Outcomes of Reverse Total Shoulder Arthroplasty

Authors:
William B. Ashford, MD
Medical University of South Carolina
ashfordw@musc.edu
Josef K Eichinger, MD
Medical University of South Carolina
eichinge@musc.edu
Richard J. Friedman, MD, FRCSC
Medical University of South Carolina
friedman@musc.edu

Abstract:
Over the past decade, reverse total shoulder arthroplasty (rTSA) utilization has increased dramatically. By 2011, rTSA accounted for one third of shoulder arthroplasties, and as of 2013, rTSA utilization surpassed that of anatomic total shoulder arthroplasty (aTSA) in the Medicare population. This gradual expansion is a result of widening indications for rTSA to include younger patients with cuff arthropathy, primary arthritis, inflammatory arthropathy of the shoulder, comminuted proximal humerus fractures not amenable to surgical fixation, massive cuff tears without cuff tear arthropathy, tumor surgery, and revision of a failed aTSA or HA. This paper will review the outcomes for rTSA in these clinical situations

Introduction

Since its approval by the FDA in 2004, the reverse total shoulder arthroplasty (rTSA) has become an increasingly utilized procedure by orthopedic surgeons in the United States. [1] The original indication for rTSA was primarily the low-demand elderly patient with rotator cuff arthropathy. The problems associated with the early designs of the reverse including component loosening, instability, and scapular notching dampened enthusiasm for expanding its use beyond this specific subset of the population.

The design of the rTSA has improved substantially in the last decade as it relates to prior clinical limitations. Early designs of the rTSA were plagued by glenoid component loosening due to the excessive force transmitted through the prosthesis-glenoid interface. [2] This problem was addressed with the introduction of the Grammont modification to the rTSA in 1985. One important modification included changing the glenoid design to a neckless hemisphere, effectively medializing the center of rotation which both decreased implant-glenoid shear forces while also creating a longer lever arm for the deltoid to function. [3] This provides a stable fulcrum for the deltoid to act as the primary forward flexor and abductor of the humerus in the absence of the rotator cuff. Further modifications of the design by Grammont led to modern designs with greater than 85% survivorship. [4, 5]

Over the past decade rTSA utilization has increased dramatically. The ascent in utilization from 2004 resulted in usage for one third of shoulder arthroplasties by 2011, and as of 2013, rTSA utilization surpassed that of anatomic total shoulder arthroplasty (aTSA) in the Medicare population. [6, 7] This gradual expansion is a result of widening indications for rTSA to include younger patients with cuff arthropathy, primary arthritis, inflammatory arthropathy of the shoulder, comminuted proximal humerus fractures not amenable to surgical fixation, massive cuff tears without cuff tear arthropathy, tumor surgery, and revision of a failed aTSA or HA. The following sections will review the outcomes for rTSA in these clinical situations.

rTSA for young patients with rotator cuff disease

aTSA restores the anatomy of the native glenohumeral joint, therefore allowing the cuff and extrinsic shoulder muscles to power motion and stabilize the shoulder. However, for shoulders lacking the intrinsic stability of a rotator cuff, these prostheses fail rapidly and published results in this population are disappointing. [8-10] In these patients, the use of aTSA has largely been abandoned due to excessive shear forces transmitted through the glenoid. This so-called “rocking horse” effect results in unacceptably high rates of glenoid component loosening and failure. [3, 11-13]

While outcomes of rTSA and aTSA are not significantly different with regards to pain, range of motion, and function, [14, 15] the rTSA demonstrated superior outcomes in patients with insufficient rotator cuff function. [16-25] However, these studies primarily focus on older patients over the age of 70. Concerns about the longevity of the rTSA resulted in hesitancy among many surgeons in adopting this prosthesis for younger, higher demand patients. A multicenter retrospective cohort study by Dillon et al. [26] evaluated shoulder arthroplasty (aTSA, rTSA, HA, and resurfacing) in 504 patients under 59 years compared to 2,477 patients 60 years and older. The mean follow-up was 2.2 years. They found twice the risk of revision arthroplasty in the younger population compared to those 60 years or older and,

specifically, a risk of revision 11 times higher for young patients receiving rTSA compared to young patients receiving aTSA. In patients older than 60, no significant difference existed in revision rates between rTSA and aTSA. They concluded that their findings are consistent with the recommendations of Guery et al. [5] to avoid use rTSA in patients under 70 years old when possible.

Conversely, other studies examining outcomes of rTSA in young patients indicate that these fears may be unsubstantiated or at least over emphasized. Ek et al. [27] examined the medium-term outcomes (5-15 years) of rTSA for patients younger than 65 with massive irreparable tears of the rotator cuff. The mean patient age in the study was 60 years old with a mean follow up of 93 months. They found a significant subjective improvement in satisfaction (subjective shoulder value improved from 23% to 66%) and a substantial gain in overall function (active forward flexion, pain, and strength). The observed complication rate was 37.5%, and 25% required revision surgery. Despite this high complication rate, they concluded that rTSA in this extremely complicated cohort can yield excellent results and that it reliably provides significant improvements in function and satisfaction in the medium to long-term.

These results were supported by a 2014 study by Sershon et al. [28] of young patients (mean age 54 years) undergoing rTSA for a variety of preoperative diagnoses. They compared their patients receiving rTSA for massive irreparable rotator cuff tears with patients in a study of older patients (mean age 71 years) by Muliere et al. [20] with the same etiology and found that functional outcomes were very similar (VAS score, 1.7 vs 1.9; ASES score, 71.8 vs 75.4; SST score, 7.4 vs 6.5). The complication rate was 13.9%. Additionally, a prospective cohort study by Castricini et al. [29] found that younger patients achieved a better Constant-Murley Score (CMS) and postoperative range of motion, and obtained the greatest benefit from rTSA.

A 2013 study by Muh et al. [30] examined early objective outcomes and patient satisfaction of patients younger than 60 years of age who underwent rTSA. In this study, the mean age at time of rTSA was 52 years old with an average follow up of 36.5 months. They found that mean American Shoulder and Elbow Surgeons (ASES) score and visual analog scale (VAS) score for pain improved from 40.0 to 72.5 and 7.5 to 3.0 respectively. In their study, patients undergoing rTSA for rotator cuff insufficiency had the most reproducible increase in function. The percentage of patients who were either very satisfied or satisfied was 81%, which is lower compared to other studies focused on older patients undergoing the procedure (90%-96%). [18, 19, 22] There was a 15% rate of major complications and 11% revision rate in this study. The authors concluded that for the properly selected young patient, the rTSA can be an effective treatment.

In a 2016 study by Samuelsen et al. [31], a cohort of 63 patients ages 50-65 with a mean age of 60 underwent rTSA. The majority of these cases (51) were performed for cuff tear arthropathy. At an average follow up of 3 years, the 2 and 5 year revision-free survival was 99% and 91% respectively and a there was a reoperation rate of 3% and 10%. They found significant improvements in pain, shoulder range of motion and 90% patient satisfaction with the procedure. The complication rate was 9%. Again, the authors acknowledge the need for long-term results to understand late component mechanical problems and loosening in this younger population. This study is significant because it is more current, has a longer follow

up, and the arthroplasties were performed using a modern reverse design. Many of the other studies discussed earlier included patients who received older designs of the prosthesis and complication rates much higher than our current clinical experience.

rTSA for Primary Glenohumeral Osteoarthritis

aTSA has been the operation of choice for patients with glenohumeral osteoarthritis (GHOA) due to its ability to restore function, decrease pain, and its relatively low complication rate. [32-34] In the setting of an intact cuff, the anatomic reconstruction of the glenohumeral joint restores dynamic stability and motion of the shoulder. However, failure of the rotator cuff after aTSA alters this mechanical relationship and can lead to glenoid component loosening, accelerated polyethelene wear, and proximal migration of the humeral head. [12] Secondary rotator cuff tearing is an increasingly recognized complication of aTSA and reports in the the literature for cuff tearing after aTSA range from 1.3% to 16.8%, with longer follow ups correlating to higher cuff dysfunction rate. [35-38] In a 2012 study by Young et al., [38] the authors found that at average follow up of 8.5 years, the rate of rotator cuff dysfunction was 16.8%. The rate of secondary cuff dysfunction at 15 year follow up was 55%. In a subgroup analysis, patients with secondary cuff dysfunction demonstrated worse functional outcomes than those without. These findings have increased interest in the use of rTSA as the primary treatment for GHOA even with intact cuffs, thereby avoiding this problem.

In a 2015 retrospective cohort study, 24 patients who underwent primary rTSA for GHOA were matched to 96 patients who underwent aTSA. These patients were originally scheduled for aTSA but were converted intraoperatively to rTSA due to difficulties with the glenoid component or instability. There was no significant difference in clinical outcomes (ASES and SST) or range of motion after rTSA and aTSA. Follow-up between the groups was similar, average 42 months for rTSA and 49 months for aTSA. 5 of 96 aTSA showed evidence of loosening at final follow-up while none of the rTSA showed evidence of prosthesis loosening. The authors concluded that in the setting of GHOA, rTSA and aTSA have similar functional outcomes at least in the midterm. [39]

In addition to the concern over cuff failure after aTSA, anatomic considerations may also effect choice of rTSA over aTSA. While aTSA has a revision-free survival of 90-95% at 10 years, glenohumeral morphology has been proposed as a parameter that may help predict outcomes. [40-42] In a study evaluating patients with B2 glenoids as defined by the Walch classification, Walch et al. [43] evaluated 92 aTSAs and found a 66.3% rate of patient satisfaction at an average of 77 months follow up. In this series, glenoid loosening was found in 20.6%, and the revision rate was 16.3%. The authors concluded that while aTSA may offer acceptable clinical outcomes in patients with GHOA, there is a high rate of complications, particularly in patients with a retroverted glenoid and posterior subluxation. A recent study by Chin et al. [44] confirms this high rate of glenoid radiolucencies in B2 glenoids, with a rate of 47.9% at mean 60 months. Thus, the rTSA has been postulated to be a potential solution for the patient with GHOA and glenoid deformity.

Mizuno et al. [45] retrospectively studied a group of 27 rTSA performed for a primary diagnosis of GHOA and biconcave glenoid. At a mean follow up of 54 months, Constant scores and functional scores increased significantly. There was a 15% complication rate

with a 4% revision rate, and 37% showed evidence of scapular notching. At final follow-up, 93% of patients were either satisfied or very satisfied with their results. They concluded that rTSA can yield excellent results in this patient population. However, the short follow-up in this study is a significant limitation.

The use of rTSA for patients with GHOA is an area that needs considerably more investigation as there is insufficient long term follow-up data on this topic. However, some experienced surgeons suggest that the rTSA is a reliable, and in some cases preferable, alternative to aTSA in patients with primary GHOA. [39, 40, 43, 45]

rTSA for Fractures of the Proximal Humerus

Fractures of the proximal humerus are common in the elderly with osteoporotic bone, accounting for the third most common fracture seen in orthopedic clinics. [46] Surgical treatment options for these fractures include open reduction with internal fixation (ORIF), percutaneous fixation, HA, aTSA and more recently, rTSA. For young patients with simple fracture patterns, many surgeons prefer ORIF. For elderly patients with complex fractures, the treatment of choice has traditionally been HA, which has inconsistent results. [47] However, for osteoporotic proximal humerus fractures, complex fractures, and elderly patients, there is mounting evidence that rTSA is a promising alternative to conventional treatments and its use in this population is supported by current literature. [16, 48-57]

Healing of the fractured tuberosity dramatically impacts outcomes for HA, [58-61] and in the elderly patient population, medical comorbidities frequently predispose to nonunion. While some studies have indicated that tuberosity healing portends superior results, it is not a prerequisite to good functional outcomes in patients undergoing rTSA. [1, 48, 55, 62] Therefore, it has been postulated that in patients such as elderly patients and those with complex fractures of the proximal humerus who may be predisposed to fracture nonunion/malunion or ORIF is not feasible, rTSA may be a better option than HA.

Bufquin et al. [48] presented mid-term results (mean 22 months) for 43 three and four-part proximal humerus fractures treated with rTSA. Pain relief was the most dramatic improvement for these patients, and the authors concluded functional outcomes were satisfactory compared to HA. However, there was a complication rate of 28% in this study. This contrasts with a prospective, randomized controlled Level I study done by Sebastia-Forcada et al. [57] which found that patients undergoing rTSA for complex proximal humerus fractures experienced superior outcomes with regards to pain and function, and also had lower revision rates. These findings were supported by Cuff et al. [51] in a 2013 study which found higher outcome scores as well as satisfaction scores in the rTSA group than the HA group for comminuted proximal humerus fractures in the elderly. These findings concurred with a 2016 study by Grubhofer et al. [53], which retrospectively reviewed clinical and radiographic outcomes of 52 shoulders undergoing primary rTSA for acute, complex fractures of the proximal humerus. The mean age in their study was 77 years and the mean follow up was 35 months. They found a mean relative constant score of 86% and a mean subjective Shoulder Value of 83%. 92% rated their outcome as excellent or good, and the revision rate was 7.7%. The conclusion of this study was that rTSA can provide predictably good clinical results with low complication rates and rapid postoperative recovery of pain-free function in this patient population.

rTSA for Inflammatory Arthropathies of the Glenohumeral Joint

The pathoanatomy of rheumatoid arthritis (RA) has spurred interest in rTSA as an alternative to aTSA (currently considered the gold standard) in this population. RA is a disease which damages both dynamic and static soft tissue stabilizers of the glenohumeral joint, induces cuff dysfunction, and decreases glenoid bone stock. (Figure 1A) In essence, it is a disease that produces many of the anatomical factors that predispose to inferior outcomes with traditional, unconstrainted aTSA.

Figure 1A: Preoperative AP of the left shoulder in a 54-year-old female with RA showing superomedial erosion and severe arthritis. Her cuff is non-functioning

Figure 1B: The same patient as figure 1A status post rTSA with a superior augment that re-orients the glenoid to correct superior tilt and lateralizes the humerus

Several studies have shown that despite moderate pain relief, aTSA does not offer reliable improvements in function or range of motion for these patients, mainly due to rotator cuff involvement. A study that evaluated the outcomes of aTSA performed for RA with a mean 5 year follow up found that while improvements in pain, ROM, and function were all statistically significant, pain was the only factor that appeared to be clinically significant. [63] Additionally, medium and long-term outcomes of aTSA in this population leave room for improvement. In one study, radiolucencies were found in 23 of 37 glenoid components (62%) at an average 9.5 year follow-up, and a high percentage of those represented progressive changes. The authors also found that 57% of the aTSA had superior subluxation of the humeral components. There was a revision rate of 8.6% in their series. [64] Interestingly, in a follow up study performed in 2009 on the same patient sample at an average 19.8 year follow-up, Betts et al. [65] evaluated 14 shoulders in 12 surviving patients from the original group of 49 patients. 11 of the remaining 14 shoulders had radiolucency of the glenoid components and all of the shoulders showed superior migration of the humeral component. They noted that while

pain, ROM, and function remained reasonable, there was a noted decline from their 9.5 year follow-up to the 19.8 year follow-up.

While literature remains sparse on this topic and the available studies are small, there is increasing interest in rTSA for this patient population as it provides a higher degree of constraint and is less reliant on soft tissue such as rotator cuff and capsule. Holcomb et al. [66] prospectively evaluated 21 shoulders after rTSA in patients with RA. At a mean of 2.5 year follow-up, pain, function, and ROM improved significantly. 18 of the 21 rated their outcome as good or excellent. These results were supported by a later study by Young et al. [67], which found similar improvements in function and ROM at mean follow-up of 3.8 years. 17 of the 18 patients in the study rated their outcomes as good or excellent. However, the authors did report a high rate of scapular notching (55%) and perioperative fracture (22%). Similarly, a 2012 retrospective review of 19 RA patients who had undergone rTSA found improved function, pain, and ROM, and noted that the ROM improvement was superior to the typical range reported after anatomical replacements in other studies. [68] The findings of these studies reinforce findings from other published studies that show promising results with rTSA for patients with RA. [69-71]

While iatrogenic fractures, radiographic loosening, scapular notching, and high revision rates are areas of concern, rTSA for the rheumatoid population has shown favorable functional outcomes in the short, medium, and long term. (Figure 1B) This is encouraging, as the previous gold standard treatment with aTSA has left much to be desired.

rTSA for Revision of Failed Shoulder Arthroplasty

Revision of failed HA and aTSA presents a challenge due to altered bony and soft tissue anatomy, and revision surgery is associated with inferior outcomes compared to primary shoulder arthroplasty. [72-76]

In 2009, Sajadi et al. [77] retrospectively evaluated 35 patients who underwent revision of aTSA or HA using a rTSA, and found that all measured outcomes including pain, function, and ROM were significantly improved after revision. They noted a 71% satisfaction rate. However, they did have a wide variability in the outcomes. They subdivided the patients into 2 groups based on failure rates. The first group included patients who had revision due to glenoid erosion or component loosening and the second group for infection, instability, or other soft tissue dysfunction. They found that patients who were revised for glenoid erosion or component loosening did significantly better than those with infection or soft tissue problems.

In a 2015 systematic review, Randelli et al. [78] analyzed 226 patients from 9 studies and reported on outcomes for revision shoulder replacement after failure of the primary implant (HA or aTSA) due to rotator cuff insufficiency. Their findings supported the findings of others that outcomes for revision with rTSA were inferior to those obverted after primary rTSA and the observed revision rate was 28%. However, patients did have significant improvements in pain and functional outcomes, thus positively affecting patient quality of life. The authors concluded that revision of failed HA and aTSA with rTSA is valid and sometimes the only available option.

While rTSA has gained popularity recently for revision of failed HA, a recent study by Hartel et al. [79] reviewed 19 patients with failed HA who underwent revision with either a aTSA (7 patients) or rTSA (12 patients) for a

variety of indications including glenoid erosion, humeral component malposition, and cuff pathology. They found that while overall outcomes were poor to reasonable, results with aTSA were generally better than with rTSA for all clinical outcome measures including Constant, DASH, DSST, OSS, and SF-36 scores.

rTSA for revision of a failed prior arthroplasty is a reasonable option. However, it is fraught with complications and high revision rates even in experienced hands. In many instances, rTSA may be the only available option for these challenging cases.

rTSA for Chronic Shoulder Instability and Dislocations

Patients with chronic shoulder instability present a challenging population for the orthopedic surgeon. While there is no literature that we are aware of that specifically evaluates rTSA in this population, the resulting damage to soft tissues and bony architecture of the glenohumeral joint in chronically unstable shoulders likely makes aTSA a challenge for these patients. The higher degree of constraint of the rTSA design is an attractive option for this reason. Again, while data on outcomes for patients with chronic instability is lacking, it seems likely that arthroplasty in these patients will have inferior outcomes given the typically high number of previous operations as well as damage to surrounding bone and soft tissues. However, more investigation for this indication is warranted.

Chronic dislocations of the shoulder are also problematic. Reconstructive options for these patients include HA, asymmetric reaming with or without bone grafting, and 2 staged reconstructions of the glenoid. These patients frequently have cuff deficiency, capsular contractures and redundancies, muscle dysfunction, and advanced glenoid bone loss. For this reason, rTSA is emerging as an attractive alternative to HA and traditional aTSA.

The use of HA or aTSA for chronic dislocations has disappointing results as there is a high rate of instability, glenoid loosening, and failure. In 2006, Matsoukis et al. [80] reported on 11 shoulders at a mean 4 year follow up after undergoing HA or aTSA for fixed anterior shoulder dislocations. They found that while pain relief was substantial and 8 of the 11 patients reported good to excellent results, function and range of motion fared poorly when compared with patients who undergo arthroplasty for primary osteoarthritis. Additionally, they noted a complication rate of 45% including 36% with recurrent instability and a revision rate of 18%. Similar results were obtained by several authors reporting consistent improvements in pain but with limited improvements in function, ROM for locked posterior shoulder dislocations. [81-85]

A recent review by Werner et al. [86] of 21 patients treated with rTSA and bone grafting for chronic anterior dislocation demonstrated improved constant scores (5.7 to 57.2) and improved elevation and abduction. 18 of the 21 patients rated their outcomes as good or excellent. No patients experienced recurrent instability but 2 of the 21 patients had loosening of the glenoid component requiring revision.

rTSA is an inherently attractive option for these patients given the high incidence of soft tissue deficiency and glenoid deficiency. While more inquiry is needed to determine the long-term outcomes, rTSA may be more effective for patients with chronic shoulder dislocations than HA or TSA.

rTSA for Proximal Humeral Tumors

The proximal humerus is the second most common site for malignant tumors and in most cases must be resected with wide margins. In these instances, reconstruction can be difficult, especially when the rotator cuff must be sacrificed. Prior reconstructive options have included arthrodesis with allograft or autograft, osteoarticular allografts, endoprostheses, or allograft-prosthetic composites using allograft and either stemmed or resurfacing HA. [87] When the axillary nerve and deltoid function can be maintained, rTSA is an option for reconstruction. Due to the rarity of the problem, the available studies are small, the largest of which evaluated 10 patients, and there are currently no randomized or prospective trials on this topic that we are aware of.

In 2015, Bonnevialle et al. [88] reviewed 10 patients who underwent rTSA after transarticular resection of a malignant tumor. At a mean follow up of 42 months, the mean Constant score was 52, with a mean forward active elevation of 122 degrees. However, the complication rate was high, with a third of patients experiencing instability. They concluded that while the high complication rate is worrisome, rTSA seems to be an acceptable option to preserve function. Kaa et al. [89] reached a similar conclusion in their study, which evaluated 10 patients with a mean follow up of 46 months and found a mean forward flexion of 98 degrees, and subjective shoulder value (SSV) scores of 58%. A 2016 study by Guven et al. [90] also evaluated 10 patients undergoing rTSA after proximal humeral resection for tumor and reported a mean constant score of 53%, with active forward elevation of 96 degrees, and a visual analog scale score of 1.3. DeWilde et al. [91] had slightly better results with a mean active abduction of 157 degrees and mean Constant score of 76%.

While scarce, the available literature seems to suggest that rTSA is a viable option for reconstruction after resection of the proximal humerus for malignant tumors. This is an emerging indication and further head-to-head comparisons with other treatment options as well as long-term follow up is needed.

Summary

The rTSA is gaining popularity recently for a wide range of indications beyond its original use in the elderly, low-demand patient with osteoarthritis and deficient rotator cuffs. There is an abundance of literature to suggest that rTSA has favorable outcomes compared to aTSA and HA in the primary setting and for rotator cuff deficient shoulders. However, for many of the emerging indications, including young patients with irreparable rotator cuff disease, primary glenohumeral arthritis, fractures of the proximal humerus, inflammatory arthropathy of the glenohumeral joint, revision of failed HA and aTSA, chronic shoulder instability and dislocations, and proximal humeral tumors, the outcomes are improved over aTSA. rTSA seems to offer a reliable reconstructive option for these indications despite higher complication and reoperation rates in the medium term.

References

1. Urch, E., J.S. Dines, and D.M. Dines, *Emerging Indications for Reverse Shoulder Arthroplasty.* Instr Course Lect, 2016. **65**: p. 157-69.
2. Post, M., *Constrained arthroplasty: its use and misuse.* Semin Arthroplasty, 1990. **1**(2): p. 151-9.
3. Boileau, P., et al., *Grammont reverse prosthesis: design, rationale, and biomechanics.* J Shoulder Elbow Surg, 2005. **14**(1 Suppl S): p. 147s-161s.
4. Favard, L., et al., *Reverse prostheses in arthropathies with cuff tear: are survivorship and function maintained over time?* Clin Orthop Relat Res, 2011. **469**(9): p. 2469-75.
5. Guery, J., et al., *Reverse total shoulder arthroplasty. Survivorship analysis of eighty replacements followed for five to ten years.* J Bone Joint Surg Am, 2006. **88**(8): p. 1742-7.
6. Day, J.S., et al., *Use of reverse total shoulder arthroplasty in the Medicare population.* J Shoulder Elbow Surg, 2015. **24**(5): p. 766-72.
7. Westermann, R.W., et al., *Reverse Shoulder Arthroplasty in the United States: A Comparison of National Volume, Patient Demographics, Complications, and Surgical Indications.* Iowa Orthop J, 2015. **35**: p. 1-7.
8. Brostrom, L.A., et al., *The Kessel prosthesis in total shoulder arthroplasty. A five-year experience.* Clin Orthop Relat Res, 1992(277): p. 155-60.
9. Coughlin, M.J., J.M. Morris, and W.F. West, *The semiconstrained total shoulder arthroplasty.* J Bone Joint Surg Am, 1979. **61**(4): p. 574-81.
10. Post, M., S.S. Haskell, and M. Jablon, *Total shoulder replacement with a constrained prosthesis.* J Bone Joint Surg Am, 1980. **62**(3): p. 327-35.
11. Arntz, C.T., S. Jackins, and F.A. Matsen, 3rd, *Prosthetic replacement of the shoulder for the treatment of defects in the rotator cuff and the surface of the glenohumeral joint.* J Bone Joint Surg Am, 1993. **75**(4): p. 485-91.
12. Franklin, J.L., et al., *Glenoid loosening in total shoulder arthroplasty. Association with rotator cuff deficiency.* J Arthroplasty, 1988. **3**(1): p. 39-46.
13. Pollock, R.G., et al., *Prosthetic replacement in rotator cuff-deficient shoulders.* J Shoulder Elbow Surg, 1992. **1**(4): p. 173-86.
14. Flurin, P.H., et al., *A Comparison and Correlation of Clinical Outcome Metrics in Anatomic and Reverse Total Shoulder Arthroplasty.* Bull Hosp Jt Dis (2013), 2015. **73 Suppl 1**: p. S118-23.
15. Triplet, J.J., et al., *Anatomic and Reverse Total Shoulder Arthroplasty in Patients Older Than 80 Years.* Orthopedics, 2015. **38**(10): p. e904-10.
16. Boileau, P., et al., *Neer Award 2005: The Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty.* J Shoulder Elbow Surg, 2006. **15**(5): p. 527-40.
17. Ecklund, K.J., et al., *Rotator cuff tear arthropathy.* J Am Acad Orthop Surg, 2007. **15**(6): p. 340-9.
18. Frankle, M., et al., *The Reverse Shoulder Prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients.* J Bone

Joint Surg Am, 2005. **87**(8): p. 1697-705.

19. Mole, D. and L. Favard, *[Excentered scapulohumeral osteoarthritis]*. Rev Chir Orthop Reparatrice Appar Mot, 2007. **93**(6 Suppl): p. 37-94.
20. Mulieri, P., et al., *Reverse shoulder arthroplasty for the treatment of irreparable rotator cuff tear without glenohumeral arthritis.* J Bone Joint Surg Am, 2010. **92**(15): p. 2544-56.
21. Nolan, B.M., E. Ankerson, and J.M. Wiater, *Reverse total shoulder arthroplasty improves function in cuff tear arthropathy*. Clin Orthop Relat Res, 2011. **469**(9): p. 2476-82.
22. Sirveaux, F., et al., *Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders.* J Bone Joint Surg Br, 2004. **86**(3): p. 388-95.
23. Wall, B., et al., *Reverse total shoulder arthroplasty: a review of results according to etiology.* J Bone Joint Surg Am, 2007. **89**(7): p. 1476-85.
24. Werner, C.M., et al., *Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis.* J Bone Joint Surg Am, 2005. **87**(7): p. 1476-86.
25. Young, S.W., et al., *The SMR reverse shoulder prosthesis in the treatment of cuff-deficient shoulder conditions.* J Shoulder Elbow Surg, 2009. **18**(4): p. 622-6.
26. Dillon, M.T., et al., *Shoulder arthroplasty in patients 59 years of age and younger*. J Shoulder Elbow Surg, 2013. **22**(10): p. 1338-44.
27. Ek, E.T., et al., *Reverse total shoulder arthroplasty for massive irreparable rotator cuff tears in patients younger than 65 years old: results after five to fifteen years.* J Shoulder Elbow Surg, 2013. **22**(9): p. 1199-208.
28. Sershon, R.A., et al., *Clinical outcomes of reverse total shoulder arthroplasty in patients aged younger than 60 years.* J Shoulder Elbow Surg, 2014. **23**(3): p. 395-400.
29. Castricini, R., et al., *Health-related quality of life and functionality after reverse shoulder arthroplasty.* J Shoulder Elbow Surg, 2013. **22**(12): p. 1639-49.
30. Muh, S.J., et al., *Early follow-up of reverse total shoulder arthroplasty in patients sixty years of age or younger*. J Bone Joint Surg Am, 2013. **95**(20): p. 1877-83.
31. Samuelsen, B.T., et al., *Primary reverse shoulder arthroplasty in patients aged 65 years or younger*. J Shoulder Elbow Surg, 2016.
32. Favard, L., et al., *Total shoulder arthroplasty - arthroplasty for glenohumeral arthropathies: results and complications after a minimum follow-up of 8 years according to the type of arthroplasty and etiology.* Orthop Traumatol Surg Res, 2012. **98**(4 Suppl): p. S41-7.
33. Godeneche, A., et al., *Prosthetic replacement in the treatment of osteoarthritis of the shoulder: early results of 268 cases*. J Shoulder Elbow Surg, 2002. **11**(1): p. 11-8.
34. Norris, T.R. and J.P. Iannotti, *Functional outcome after shoulder arthroplasty for primary osteoarthritis:*

a multicenter study. J Shoulder Elbow Surg, 2002. **11**(2): p. 130-5.

35. Chin, P.Y., et al., *Complications of total shoulder arthroplasty: are they fewer or different?* J Shoulder Elbow Surg, 2006. **15**(1): p. 19-22.
36. Levy, D.M., et al., *Rotator cuff tears after total shoulder arthroplasty in primary osteoarthritis: A systematic review.* Int J Shoulder Surg, 2016. **10**(2): p. 78-84.
37. Wirth, M.A. and C.A. Rockwood, Jr., *Complications of total shoulder-replacement arthroplasty.* J Bone Joint Surg Am, 1996. **78**(4): p. 603-16.
38. Young, A.A., et al., *Secondary rotator cuff dysfunction following total shoulder arthroplasty for primary glenohumeral osteoarthritis: results of a multicenter study with more than five years of follow-up.* J Bone Joint Surg Am, 2012. **94**(8): p. 685-93.
39. Steen, B.M., et al., *Outcome and value of reverse shoulder arthroplasty for treatment of glenohumeral osteoarthritis: a matched cohort.* J Shoulder Elbow Surg, 2015. **24**(9): p. 1433-41.
40. Denard, P.J. and G. Walch, *Current concepts in the surgical management of primary glenohumeral arthritis with a biconcave glenoid.* J Shoulder Elbow Surg, 2013. **22**(11): p. 1589-98.
41. Singh, J.A., J.W. Sperling, and R.H. Cofield, *Revision surgery following total shoulder arthroplasty: analysis of 2588 shoulders over three decades (1976 to 2008).* J Bone Joint Surg Br, 2011. **93**(11): p. 1513-7.
42. Young, A., et al., *A multicentre study of the long-term results of using a flat-back polyethylene glenoid component in shoulder replacement for primary osteoarthritis.* J Bone Joint Surg Br, 2011. **93**(2): p. 210-6.
43. Walch, G., et al., *Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid.* J Shoulder Elbow Surg, 2012. **21**(11): p. 1526-33.
44. Chin, P.C., et al., *Outcomes of anatomic shoulder arthroplasty in primary osteoarthritis in type B glenoids.* J Shoulder Elbow Surg, 2015. **24**(12): p. 1888-93.
45. Mizuno, N., et al., *Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid.* J Bone Joint Surg Am, 2013. **95**(14): p. 1297-304.
46. Badman, B.L. and M. Mighell, *Fixed-angle locked plating of two-, three-, and four-part proximal humerus fractures.* J Am Acad Orthop Surg, 2008. **16**(5): p. 294-302.
47. Antuna, S.A., J.W. Sperling, and R.H. Cofield, *Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up.* J Shoulder Elbow Surg, 2008. **17**(2): p. 202-9.
48. Bufquin, T., et al., *Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up.* J Bone Joint Surg Br, 2007. **89**(4): p. 516-20.
49. Cazeneuve, J.F. and D.J. Cristofari, *Grammont reversed prosthesis for acute complex fracture of the proximal humerus in an elderly population with 5 to 12 years follow-up.* Orthop Traumatol Surg Res, 2014. **100**(1): p. 93-7.

50. Chalmers, P.N., et al., *Reverse total shoulder arthroplasty for acute proximal humeral fracture: comparison to open reduction-internal fixation and hemiarthroplasty.* J Shoulder Elbow Surg, 2014. **23**(2): p. 197-204.
51. Cuff, D.J. and D.R. Pupello, *Comparison of hemiarthroplasty and reverse shoulder arthroplasty for the treatment of proximal humeral fractures in elderly patients.* J Bone Joint Surg Am, 2013. **95**(22): p. 2050-5.
52. Ferrel, J.R., T.Q. Trinh, and R.A. Fischer, *Reverse total shoulder arthroplasty versus hemiarthroplasty for proximal humeral fractures: a systematic review.* J Orthop Trauma, 2015. **29**(1): p. 60-8.
53. Grubhofer, F., et al., *Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly.* J Shoulder Elbow Surg, 2016.
54. Kaisidis, A., et al., *Reverse shoulder arthroplasty for the treatment of three and four part fractures of the proximal humerus in patients older than 75 years old.* Acta Orthop Belg, 2014. **80**(1): p. 99-105.
55. Klein, M., et al., *Treatment of comminuted fractures of the proximal humerus in elderly patients with the Delta III reverse shoulder prosthesis.* J Orthop Trauma, 2008. **22**(10): p. 698-704.
56. Mata-Fink, A., et al., *Reverse shoulder arthroplasty for treatment of proximal humeral fractures in older adults: a systematic review.* J Shoulder Elbow Surg, 2013. **22**(12): p. 1737-48.
57. Sebastia-Forcada, E., et al., *Reverse shoulder arthroplasty versus hemiarthroplasty for acute proximal humeral fractures. A blinded, randomized, controlled, prospective study.* J Shoulder Elbow Surg, 2014. **23**(10): p. 1419-26.
58. Boileau, P., et al., *Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus.* J Shoulder Elbow Surg, 2002. **11**(5): p. 401-12.
59. Boileau, P., et al., *Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus.* J Shoulder Elbow Surg, 2001. **10**(4): p. 299-308.
60. Mighell, M.A., et al., *Outcomes of hemiarthroplasty for fractures of the proximal humerus.* J Shoulder Elbow Surg, 2003. **12**(6): p. 569-77.
61. Noyes, M.P., et al., *Functional and radiographic long-term outcomes of hemiarthroplasty for proximal humeral fractures.* J Shoulder Elbow Surg, 2011. **20**(3): p. 372-7.
62. Jones, K.J., et al., *Management of proximal humerus fractures utilizing reverse total shoulder arthroplasty.* Curr Rev Musculoskelet Med, 2013. **6**(1): p. 63-70.
63. Trail, I. and D. Nuttall, *The results of shoulder arthroplasty in patients with rheumatoid arthritis.* Bone & Joint Journal, 2002. **84**(8): p. 1121-1125.
64. Stewart, M. and I. Kelly, *Total shoulder replacement in rheumatoid disease.* Bone & Joint Journal, 1997. **79**(1): p. 68-72.
65. Betts, H., et al., *Total shoulder replacement in rheumatoid disease.* Bone & Joint Journal, 2009. **91**(9): p. 1197-1200.

66. Holcomb, J.O., et al., *Reverse shoulder arthroplasty in patients with rheumatoid arthritis.* Journal of Shoulder and Elbow Surgery, 2010. **19**(7): p. 1076-1084.
67. Young, A.A., et al., *Early results of reverse shoulder arthroplasty in patients with rheumatoid arthritis.* J Bone Joint Surg Am, 2011. **93**(20): p. 1915-23.
68. Hattrup, S.J., et al., *Reverse shoulder replacement for patients with inflammatory arthritis.* J Hand Surg Am, 2012. **37**(9): p. 1888-94.
69. Ekelund, A. and R. Nyberg, *Can reverse shoulder arthroplasty be used with few complications in rheumatoid arthritis?* Clinical Orthopaedics and Related Research®, 2011. **469**(9): p. 2483-2488.
70. John, M., et al., *Short-term results after reversed shoulder arthroplasty (Delta III) in patients with rheumatoid arthritis and irreparable rotator cuff tear.* International orthopaedics, 2010. **34**(1): p. 71-77.
71. Rittmeister, M. and F. Kerschbaumer, *Grammont reverse total shoulder arthroplasty in patients with rheumatoid arthritis and nonreconstructible rotator cuff lesions.* Journal of Shoulder and Elbow Surgery, 2001. **10**(1): p. 17-22.
72. Cheung, E.V., J.W. Sperling, and R.H. Cofield, *Revision shoulder arthroplasty for glenoid component loosening.* J Shoulder Elbow Surg, 2008. **17**(3): p. 371-5.
73. Deutsch, A., et al., *Clinical results of revision shoulder arthroplasty for glenoid component loosening.* J Shoulder Elbow Surg, 2007. **16**(6): p. 706-16.
74. Dines, J.S., et al., *Outcomes analysis of revision total shoulder replacement.* J Bone Joint Surg Am, 2006. **88**(7): p. 1494-500.
75. Petersen, S.A. and R.J. Hawkins, *Revision of failed total shoulder arthroplasty.* Orthop Clin North Am, 1998. **29**(3): p. 519-33.
76. Sperling, J.W. and R.H. Cofield, *Revision total shoulder arthroplasty for the treatment of glenoid arthrosis.* J Bone Joint Surg Am, 1998. **80**(6): p. 860-7.
77. Sajadi, K.R., Y.W. Kwon, and J.D. Zuckerman, *Revision shoulder arthroplasty: an analysis of indications and outcomes.* J Shoulder Elbow Surg, 2010. **19**(2): p. 308-13.
78. Randelli, P., et al., *Revision reverse shoulder arthroplasty in failed shoulder arthroplasties for rotator cuff deficiency.* Joints, 2015. **3**(1): p. 31-7.
79. Hartel, B.P., et al., *Difference in clinical outcome between total shoulder arthroplasty and reverse shoulder arthroplasty used in hemiarthroplasty revision surgery.* Int J Shoulder Surg, 2015. **9**(3): p. 69-73.
80. Matsoukis, J., et al., *Primary unconstrained shoulder arthroplasty in patients with a fixed anterior glenohumeral dislocation.* J Bone Joint Surg Am, 2006. **88**(3): p. 547-52.
81. Cheng, S.L., M.B. Mackay, and R.R. Richards, *Treatment of locked posterior fracture-dislocations of the shoulder by total shoulder arthroplasty.* J Shoulder Elbow Surg, 1997. **6**(1): p. 11-7.
82. Gavriilidis, I., et al., *Chronic locked posterior shoulder dislocation with severe head involvement.* Int Orthop, 2010. **34**(1): p. 79-84.
83. Schliemann, B., et al., *Locked posterior shoulder dislocation: treatment options*

and clinical outcomes. Arch Orthop Trauma Surg, 2011. **131**(8): p. 1127-34.

84. Sperling, J.W., et al., *Shoulder arthroplasty for locked posterior dislocation of the shoulder.* J Shoulder Elbow Surg, 2004. **13**(5): p. 522-7.
85. Wooten, C., et al., *Anatomic shoulder arthroplasty as treatment for locked posterior dislocation of the shoulder.* J Bone Joint Surg Am, 2014. **96**(3): p. e19.
86. Werner, B.S., et al., *Glenoid bone grafting in reverse shoulder arthroplasty for long-standing anterior shoulder dislocation.* J Shoulder Elbow Surg, 2014. **23**(11): p. 1655-61.
87. King, J.J., et al., *Allograft-prosthetic composite reverse total shoulder arthroplasty for reconstruction of proximal humerus tumor resections.* J Shoulder Elbow Surg, 2016. **25**(1): p. 45-54.
88. Bonnevialle, N., et al., *Reverse shoulder arthroplasty for malignant tumors of proximal humerus.* J Shoulder Elbow Surg, 2015. **24**(1): p. 36-44.
89. Kaa, A.K., et al., *Reverse shoulder replacement after resection of the proximal humerus for bone tumours.* Bone Joint J, 2013. **95-b**(11): p. 1551-5.
90. Guven, M.F., et al., *Functional outcome of reverse shoulder tumor prosthesis in the treatment of proximal humerus tumors.* J Shoulder Elbow Surg, 2016. **25**(1): p. e1-6.
91. De Wilde, L., P. Boileau, and H. Van der Bracht, *Does reverse shoulder arthroplasty for tumors of the proximal humerus reduce impairment?* Clin Orthop Relat Res, 2011. **469**(9): p. 2489-95.

