were combined, the total cost for HA was  $\$6081 \pm 1784$ ; for ORIF, the total cost was  $\$5296 \pm 1964$ ; and for RTSA, the total cost was  $\$1735 \pm 65$  (Fig. 3;  $P < .001$ ). With use of list prices, when visit numbers and average physical therapy charges were combined with implant prices, the mean total cost was  $\$20,899 \pm 4891$  for HA,  $\$14,321 \pm 5386$  for ORIF, and  $\$15,352 \pm 187$  for RTSA (Fig. 3;  $P = .033$ ).



**Figure 2** Mean active forward elevation and active external rotation for hemiarthroplasty (HA), open reduction and internal fixation (ORIF), and reverse total shoulder arthroplasty (RTSA). Error bars represent 1 standard deviation.



**Figure 3** Mean cost as would have been charged to the individual patients ("List" price) and as reimbursed by Medicare for hemiarthroplasty (HA), open reduction and internal fixation (ORIF), and reverse total shoulder arthroplasty (RTSA). Error bars represent 1 standard deviation.

**Table II** Range of motion at final follow-up for each cohort

Group	AFE	AER	Time to achieve 90° of AFE in months	AIR
RTSA	133 ± 20	41 ± 19	5.4 ± 3.8	46 ± 15
HA	106 ± 29	28 ± 19	6.9 ± 4.0	50 ± 8
ORIF	108 ± 40	46 ± 21	3.8 ± 2.0	42 ± 13

RTSA, reverse total shoulder arthroplasty; HA, hemiarthroplasty; ORIF, open reduction and internal fixation; AFE, active forward elevation; AER, active external rotation; AIR, active internal rotation. Data are reported as arithmetic means ± standard deviation.

**Table III** Quantitative outcomes at final follow-up for each cohort

Group	VAS-pain	SST	ASES	SF-12	SF-12-PCS	SF-12-MCS
RTSA	1 ± 1	7 ± 2	80 ± 11	35 ± 4	44 ± 11	50 ± 10
HA	3 ± 3	7 ± 4	66 ± 31	34 ± 7	42 ± 8	48 ± 3
ORIF	1 ± 1	8 ± 4	75 ± 15	34 ± 6	44 ± 7	53 ± 7

RTSA, reverse total shoulder arthroplasty; HA, hemiarthroplasty; ORIF, open reduction and internal fixation; VAS-pain, visual analogue scale for pain; SST, Simple Shoulder Test; ASES, American Shoulder and Elbow Surgeons score; SF-12, Short-Form 12-item quality of life score; SF-12-PCS, SF-12 physical component score; SF-12-MCS, SF-12 mental component score.

Data are reported as arithmetic means ± standard deviation. No significant differences were seen with independent samples Kruskal-Wallis testing.

**Radiographic outcomes**

Among the patients status post RTSA, there were no radiolucencies at the glenoid baseplate or screws, no scapular notches, and no other radiographic signs of loosening or failure at final follow-up. There were no dislocations.

Among the patients status post HA, anatomic tuberosity reduction and healing were noted in all cases at final follow-up. There were no radiographic signs of loosening of the humeral component. One patient, noted intraoperatively to have a rotator cuff tear, developed proximal migration of the humeral head with residual pain. At the time of final follow-up, this patient did not think that his discomfort was sufficient to warrant further treatment. Among the patients status post ORIF, all went on to radiographic and clinical union, with 2 cases of late displacement of the greater tuberosity.

**Complications**

In the patients status post RTSA, 1 patient developed complex regional pain syndrome, required referral to a pain management specialist, but experienced complete relief with 2 stellate ganglion blocks and pregabalin. Among the patients status post HA, 1 patient developed arthrofibrosis and was offered capsular release but declined. One patient developed ulnar neuritis at the cubital tunnel. Whereas this patient was symptomatic before the injury with exacerbation by sling use, he required ulnar nerve release and transposition, with subsequent complete resolution of his symptoms. Among the patients status post ORIF, 1 patient developed arthrofibrosis and underwent subsequent arthroscopic capsular release and subacromial decompression. This patient then developed avascular necrosis at 2.3 years after fixation and probably will require total shoulder replacement.

**Discussion**

In this series with short-term follow-up, RTSA for treatment of proximal humeral fracture appears to provide range

of motion superior to that of HA and ORIF, with similar ASES scores, SST scores, and SF-12 scores. RTSA provided these outcomes largely without the need for supervised physical therapy, and thus the postoperative costs for ORIF and HA are \$3500 to \$4000 higher as calculated by Medicare reimbursement. With use of list prices, the cost of RTSA is equivalent to that of ORIF and on average \$5000 lower than that of HA. In an appropriately selected patient population, surgeons could consider RTSA as an alternative to HA or ORIF. Patients unable to attend supervised physical therapy but sufficiently motivated for a home exercise program may be particularly good candidates. Larger studies with long-term follow-up will be necessary to confirm these findings.

Whereas no randomized clinical trials have compared ORIF, HA, or RTSA with one another, several previous retrospective studies have compared RTSA with HA and have described functional advantages to RTSA. In a retrospective comparison through the New Zealand Joint Registry including 55 RTSAs and 313 HAs performed for proximal humeral fractures, Boyle et al<sup>8</sup> found significantly better Oxford Shoulder Scores in patients status post RTSA at 5 years of follow-up. In a retrospective comparison of 21 HAs and 19 RTSAs evaluated at a minimum of 6 months, Gallinet et al<sup>15</sup> found significantly better AFE, abduction, and Constant-Murley scores in the RTSA group. In another recent retrospective comparison of 11 RTSAs and 12 HAs evaluated at a minimum of 1.3 years, Garrigues et al<sup>16</sup> found significantly better forward flexion, ASES scores, University of Pennsylvania Shoulder Scores, and Single Assessment Numeric Evaluation scores in the RTSA group. Alternatively, in a retrospective comparison of 10 patients, each of whom underwent HA and RTSA for proximal humeral fractures, Young et al<sup>49</sup> found equivalent ASES scores, Oxford Shoulder Scores, AFE, and active external rotation in both groups.

RTSA was originally considered for proximal humeral fractures because of the poor functional outcomes after HA in some patients.<sup>15,26,29,38,52</sup> Although previous series have demonstrated predictable pain relief with HA,<sup>2,6,10,18,22,25,26,32,33,38,39,44,52</sup> functional results have been less predictable. In particular, significant variability has been noted in AFE at final follow-up.<sup>15,26,29,38,52</sup> Many studies<sup>15,26,29,38,52</sup> have demonstrated that less than 50% of their patients were able to achieve AFE >90°, which is a requirement of Neer's criteria to be classified as a satisfactory outcome.<sup>44</sup> Whereas this degree of functional deficit was not observed in the HA cohort for this study, several larger studies<sup>15,26,29,38,52</sup> have confirmed that inability to achieve AFE >90° may limit the patient's ability to perform activities of daily living and could preclude living independently for some patients.<sup>15</sup> Other low-demand elderly patients appear to tolerate this degree of functional deficit well.<sup>6,45</sup> Several previous studies have demonstrated superior AFE with RTSA compared with HA regardless of tuberosity status.<sup>8,15,41,49</sup>

Significant disagreement exists in the literature as to the risk factors for poor outcome that should lead the surgeon to consider RTSA. Various studies have identified risk factors for failure after HA: likelihood of anatomic tuberosity placement, stability, and healing<sup>2,6,7,32,38,39</sup>; age<sup>18,26,39</sup>; use of a fracture-specific prosthesis<sup>26</sup>; number of medical comorbidities<sup>22</sup>; and whether the procedure was performed as primary fracture treatment or as a salvage after ORIF.<sup>7,30</sup> Of note, in our sample of HAs, a higher rate of anatomic tuberosity healing was observed than has been previously published in the literature,<sup>2,6,7,32,38,39</sup> which could diminish the functional difference between RTSA and HA in our study. Further research will be necessary to identify which patients will be most likely to achieve a poor functional result after HA and could thus be considered for RTSA.

Significant concern remains for the high complication rate after RTSA. Instability has been noted in 4% to 11% of cases,<sup>11,13,14,19,24</sup> infection in 2% to 10% of cases,<sup>13,15,24,47</sup> radiographic signs of glenoid loosening in 2% to 63% of cases,<sup>11,13,24</sup> and scapular notching in 0% to 79% of cases,<sup>9,12,13,15</sup> the clinical significance of which remains largely unknown.<sup>1</sup> In this series, no complications were noted, although the small sample size and relatively short follow-up limit the generalizability of these findings. Despite worrisome radiographic findings, revision rates after RTSA remain at ~10%, although only 6-year follow-up for this indication is available to date.<sup>9,12,13,15</sup>

This study has several limitations. The small sample size raises concern about the generalizability of these findings and increases the likelihood of type II error, especially with respect to functional outcomes. To better quantify this possibility, a post-hoc power analysis was conducted. To achieve an 80% probability of determining a difference in ASES scores given the mean and standard deviations in this sample population, 74 patients (37 patients per group) would need to be recruited into a randomized clinical trial comparing HA with RTSA. Given that one-third this number were recruited in this single-surgeon comparative study in 2 years, such a trial would be easily accomplished with multicenter collaboration or a single busy trauma center and is crucial to determine the optimal treatment of this injury. Despite age and sex matching, because retrospective, nonrandomized study design was used, bias is likely to exist between study cohorts that could contribute to differences between groups. For instance, ORIF patients may tend to be more active and physiologically younger individuals, and thus differences between ORIF and RTSA may be greater than described in this study.

Only short-term follow-up was obtained on patients status post RTSA. In addition, patients status post HA and ORIF had slightly longer follow-up, which may also affect comparisons, although previous authors have noted longer follow-up to be most likely to demonstrate an advantage for RTSA.<sup>8</sup> However, the difference between groups was sufficiently remarkable, especially with respect to the cost differential, at this short-term follow-up that we thought

these findings warranted publication. We intend to observe these cohorts to obtain medium- and long-term follow-up and to continue to prospectively enroll patients to undergo RTSA for proximal humeral fracture. We also do not have preinjury function and range of motion, which could improve cohort matching and could confound our results. Because these patients presented with acute fractures, obtaining a preinjury data point is not feasible. We also did not obtain electromyographic evaluation to confirm axillary nerve function, a potential cause of failure after RTSA and a common concomitant injury occurring in upward of 40% of cases.<sup>27</sup> Another significant limitation for this paper was the limited nature of the cost analysis. Numerous additional factors could be considered to gain a more complete understanding of the costs, such as additional hospital costs, readmission costs, surgeon fees, radiology fees, the need for home health aides, the need for transportation to and from physical therapy, costs due to late complications of RTSA such as glenoid loosening or infection requiring reoperation, and societal costs in terms of lost wages. Whereas these analyses should be performed, they will require larger series with long-term follow-up to create a meaningful picture. In addition, given the equivalent clinical outcomes, no current evidence exists to suggest that these costs would vary. Given the significant differences in cost with this pilot analysis, we thought these results warranted publication to spur further discussion of this issue.

Further research will be necessary to investigate which patients will be most likely to experience an optimal result after RTSA compared with HA and thus to clarify indications. Long-term studies will be necessary to investigate the significance of worrisome glenoid mid-term radiographic findings as well as to determine the longevity of the RTSA implanted for a proximal humeral fracture. Ideally, adequately powered randomized clinical trials with long-term follow-up will be performed to determine the role of RTSA in the treatment of proximal humeral fractures.

## Conclusion

In this small case-control study with short-term follow-up, RTSA appears to provide range of motion superior to that of HA and ORIF. RTSA predictably restored active elevation  $>90^\circ$  in all patients within 4 months, without the need of formal outpatient therapy. RTSA realized significant cost savings to Medicare compared with ORIF and HA.

## Disclaimer

Gregory Nicholson is a paid consultant for Tornier and receives research support from Tornier, Ossur, and Smith

& Nephew. Royalties are received from Innomed, Inc. All the other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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