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Impact of fatty infiltration of the rotator cuff on reverse total shoulder arthroplasty outcomes: a systematic review

Sarah N. Powell¹, BS; Brendan M. Lilley, BA²; Annalise M. Peebles, BA³; Travis J. Dekker, MD⁴, Jon J.P. Warner, MD⁵; Anthony A. Romeo, MD⁶; Patrick J. Denard, MD⁷; Matthew T. Provencher, MD³,⁸

¹Georgetown University School of Medicine, Washington, D.C., USA
²Frank H. Netter MD School of Medicine, North Haven, CT, USA
³The Steadman Philippon Research Institute, Vail, CO, USA
⁴Eglin Air Force Base, 96th Medical Group, United States Air Force, Eglin, FL, USA
⁵Massachusetts General Hospital, Boston, MA, USA
⁶Department of Orthopaedic Surgery, DuPage Medical Group, Chicago, IL, USA
⁷Southern Oregon Orthopedics, Medford, OR, USA
⁸The Steadman Clinic, Vail, CO, USA

Corresponding Author:
Matthew T. Provencher, M.D., 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA
mprovencher@thesteadmanclinic.com

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Abstract

Background: The impact of preoperative fatty infiltration of specific rotator cuff muscles on the outcomes of rTSA has not been well defined.

Hypothesis: Preoperative fatty infiltration of the shoulder musculature will negatively affect rTSA outcomes.

Methods: A comprehensive literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) using PubMed, Embase, OVID Medline, Scopus, Cinahl, Web of Science, and Cochrane databases for original, English-language studies evaluating effect of fatty infiltration of shoulder musculature on rTSA outcomes published from January 1st, 2000 to present. Blinded reviewers conducted multiple screens. All included studies were graded based on level of evidence and data concerning patient demographics and postoperative outcomes were extracted.

Results: A total of 11 articles were included, including one Level I, three Level III, and seven Level IV. The review consisted of 720 patients and 731 shoulders (320 females, 157 males), with a mean age of 72.4 years. A single deltopectoral approach was performed for a majority of studies (627/731 shoulders), followed by superolateral approach (70/731 shoulders) and single transdeltoid approach (4/731 patients). 11 studies reported data specifically about preoperative fatty infiltration of the rotator cuff musculature; the teres minor was studied most widely (298/731 shoulders), followed by the subscapularis (256/731 shoulders) and infraspinatus...
(232/731 shoulders). The Constant score (562/731 shoulders), and ASES (284/731 shoulders) were the most common recorded outcome scores. Fatty infiltration of the teres minor, supraspinatus, and infraspinatus were associated with worse range of motion after rTSA.

**Conclusion:** Preoperative fatty infiltration of the rotator cuff, particularly of the teres minor and infraspinatus, has a negative impact on subjective patient outcomes and restoration of range of motion, especially external rotation, after rTSA. The impact of fatty infiltration of the other rotator cuff muscles remains unclear, which may be due to inter-surgeon differences in the handling of the remaining rotator cuff muscles or differences in implant design. The evaluated literature provides information upon which patients can be educated about probable outcomes and restoration of function after rTSA.

**Keywords:** rTSA, reverse total shoulder arthroplasty, fatty infiltration, postoperative outcomes

**Level of Evidence:** Level IV; Review Article

Traditionally, massive or irreparable rotator cuff tears have been treated surgically by total shoulder arthroplasty (TSA), in which the humeral head and glenoid cavity are replaced with prostheses in order to reduce pain and increase active range of motion (ROM). Reverse total shoulder arthroplasty (rTSA) has grown in popularity in recent years, with its alternative design relying on re-engineering shoulder dynamics -- augmenting the moment arm of the deltoid to better enable forward elevation and abduction -- to create an effective joint in the absence of a sufficient rotator cuff. In cases with major or complete rotator cuff tears, rTSA can help to restore external rotation and forward elevation.
The increasing usage of rTSA has come with some limitations in its effects. rTSA has been shown to have significantly high rates of complications due to a variety of factors -- acromial fractures, scapular notching, infection, hematoma, baseplate failure, and instability -- with complication rates ranging from 16-68%[^4,5,7,9,25,26,29]. Studies have delved into determining preoperative factors that may have clinically significant effects on the outcomes in rTSA. One such factor is fatty infiltration (FI) or degeneration of the rotator cuff. With the altered design of rTSA relying less on the rotator cuff, the impacts of fatty infiltration of the rotator cuff musculature on outcomes of rTSA is less well understood, particularly the impact that fatty infiltration of specific rotator cuff muscle has on outcomes. Additionally, many patients who undergo rTSA have varying degrees of rotator cuff pathology.[^21]. The purpose of this review was to systematically evaluate the literature to determine the impacts of fatty infiltration of the rotator cuff on the outcomes of rTSA. We predict that outcomes of rTSA will be significantly, negatively impacted by increasing amounts of rotator cuff fatty infiltration.

**Materials and Methods**

**Information sources**

A comprehensive literature was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) using OVID Medline, Embase, PubMed Medline, Cochrane Database of Systematic Reviews (via OVID), Cochrane Central Register of Controlled Trials (via OVID), Scopus, Cinahl, and Web of Science from inception up to April 15, 2021.
A search strategy was created using a combination of keywords and data-base specific headings related to each concept including reverse total shoulder arthroplasty and fatty infiltration of the shoulder musculature. Please refer to the supplementary data for complete and reproducible search strategies. Non-English and non-human studies were excluded from the search. Duplicates were removed using ProQuest RefWorks (Ex Libris, Jerusalem, Israel).

**Eligibility criteria**

For studies to be considered for inclusion, they had to discuss patients undergoing a primary reverse total shoulder arthroplasty (rTSA) with data on fatty infiltration gathered preoperation and with follow-up data detailing the status of the shoulder postoperation. Postoperative follow-up was not limited to a minimum timeline during the initial search to prevent limiting the potential available literature.

Publication year limit was set within each database search from January 2000 to April 2021. Studies were only included if published in the English language. Studies that focused on bilateral rTSA, revision rTSA, shoulder resurfacing, shoulder hemiarthroplasty, rTSA due to trauma, or TSA were not included in the review. If there was no discussion of preoperative fatty infiltration or postoperative follow-up, studies were excluded. Studies that focused purely on fatty infiltration of the deltoid and no rotator cuff muscles were excluded. Studies which included concomitant procedures (e.g. fracture fixation, cadaver studies, pre-prints) were not included. Types of publications excluded from this review included addresses, comments, editorials, case reports, and narrative review (i.e. Level V evidence).

**Data collection process**
The data collection process consisted of multiple, tiered reviews. All reviews were conducted using Rayyan QCRI (Doha, Qatar). For the first review, reviews were performed by two authors in an independent, blinded fashion based on title and abstract. Studies were included if the title or abstract indicated data collection of preoperative fatty infiltration of the shoulder, procedure of an rTSA, and follow-up and analysis of rTSA results postoperation. Articles marked for inclusion were then subjected to a full-text screening, again by two blinded, independent reviewers to ensure each study met the inclusion criteria listed above (SP and BL).

Once each article had been screened by two reviewers, a third, independent reviewer resolved any conflicts that were present (AP). Once the full text screening was complete, the final article bank was collated in Rayyan, including the full-text PDFs of each study. Relevant data from each study was then extracted and recorded by one of three team members in a shared Excel document on a private Google Drive.

**Summary of Measures and Results**

For each included study, the level of evidence was determined by two independent reviewers (SP and BL) and settled by a third in case of conflict (AP). Assignment of levels was given in a systematic approach. Level I was assigned to all randomized controlled trials and systematic reviews. Prospective cohort studies were considered level II. All retrospective case-control studies were considered level III. Level IV studies were those of case series.

Each article was assigned to one of three reviewers (SP, BL, or AP) for data extraction. To preclude bias in data extraction, the variables and data that were extracted were decided upon prior to the extraction process beginning. For each study analyzed, the following data were extracted: number of patients, number of shoulders, sex of patients, mean age, study design, inclusion criteria, exclusion criteria, mean follow-up time, surgical technique, preoperative fatty
infiltration of shoulder musculature by individual muscle when specified, preoperative and postoperative functional scales, preoperative and postoperative range of motion measurements, patient satisfaction, complications, revisions, radiographic findings, and conclusions (Tables 1, 2, Supplemental Table 1, Supplemental Table 2).

Risk of bias

The search procedure was standardized at each level and within each database in order to ensure minimal bias. Screening at each level and for each study was performed by two reviewers in a blinded fashion in order to eliminate inter-observer bias. A third reviewer was used in a necessarily unblinded fashion to settle any conflicts, posing the possibility of slight interobserver bias in those scenarios. Levels I through IV were only included in the review, minimizing any bias from studies of lesser quality. The greatest risk of bias comes from the limited number of studies on the subject of fatty infiltration and rTSA. Within this limited pool of current literature, only a smaller percentage had the main objective focused on fatty infiltration’s effect on the outcomes in rTSA, creating risk of bias towards limited results. Additionally, a formal assessment for bias in the form of the methodological index for non-randomized studies (MINORS) was performed by two independent reviewers (SP and BL) with conflicts resolved by an independent third reviewer (AP). An overall ideal score for a noncomparative study is 16 and an ideal overall score for a comparative study is 24. A score less than 14 or less than 22 for a noncomparative study or a comparative study, respectively was considered a “B” grade. Of the included articles, 2 were grade A, with the remainder being grade B.

Results
Study Selection

From the initial searches of all databases, 542 articles were identified (Fig 1). After screening as detailed in the Methods section, a total of 11 articles were included in the qualitative analysis, including one Level I, three Level III, and seven Level IV articles.

Synthesis of results

Overall, the review included 720 patients and 731 shoulders. However, the study by Merolla et al discussed both rTSA and TSA but did not give a discrete number of rTSAs studied; therefore this number is not included in the total number of patients or shoulders reported above and in Table 1, but this study was included in the review and discussion of results since their results were broken down by arthroplasty type\textsuperscript{24}. The population included in the studies was predominantly female, with 320 female patients compared to 157 male patients. One study did not give a sex breakdown of their patients and therefore these patients are not included in the reported male female numbers\textsuperscript{22}. The average age of the patients in the studies was 72.4 years old (Table 1).

Surgical techniques were largely uniform across all 11 studies — all but two studies used a deltopectoral approach to the joint for all operations\textsuperscript{3,5,13,14,16-18,21,24,28,31}. Other approaches that were used include a single transdeltoid approach\textsuperscript{5} or a superolateral approach\textsuperscript{17}. Boileau and colleagues transitioned from a single transdeltoid approach to a deltopectoral approach after four cases due to concerns about damage to the deltoid and the need for access to the humeral diaphysis in some cases\textsuperscript{5}. Glenoid bone grafting was utilized in two studies\textsuperscript{14,18}. Greiner and colleagues were specifically comparing standard technique to a lateralized technique and glenoid bone grafting was implemented in 34 of 34 shoulders to achieve lateralization of the center of
Merolla et al used glenoid bone grafting in nine out of 83 shoulders to achieve adequate lateralization. One study described using a combined transfer of the latissimus dorsi and teres major tendons in addition to standard rTSA with an anatomic target of the posterolateral humerus for the tendon reattachment. With regards to the handling of the remaining rotator cuff, 6 studies specifically mentioned repairing the subscapularis or what remained of the muscle belly.

11 studies reported data specifically about fatty infiltration of the rotator cuff musculature (Table 2, Supplemental Table 1). All studies used the grading criteria as put forth by Goutallier and Fuchs. However, studies differed with how they grouped various grades of fatty infiltration and what specific muscles were investigated. The teres minor was looked at most often, with 10 studies describing the fatty infiltration of this muscle specifically.

A variety of clinical and functional scores and scales were used to measure postoperative improvement after rTSA, with the Constant score being used most often (n=9), followed by ASES (n=5). Multiple studies demonstrated a significant improvement in clinical outcomes postoperatively.

With regards to fatty infiltration of the rotator cuff and its impacts on outcomes, Simovitch et al found that the patients with less fatty infiltration of the teres minor (stage 0-2) had a significantly better Constant score postoperatively (83± 15.5%) than those shoulders with higher grade fatty infiltration (61 ± 12.6%, p < 0.01). Similarly, Hung et al found that the ASES score postoperatively was significantly lower in those with teres minor hypertrophy (77.3±22.8 vs 84.2±16.9, hypertrophy vs. normal muscle volume, p = 0.02). However, two studies found that there were no significant differences between patients with minimal fatty
infiltration and those with moderate or severe fatty infiltration when comparing clinical outcomes \textsuperscript{13,21}.

With regards to postoperative range of motion, multiple studies found that fatty infiltration of the rotator cuff was associated with worse range of motion after rTSA. They found that fatty infiltration of the teres minor is associated with decreased external rotation postoperatively \textsuperscript{5,14,24}. There were also studies that found preoperatively fatty infiltration of the infraspinatus negatively impacted postoperative active anterior elevation and external rotation \textsuperscript{18,28}. However, Boileau and colleagues found that fatty infiltration of the infraspinatus did not have a significant impact on postoperative external rotation \textsuperscript{5}. One study found that there were no significant impacts on range of motion due to fatty infiltration of the supraspinatus \textsuperscript{28}. Wiater et al also found that there were no significant impacts on postoperative range of motion secondary to fatty infiltration of the subscapularis or teres minor \textsuperscript{3}. Furthermore, one study that looked at rTSA in patients with an intact rotator cuff found that there was no impact of fatty infiltration on postoperative range of motion \textsuperscript{21}.

Only one included study was a level 1 randomized control trial that examined the impacts of lateralization of the glenosphere on outcomes of rTSA \textsuperscript{14}. While they did find that patients had better outcomes after a lateralized rTSA with bone grafting, they did not examine rotator cuff fatty infiltration in detail. However, they did find that patients without major degeneration of the teres minor that had a lateralized implant had significantly improved external rotation (Δ42±28 vs Δ16±26, p = 0.39) compared to patients with a standard implant \textsuperscript{14}.

One study specifically examined preoperatively factors that influenced scapular notching, a common complication of rTSA, and found that high grade fatty infiltration of the infraspinatus was associated with higher rates of scapular notching \textsuperscript{17}. Other commonly reported complications
included acromial stress fractures\textsuperscript{13,14,31}, nerve palsies which were largely transient \textsuperscript{3,5,21} and deep infection \textsuperscript{9} among other less common complications. Some studies discussed the need for revision, which was largely due to recurrent instability or postoperative fractures \textsuperscript{3,13} although there were also studies that reported no need for revision at the completion of follow-up \textsuperscript{5,21}. 

**Discussion**

**Summary of evidence**

The impact of fatty infiltration of the rotator cuff on the outcomes of rTSA is a complex topic, partially due to rTSA being a relatively new procedure and partially due to the variety of surgical techniques that are employed in order to restore as much functionality as possible. Additionally, there is a lack of well-powered, prospective cohort studies that evaluate this particular preoperative factor. Despite this relative paucity of cohort and randomized control trials, the available literature does provide some insight into the effects of fatty infiltration of the cuff on clinical and functional outcomes after rTSA.

In general, studies found that preoperative fatty infiltration of the rotator cuff negatively impacted both postoperative functional outcomes and clinical scores \textsuperscript{5,14,16,18,24,28}. Although Puzzitiello et al did not find any significant differences in clinical scores or range of motion between patients with minimal and those with moderate/severe fatty infiltration of the rotator cuff, the study population only included patients with an intact rotator cuff \textsuperscript{21}. While there are a wide range of indications for rTSA, it is relatively uncommon for this procedure to be done in patients with an intact rotator cuff. Among the studies included in this review, 8 specifically mention cuff tear arthropathy or a massive, irreparable rotator cuff tear as inclusion criteria \textsuperscript{3,5,13,14,24,28,31}, while only two studies operated on patients with intact rotator cuffs \textsuperscript{18,21}. Another
study found no significant correlation of fatty infiltration with postoperative clinical scores and no significant difference in Constant scores in a subgroup analysis comparing low (Goutallier 0-2) and high grade (Goutallier 3-4) fatty infiltration of each rotator cuff muscle. However, only 18 patients in this study had MRIs, so it is possible sample size was a limiting factor in distinguishing between subgroups given that the study also found that overall Constant scores improved postoperatively for all patients.

While there may not be a clear consensus about impacts of overall rotator cuff fatty infiltration on rTSA outcomes, the data is more clear with regards to fatty infiltration of the teres minor. Although the teres minor plays a relatively minor role in stability of the glenohumeral joint and external rotation in patients with an intact rotator cuff, in patients with supraspinatus or infraspinatus tears, the teres minor must counteract the subscapularis to provide joint stability. Furthermore, with loss of the posterior deltoid, the main external rotators of the shoulder become the infraspinatus and teres minor. Additionally, the teres minor becomes the main external rotator of the shoulder in the setting of infraspinatus insufficiency; although rTSA can aid in restoring active elevation, the teres minor plays an important role in restoring external rotation after this procedure.

While there have been previous studies showing the negative impact of teres minor fatty infiltration, the consensus among the studies included in this review are less clear cut. Four studies in this review that specifically examined fatty infiltration of the teres minor found that it had negatively impacted both clinical scores and external rotation after rTSA. Two studies found a significant difference in postoperative external rotation between patients with low grade fatty infiltration of the teres minor compared to those with high grade, with high grade fatty infiltration being associated with ~10-15º less external rotation postoperatively.
Simovitch et al did find that patients with higher grade preoperative fatty infiltration of the teres minor had less active external rotation preoperatively (19 degrees vs 9 degrees, grade 0-2 vs grade 3-4, p < 0.01). However, the group with worse preoperative fatty infiltration also had significantly less increase in postoperative external rotation (Δ9±15.8 vs Δ-7±17.3, grade 0-2 vs grade 3-4, p < 0.001) \(^\text{24}\). Hung et al also found that severe hypertrophy of the teres minor was associated with worse ASES scores postoperatively (73.3±22.8 vs. 84.2±16.9 [p=.02]) \(^\text{16}\). They found that, even after adjusting for confounding variables such as preoperative muscle quality, rotator cuff tendon tear size, and implant positioning, that teres minor hypertrophy was the only significant negative predictor of ASES score after rTSA \(^\text{16}\). However, one of these studies also employed a lateralized implant design with bone augmentation of the glenoid and found that patients with a lateralized implant had greater external rotation than those with a standard implant when patients with teres minor hypertrophy were excluded \(^\text{14}\). While the overall consensus was that teres minor fatty infiltration negatively affects rTSA outcomes, Greiner et al did not find any association between teres minor integrity and clinical outcomes or active external rotation \(^\text{14}\). They speculate that this is due to a change in biomechanics and force vectors in rTSA implants, although this conflicts with not only the other studies in this review but also those trials that implement tendon transfers to compensate for fatty infiltration of the teres minor to aid in restoration of external rotation \(^\text{3}\). Additionally, another study found that fatty infiltration of the teres minor did not correlate with a lack of external rotation; they suspect that this may have been due to a lack of power as relatively few patients (n=2) in their study had high grade fatty infiltration of the teres minor \(^\text{28}\). As discussed above, Puzzitello et al did not find any impact of fatty infiltration of the teres minor on postoperative outcomes \(^\text{21}\).
One study employed an LDT in addition to a teres major transfer (LD/TM) and they found a significant improvement in external rotation postoperatively. These results show that LD/TM transfer in rTSA may be a reliable method for restoring external rotation and should be considered in patients with teres minor deficits or fatty infiltration for optimal outcomes.

Although the design of rTSA generally dictates the resection of the supraspinatus, the majority of studies did not detail their handling of all rotator cuff muscles, with some not even discussing if they repaired or resected the subscapularis. While this rotator cuff muscle is often completely torn in patients receiving a rTSA or is resected during the operation, there are studies who still looked at fatty infiltration, and we therefore felt it was most accurate to include these data (Table 2). In particular, one study performed rTSA in patients with intact rotator cuffs and they found no impact of fatty infiltration of the supraspinatus on outcomes. Another study did not find any correlation between fatty infiltration of the supraspinatus on postoperative outcomes. Additionally, many studies did not clarify their handling of the remaining rotator cuff, so we are including their results about the supraspinatus to be thorough.

This review is not without limitations, largely due to the quality of evidence in the included studies. Although rTSA is increasing in popularity, there are few cohort or randomized control trials that assess preoperative fatty infiltration and its impacts on outcomes. Therefore, most of the data on fatty infiltration of the rotator cuff in rTSA comes as adjunct data from many studies, rather than being the main focus. Additionally, there were many different types of implant designs used amongst the included studies (Supplemental Table 1); four studies specifically mention lateralization of the implant, either on the humeral or glenosphere component. Given that this can alter the biomechanics of the implant and the relative impact that each muscle has on range of motion, and therefore patient satisfaction with a
procedure and its outcomes, this impacts the strength of conclusions that we can draw from this
review.

**Conclusion**

rTSA is a relatively new operative technique to restore shoulder functionality in older
individuals with otherwise irreparable rotator cuff tears or debilitating glenohumeral
osteoarthritis. The reviewed literature consistently demonstrated that preoperative fatty
infiltration of the rotator cuff, particularly of the teres minor, has a negative impact on the
restoration of range of motion, especially external rotation, after rTSA. The impact of fatty
infiltration of the other rotator cuff remains unclear, which may be due to inter-surgeon technical
differences in the handling of the remaining rotator cuff muscles or differences in prosthetic
design. Nevertheless, preoperative fatty infiltration of the rotator cuff has the potential to degrade
outcomes and therefore should be evaluated further. The evaluated literature provides a valid
data point upon which patients can be educated about probable outcomes and restoration of
function after rTSA.

**Figure 1.**

Flow chart of systematic review screening process.

**Table 1.** An overview of demographics and focus of the studies included in the systematic
review.

**Table 2.** A breakdown by rotator cuff muscle of the severity of fatty infiltration encountered
across each study as well as the consensus from the included studies about the impact of fatty
infiltration of that specific rotator cuff muscle on outcomes of rTSA.
Supplemental Table 1.
Demographic data -- level of evidence (LoE), number of patients, sex of patients, mean age of patients, study design, mean follow-up, and surgical technique -- of the included articles.

Supplemental Table 2.
Extracted data from each study regarding fatty infiltration, clinical outcomes, range of motion, and conclusions.

References


Puzzitiello RN, Moverman MA, Menendez ME, Hart P-A, Kirsch J, Jawa A. Rotator cuff fatty infiltration and muscle atrophy do not impact clinical outcomes after reverse total shoulder...
arthroplasty for glenohumeral osteoarthritis with intact rotator cuff 2021. 


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| Impact of fatty infiltration                  | Consistently associated with poorer external rotation after rTSA and worse clinical outcomes (Greiner et al. 2015, Simovitch et al. 2007, Boileau et al. 2006, Hung et al. 2021) | Not consistently correlated with worse outcomes (Greiner et al. 2009, Puzzitiello et al. 2021) | One study found negative impacts on postoperative external rotation and lateral elevation (Wiater et al). One study found it had no impact on external rotation (Boileau et al. 2006). One study an association with scapular notching (Levigne et al. 2008) | No correlation with ROM or patient recorded outcomes (Puzzitiello, Wiater) |

*For studies that reported fatty infiltration only as an average, these numbers were excluded from the above table; hence why the number of shoulders graded in these tables differs from the total number of shoulders included in overall analysis (Greiner 2010, Yoon, Wiater). One study (Merolla) did not give discrete numbers for rTSA patients and their respective musculature status, so they were also not included in the above table.*