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Andrew Green, MD, Kelsey Loyd, BS, Janine Molino, Ph D, Peter Evangelista, MD, Stacey Gallacher, MD, Jacob Adkins, AB

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Andrew Green MD[1] Kelsey Loyd BS[2] Janine Molino Ph D[3] Peter Evangelista MD[5] Stacey Gallacher MD[4] Jacob Adkins AB[2]

[1]Division of Shoulder and Elbow Surgery Department of Orthopaedic Surgery Warren Alpert Medical School, Brown University Providence, Rhode Island, USA

[2] Warren Alpert Medical School, Brown University Providence, Rhode Island, USA

[3] Department of Orthopaedic Surgery Warren Alpert Medical School, Brown University Providence, Rhode Island, USA

[4]Advanced Orthopedics and Sports Medicine Institute Freehold, NJ, USA

[5]Department of Diagnostic Imaging Warren Alpert Medical School of Brown University Providence, Rhode Island, USA

Corresponding Author: Andrew Green MD

Division of Shoulder and Elbow Surgery Department of Orthopaedic Surgery

Warren Alpert School of Medicine, Brown University

1 Kettle Point Avenue

East Providence, RI 02914, USA

Phone: 401-457-1515 Fax: 401-831-8637 Email: agshoulder@aol.com

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Abstract:

Background:

The long-term outcomes of rotator cuff repair have not been well studied. The purpose of this study was to evaluate long-term functional and structural outcomes after rotator cuff repair in younger patients.

Methods:

49 patients, 34 (69%) male) with mean age 51±6 years were evaluated preoperatively, and at short and long-term follow-up (minimum 15 years). There were 13 (27%) small, 17 (35%) medium, 14 (29%) large, and 5 (10%) massive tears. 15 (31%) had an acute repair of a traumatic tear.

Long-term evaluation included physical examination, plain radiographs, ultrasound, and patient reported outcome measures (PROMs) [Visual Analog Shoulder pain (VAS), Disability of Arm Shoulder and Hand (DASH), Simple Shoulder Test (SST), American Shoulder and Elbow Surgeons score (ASES), and Short Form-36 (SF-36)].

Statistical analysis was performed to determine associations between preoperative and intraoperative factors and long-term functional and structural outcome.

Results:

There were significant improvements in the mean short and long-term PROMs compared to preoperatively that exceeded reported MCIDs and SCBs. There was a slight decrease in the PROMs from the short-term to long-term follow-up.

Male sex and traumatic rotator cuff tears were associated with better long-term outcomes. The number of medical co-morbidities was associated with worse long-term outcomes. Smaller initial tear size was associated with better long-term outcomes.

There were 15 (31%) full thickness and 9 (18%) partial thickness recurrent rotator cuff tears. 17 (35%) had rotator cuff tear arthropathy (2 Hamada grade 1, 15 Hamada grade 2). 5 (10%) had revision surgery (2 revision rotator cuff repair, 2 anatomic total shoulder, and 1 reverse total shoulder). 13 (26%) had subsequent contralateral rotator cuff repair.

There were weak correlations between the presence of arthropathy and DASH (r=0.34, p=0.02) and VAS pain (r=0.29, p=0.049). There were no significant correlations between the structural outcomes (recurrent rotator cuff tear, recurrent full thickness tear, acromiohumeral space, and critical shoulder angle,) and the PROMs.

Discussion and Conclusion:

Long-term follow-up of rotator cuff repair in this relatively young patient cohort demonstrated substantial and durable patient reported functional outcome and improvement despite considerable structural deterioration. This suggests that while rotator cuff repair does not arrest the progression of rotator cuff disease it may delay this progression and that patients adapt to the structural changes as they age.

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

Keywords: rotator cuff, rotator cuff tear, rotator cuff repair, long-term outcome, structural outcome, rotator cuff tear arthropathy, natural history

Rotator cuff tears are a common cause of shoulder pain and rotator cuff repair is frequently performed to resolve pain and restore function. Short and mid-term follow-up studies of RCR report significant and clinically relevant improvements in functional outcome. Nevertheless, the rate of retear varies considerably and is associated with patient age, original tear size, preoperative fatty infiltration and rotator cuff muscle degeneration, and surgical technique, with retear having minimal effect on subjective outcomes while being associated with inferior objective outcomes. [4,14,16,20,36] Studies with 10-year or greater follow-up confirm the durability of functional outcomes despite progressive deterioration of rotator cuff structure. [5,11,12,13,30,32]

The natural history of RCT has been well characterized with unrepaired tears undergoing progressive increase in tear size and muscle degeneration. [19,25,26,27,34,41] However, understanding of the longer-term natural history, including the durability of functional outcomes and structural deterioration after RCR, remains to be fully elucidated. There is little published on outcome greater than 15 years that evaluates the natural history of RCR. Plachel, et al recently performed a systematic review of the long-term outcome of mini-open and arthroscopic rotator cuff repair and noted retear rates of 39 and 43 percent respectively and that there were no significant differences in pooled ASES scores. In contrast, they did report significantly greater absolute Constant scores when the repair was intact. Four of the studies reviewed had mean follow-up of 15 years or greater and only Bell et al reported on longitudinal follow-up. However, Bell et al did not use a patient reported outcome and did not perform imaging at the long-term follow-up evaluation. This leaves the questions "do repairs remain intact, is there time dependent structural deterioration, and what happens to function over time?" unanswered.

The purpose of this study was to evaluate the long-term functional and structural outcomes of RCR performed in a younger cohort. Two hypotheses were investigated: (1) short-term subjective PROMs are maintained at long-term follow-up and (2) structural deterioration of the rotator cuff and the glenohumeral joint is not associated with worse long-term PROMs.

Methods:

This study was approved by the Lifespan IRB and all of the patients consented to participate. The study included a retrospective analysis of a prospectively obtained database of patients who underwent rotator cuff repair performed by the senior author, as well as an up to date study evaluation as described below. Two hundred and sixty-eight patients were treated with rotator cuff repair between January 1, 1999 and December 31, 2001. The inclusion criteria for this study were patient age 60 years or less at the time of surgery, a repair that included the supraspinatus tendon, complete repair, and available follow-up evaluations at 6 and/or 12 months after surgery. Younger patients were specifically selected because we thought that longer term follow-up is more important for them. Zuke, et al performed a systematic review of recovery after arthroscopic rotator cuff repair and reported that clinically significant improvement in patient-reported outcomes was seen up to 1 year after rotator cuff repair and that most of the improvement in strength and range of motion was achieved up to 6 months without additional clinically meaningful improvement.[43] In the senior author's practice patients were routinely followed until an end result was achieved.

The exclusion criteria included prior ipsilateral RCR, partial thickness tear, isolated subscapularis tears, and incomplete rotator cuff repair. 169 patients 60 years old or less were identified. Thirty-eighty declined to participate primarily due to moving out of the region, 26 patients were deceased, 46 could not be contacted and were lost to follow-up, 9 were excluded after initial inclusion and 1 did not complete the study protocol. (see Figure 1)

The study cohort included 49 patients (**see Table 1**). The mean age at surgery was 51± 6 years. Thirty-four (69%) were male. Thirty-three patients (67%) had treatment of their dominant extremity. Nine (18%) had a Worker's Compensation claim. Tear size was determined with intra-operative measurement of anterior-posterior (width) and medial-lateral (retraction) dimensions and was classified as small 13 (27%), medium 17 (35%), large 14 (29%) and massive 5 (10%) as defined by Cofield, et al.[7] Partial subscapularis tears were present in 8 (16.3%). Fifteen (31%) tears were repaired early after acute trauma. (see Table 2)

The time period of the initial treatment corresponded to the period in which the senior author was transitioning from open to arthroscopic rotator cuff repair techniques. **Nine** open, 25 mini-open, and 15 arthroscopic repairs were performed. (**see Table 2**) Acromioplasty was routinely performed. The mini-open and open repairs were performed with transosseous no 2 Ethibond sutures and a modified Mason-Allen technique. The arthroscopic repairs were performed with a single row technique with double loaded threaded metal suture anchors.

The postoperative care included sling immobilization for 5 weeks and initiation of self-assisted passive range of motion during the first week after surgery. Active use and active range of motion was initiated after discontinuation of the sling. Progressive resisted strengthening exercises were initiated at 12 weeks after surgery. Patients were routinely evaluated at 6 weeks, 3 months, 6 and 12 months after surgery.

Prospectively recorded preoperative and short-term outcome assessments obtained at 6 and 12 months after surgery were reviewed and the data was reviewed retrospectively. Patients who were available and agreed to participate in the study underwent a long-term follow-up evaluation performed at a mean of 16.9 ± 1.6 years by the senior author. The mean age at long-term follow-up was 66 ± 11 years.

Functional Outcome Assessment

All evaluations included a physical examination, and assessment of patient reported outcome measures (PROMs). Shoulder motion was assessed in active forward elevation (AFE), active external rotation (AER), and passive internal rotation (PIR). The Disability of Arm Shoulder and Hand (DASH) score was the primary PROM outcome. The secondary PROM outcomes were VAS pain, Simple Shoulder Test (SST), and Short Form-36 (SF-36). The ASES score was only determined at the long-term follow-up. The changes in PROMs from preoperative to long-term follow-up were compared to published the Minimal Clinically Important Difference (MCID) and Substantial Clinical Benefit (SCB) values.[21,38,40] A DASH MCID value of 12.4 was reported for shoulder conditions by Van Kempen, et al.[40] There is no published DASH MCID for rotator cuff repair. An SST MCID value of 4.3 for rotator cuff repair was reported by Tashjian, et al.[38] A mean VAS pain MCID value of 1.95 was derived from Kim, et al (1.5 units) and Tashjian et al (2.4 units).[21,38] The long-term follow-up PROMs were compared to published Patient Acceptable Symptom State (PASS) values for rotator cuff repair. A mean ASES PASS value of 82.4 was derived from Cevantovich, et al (86.7) and Kim, et al (78[).10,21] The Percent Maximal Outcome Improvement (PMOI) for the SST and DASH were calculated.[1]

Structural Evaluation

The findings of preoperative plain radiographs (true anterior posterior, axillary and outlet views) were recorded in the database. At long-term evaluation, magnification controlled plain radiographs were used to assess the acromiohumeral distance (AHD), critical shoulder angle

(CSA), acromial tilt, and glenohumeral degenerative joint disease. Rotator cuff arthropathy (RCTA) was graded according to the Hamada Classification.[15] Glenoid erosion was assessed according to the Favard Classification.[23] Glenohumeral osteoarthritis was classified according to Samilson and Prieto.[35]

At long-term follow-up ultrasonography was performed and interpreted by an experienced musculoskeletal radiologist (PTE) using a GE LOGIC9 (General Electric, Boston, MA, USA) with an ML6-15-D broad spectrum linear matrix array transducer. All rotator cuff tendons were examined, and grayscale 2D US images were stored in a picture archiving and communication system (PACS). The shoulder ultrasonography protocol adapted by Beggs et al was used.[2] Tear location and depth were documented, and tear size was measured in the sagittal plane.

Statistical Analysis

Statistical analysis was performed to determine associations between preoperative and intraoperative factors and the long-term functional and structural outcomes. Continuous variables were reported as mean and standard deviation and categorical variables were reported as frequency and percentages. Mixed effect regression models with random intercept and slope and a fixed effect for follow-up period were estimated to examine durability of functional outcomes over time. Regression models were used to examine the effect of preoperative and intraoperative factors on long-term outcomes. Factors with p values <0.1 in the univariable model were included in multivariable model. Spearman correlation coefficients were used to assess the relationship between long term functional and structural outcomes. Fisher Exact test was used to assess the relationship between initial tear size and presence of recurrent full thickness tear.

Results:

Functional Outcome

Range of Motion:

AFE and PIR improved significantly from preoperative evaluation to short-term follow-up. There was a statistically significant but only slight decrease in AER and PIR from the short to long-term follow-up. (**see Table 3)**

Patient Reported Outcome Measures:

At short-term and long-term study follow-up there were statistically significant improvements in all of the mean PROMs compared to the preoperative values **(see Figure 2)** that exceeded published MCIDs for VAS pain, SST and DASH, and SCB for VAS pain (**see Tables 4 and 5**) (SCB of the SST and DASH have not been determined). While a majority of the patients achieved the MCID of the VAS pain, SST and DASH at short and long-term follow-up, there was a decrease in the number of patients achieving the MCIDs.**(see Table 5)** A majority of patients achieved the SCB of the VAS pain at short and long-term study follow-up with a decrease at long-term.**(see Table 5)** The mean long-term ASES score was within the range of published PASS and a majority of the patients achieved the PASS. **(see Table 5)** Except for the SST, were no statistically significant differences between the short-term and long-term outcomes. **(see Table 4)**

Nevertheless, there were patients who deteriorated from short to long-term follow-up. Nine patients (18 percent) had a worse DASH score at long-term compared to baseline; 7 of these patients had improved at short-term follow-up. 20 (41 percent) had a lower DASH score at long-term compared to short-term follow-up. While 7 (35 percent) of these patients had a recurrent full-thickness rotator cuff tear this was not statistically different from the patients who did not have a decrease in DASH score at long-term follow-up. Eight (40 percent) of these patients had DASH scores of less than 15 which is near normal function, while six (30 percent) were worse than preoperatively.

The univariable models consistently demonstrated that male sex was associated with better long-term PROMs. **(see Table 6)** Repair of a traumatic tear was associated with better long-term SST, SF-36 % age score, SF-36 PF, and SF-36 PCS. A greater number of medical co-morbidities was consistently associated with worse long-term PROMs.**(see Table 6)** The multivariable models only identified a significant positive association between male sex and the long-term ASES and SF-36 PF. In contrast, there was a negative association between medical co-morbidities and the long-term DASH, SF-36 % age score, SF-36 PF, and SF-36 PCS.

There were inconsistent associations between preoperative tear size and long-term PROMs. Univariable regression analysis demonstrated that there were no statistically significant relationships between preoperative tear size and SST and ASES and that patients with larger tears had better long-term DASH and VAS pain scores (p=0.03 and 0.04).**(see Table 7)**

Structural Outcome:

At long-term follow-up, 24 (49%) had a recurrent RCT (7 isolated supraspinatus, 2 combined supraspinatus-subscapularis, 6 combined supraspinatus-infraspinatus, 5 combined supraspinatus-infraspinatus-subscapularis, and 3 isolated subscapularis) of which 15 (31%) were full thickness. In the univariable model, worker's compensation claim, larger tear width, involvement of the subscapularis, and larger tear size were associated with a greater likelihood of recurrent full thickness RCT**.(see Table 8)** In the multivariable model only larger initial tear size was associated with recurrent full thickness RCT, with large and massive tears respectively having a 6.99 and 9.64 increased risk of having a recurrent full thickness tear.**(see Table 8)**. There was a significant relationship between the initial tear size and the presence of recurrent full thickness RCT (Fisher Exact test p=0006) with smaller tears less likely to be associated with full thickness retear.

33 had acromial humeral space of ≤ 7mm on long-term follow-up radiographs indicative of a large recurrent rotator cuff tear. Univariable models showed that increasing age, increasing critical shoulder angle, and increasing acromial tilt were associated with a greater likelihood of acromial humeral distance ≤ 7mm (ORs > 1), while being male was associated with a lower likelihood of acromial humeral distance ≤ 7mm (ORs < 1). The initial tear size was not significantly associated with acromial humeral distance ≤7mm. Age, male sex, critical shoulder angle, and acromial tilt remained statistically significant in the multivariable models, with the patterns of association remaining the same. On long-term radiographs acromiohumeral space ≤ 7mm was significantly associated with male sex, the critical shoulder angle, and acromial tilt angle.

Seventeen (35%) developed RCTA (2 Hamada grade 1, 15 Hamada grade 2; all Favard E0). In the univariable model only the initial tear width was significantly associated the development of RCTA (p=0.049). Glenohumeral osteoarthritis was mild in 3 patients and severe in 2, all with an intact rotator cuff. In the multivariable model tear width was nearly associated with the development of RCTA (p=0.053).). (see Table 9) Glenohumeral osteoarthritis was mild in 3 patients and severe in 2, all with an intact rotator cuff.

There were weak correlations between the presence of RCTA and the DASH (r=0.34, p=0.02) and VAS pain (r=0.29, p=0.049). There were no significant correlations between the structural outcomes (recurrent RCT, full thickness RCT, AHD space, and CSA) and the PROMs.

Reoperation

Five (10%) of patients had subsequent ipsilateral shoulder surgery. Two (4%) patients had a revision RCR (112 months and 218 months after rotator cuff repair). Three patients had (6%) had shoulder arthroplasty. Two patients (4%) had anatomic total shoulder (164 and 191 months after rotator cuff repair. One patient (2%) had reverse total shoulder (203 months after rotator cuff repair. Thirteen (26%) had subsequent contralateral RCR.

Discussion

The findings of this study generally support our hypotheses that (1) short-term subjective PROMs are maintained at long-term follow-up and that (2) structural deterioration of the rotator cuff and the glenohumeral joint is not associated with worse long-term PROMs. At greater than 15 years after surgery a substantial percentage of patients have recurrent rotator cuff tears and degenerative joint changes that one would expect to affect subjective outcomes. However, the long-term PROMs were only slightly worse, and in most cases not significantly different, than at short-term follow-up. The results of this study demonstrate that rotator cuff repair can be expected to provide lasting long-term improvement in shoulder function and comfort for most patients, with a relatively low reoperation rate. Of interest, despite the durability of the mean PROMs that we assessed, deeper analysis of the outcomes demonstrated that there was functional deterioration in some cases as evidenced by decreases in the percentage of patients achieving MCID and SCB. This finding, in addition to the relatively high prevalence of early rotator cuff tear arthropathy raise concerns about the even longer-term durability of the patient reported functional outcomes.

The relationship between rotator cuff structure and PROMs is complex and not well understood. It is well known that many individuals have asymptomatic rotator cuff tears.[30 39] Several studies with early and mid-term follow-up did not find a significant effect of retear on outcomes. [20,42,43] Consistent with most studies, we did find a significant association between preoperative tear size and the presence of recurrent rotator cuff tear. However, a number of studies, particularly those with longer term follow-up found that while patients with retear have comparable subjective outcomes to those with intact repairs, the objective outcomes, most commonly assessed with the Constant Score, are better when there is an intact repair. The findings of our longer-term study are generally consistent with these reports. [16,18,22,30,31,32]

There are few studies that report follow-up beyond 15 years. Bell, et al evaluated 49 patients who had mini-open RCR with mean follow-up of 15.2 years with the UCLA score.[3] The outcome was good or excellent in 34 patients (70%), fair in 7 (14%), and poor in eight (16%), and three patients had a reoperation. Between the two and fifteen-year evaluations, twenty-nine patients (59%) maintained a good or excellent result. The overall scores deteriorated for 15 (31%) and improved for 24 (49%). Collin, et al reported on the 20 year follow-up of a multicenter study of 53 cases with massive RCT treated with arthroscopic repair.[9] Forty-seven percent had a retear by MRI and 17 percent had Hamada stage 4 rotator cuff tear arthropathy. They found that postoperative supraspinatus fatty infiltration was predictive of postoperative CS and tendon retear, and that repair integrity was the most predictive factor of long-term clinical outcome. However, preoperative tear size was not significantly associated with outcome. They also noted maintenance of satisfactory functional outcomes and a low revision rate. In another study, the same authors reported on the 20 year follow-up of 66 cases of open repair of isolated supraspinatus tear, of which 45 had follow-up plain radiographs and MRI.[8] The mean Constant Score improved from 52 points preoperatively to 71 points at final follow-up, and the final SST was 9.5 (2-12); the SST score similar to the findings of our study. Of the 53 patients evaluated with plain radiographs 18 (34%) had no arthritis, 16 (30.2%) had stage 1, 7 (13.2%) had stage 2, 5 (9.4%) had stage 3, and 1 (1.9%) had stage 4 arthritis. Twelve patients (30%) had Hamada-Fukuda stage 4 cuff tear arthropathy. There was repair integrity (Sugaya I, II, and III) in 58%, and repair failure in 42%. In summary, they stated that "the hypotheses that 20 years after surgery, the clinical benefit of supraspinatus tendon repair is lost and revision surgery is very frequently necessary must be refuted". The findings of our study support this statement. Plachel, et al reported on 56 cases of arthroscopic RCR with mean follow-up of 15±2 years.[31] Thirty three percent had a retear by MRI. Six patients underwent revision surgery, 4 for RCT. While intact repair was significantly associated with better Constant Scores, the differences in the scores for intact and retear groups was less than the MCID for the Constant Score. There were no significant associations between repair integrity and the PROMs and the preoperative tear size did not have a significant influence on the long-term clinical outcome scores. The findings of these reports are generally consistent with the findings of this study. Our study additionally evaluated patient factors and found that long-term patient reported outcomes were associated with patient sex and preoperative co-morbidities. Most recently, Nicholson et al reported on the clinical outcomes of 60 patients with mean age of 58.1 year (range 37-75) treated with arthroscopic rotator cuff repair at minimum 15 year (mean 16.5 year) follow-up.[29] Similar to our findings, they reported that there were no significant differences between the short and long-term patient reported outcomes. While they found that male sex and younger age were associated with higher Shoulder Activity Scales, they did not find any factors that were predictive of ASES and SANE scores. Rotator cuff tear size was not predictive of PROMs. They did not assess the long-term structural outcomes.

Radiographic progression associated with rotator cuff tear has been evaluated by a limited number of investigators. Chalmers, et al found that over 8-year follow-up, non-operative treatment of RCT was associated with significant but moderate glenohumeral degenerative changes including increase in Hamada grades.[5] Paxton, et al reported that at greater than 10 year follow-up shoulders with failure of repair of large and massive tears had a high rate of RCTA.[30] Ranebo, et al studied 69 patients, including 23 who had treatment of a full thickness RCT with an isolated acromioplasty.[33] At mean follow-up of 22 years 74 percent of the patients with full thickness tears had Hamada grade ≥2 with 30 percent having Hamada 4b. Herve et al, specifically focused on the issue of glenohumeral arthritis in a cohort of 79 patients 20 years after rotator cuff repair.[17] Similar to our study, the mean age at the time of surgery was relatively young (51.9 +/- 6.5 years). In contrast to our findings they reported that a substantial percentage had advanced glenohumeral arthritis; 5 (21.7%) cases of Samilson grade 3 glenohumeral osteoarthritis and 18 cases of Hamada grade 4a and 4b. Failure of supraspinatus tendon repair and massive cuff tears were associated with arthritis; presumably rotator cuff tear arthropathy as the authors did not clearly differentiate osteoarthritis from cuff tear arthropathy in their report. The degenerative glenohumeral joint changes of our cohort were not as severe.

Not unexpectedly, in this study larger initial tear size was associated with the presence of recurrent full thickness RCT. Larger tear size was also associated with a greater risk of developing RCTA. While the findings of our study demonstrate that RCR does not prevent future structural deterioration, in comparison to the results of other studies of progression of glenohumeral degenerative changes in the presence of RCT, successful RCR appears to delay progression. Interestingly, patients in our study were only slightly more likely to have recurrent full thickness rotator cuff tear or undergo subsequent surgery than to undergo subsequent contralateral rotator cuff repair.

We specifically included only younger patients because longer term follow-up is more important for them. Sperling, et al evaluated 29 patients less than 50 years old at the time of open RCR at a minimum of 13 year follow-up.[37] The outcomes were 11 excellent, 5 satisfactory, and 13 unsatisfactory results. In addition, 7 shoulders had subsequent surgery for the treatment of a recurrent tear (5), instability (1), or osteoarthritis (1). Our cohort was somewhat older but still relatively young with a mean age at the time of RCR of 51±6 yr. In contrast, most of the patients in our cohort maintained a successful outcome and there was a lower incidence of reoperation even at longer follow-up. It is certainly possible that longer follow-up of our cohort will be associated with deterioration of the functional and structural outcomes given that the life expectancy of a 66 year old in the US is about 17 years for males and over 19 years for females and citizen (Social Security actuarial life table 2017, https://www.ssa.gov/oact/STATS/table4c6.html; accessed 5.1.2021)

We found that at long-term assessment, functional outcomes after RCR are largely maintained despite recurrent RCT and structural deterioration of the glenohumeral joint in some patients, and that there were only very limited correlations between the functional and structural outcomes. Moosmayer, et al recently reported 10 year follow-up of a randomized clinical trial that compared non-operative and operative treatment of small and medium size tears and demonstrated significantly better results after repair.[28] Chalmers, et al performed a detailed systematic review to determine the effect of repair on the natural history of RCT and concluded that RCR may not alter the natural history of RCT.[6`] In contrast, based upon the findings of our study we think that RCR does delay the natural history of rotator cuff tears.

This study had limitations. The sample size was small and probably underpowered to demonstrate potentially important and significant associations between baseline and short-term and the long-term outcomes. While a relatively large number of subjects were lost to follow-up despite a concerted effort to recruit subjects, our experience is not dissimilar to that of other investigators. Therefore, we are unable to determine if the subjects who participated in our study are truly representative of the cohort of patients that were treated with rotator cuff repair by the senior author during the time frame of this study. While the inclusion of a variety of repair techniques might have biased repair healing, affecting the long-term structural outcome, there is little available evidence that repair technique affects outcome, except for the use of single row arthroscopic repair for larger rotator cuff tears. During the period of this study the senior author used arthroscopic repair for small and medium sized tears. Despite this, the analysis of factors affecting long-term outcomes found that outcomes were not dependent upon whether the original repair had healed. We did not have longitudinal follow-up between the short and long-term follow-up that might have demonstrated greater improvement compared to preop with subsequent deterioration at longer term follow-up. Our conclusion that long-term outcomes were durable is based up subjective PROMs rather than objective outcome assessment such as the Constant Score. Lastly, this study only represents the experience of the senior surgeon and may not be generalizable.

Conclusion:

Functional outcomes assessed with PROMs are relatively durable at long-term follow-up after RCR despite structural deterioration and there were few statistically significant relationships between the structural and functional outcomes. This suggests that while RCR does not arrest the progression of rotator cuff disease it may delay this progression and that patients adapt to the structural changes as they age and maintain subjective reported outcomes. Longer-term follow-up is needed to determine if this relationship is further maintained.

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Figure Legends:

Figure 1: Flow chart of study patient inclusion and exclusion.

Figure 2: Comparison of short and long-term patient reported outcomes for DASH, SST and VAS pain. * indicates statistically significant difference for the change in SST from short to long-term follow-up.

Table Legends:

Table 1: Cohort demographic and rotator cuff characteristics

Table 2: Rotator cuff tear and repair characteristics

Table 3: Shoulder range of motion at preoperative, short-term and long-term follow-up.

Table 4 : Short-term and long-term follow-up patient reported outcomes. Statistically significant values highlighted in bold font.

Table 5: Percentage of patients who achieved MCID, SCB, and PASS for each PROM and at short and long-term outcome.

Table 6: Univariable model of associations of preoperative factors with PROMs at long-term follow-up. Statistically significant values highlighted in bold font. (B=Beta value, se=standard error)

Table 7: Analysis of association between initial rotator cuff tear size and long-term follow-up PROMs. Tear sizes 1=small, 2=medium, 3=large, 4=massive. (F= F statistic). Statistically significant values highlighted in bold font.

Table. 8: Analysis of association of preoperative and intra-operative factors with full thickness recurrent rotator cuff tears. (OR=odds ratio; CI=confidence interval). Statistically significant values highlighted in bold font

Table 9: Analysis of association of preoperative and intraoperative factors with rotator cuff tear arthropathy. Statistically significant values highlighted in bold font.

Table 1: Cohort demographic and rotator cuff characteristics

Characteristic	**n (%) or mean (±SD)**
Age in years	50.9 (±6.0)
Male sex	34 (69.4%)
Number of medical comorbidities	1.9 (1.6±)
College graduate	19 (38.8%)
Dominant shoulder involved	33 (66.4%)
Married	40 (85.1%)
Mechanism	
Atraumatic	20 (40.8%)
Other	22 (44.9%)
High energy trauma	7 (14.3%)
Workman's compensation	9 (18.4%)

Table 2: Rotator cuff tear and repair characteristics

Rotator Cuff Tear Size	**n (%)**
small	13 (27.1%)
medium	17 (35.4%)
large	14 (27.1%)
massive	5 (10.4)%
Subscapularis involved (incomplete tears)	8 (16.3%)
Repair technique	
Mini open	25 (51.02%)
Arthroscopic	15 (30.6%)
Open	9 (18.4%)

Table 3: Shoulder range of motion at preoperative, short-term and long-term follow-up.

	Preoperative	Short-term follow-up	Pre op vs short-term P value	Long-term follow-up	Short term vs long term P value
AFE	133.3±41.7°	154.5±11°	$p<0.01$	149.3±17.1°	$p=0.08$
AER	44.4±14.3°	44.2±12.4°	$p>0.05$	38.8±24.2°	$p=0.01$
PIR	T11	T9	$p<0.0001$	T11	$P<0.001$

AFE= active forward elevation
AER= active external rotation with elbow at side
PIR= passive internal rotation high level of thumb behind back

Table 4 : Short-term and long-term follow-up patient reported outcomes. Statistically significant values highlighted in bold font.

PROM	**Baseline**	**Short-Term**	**%MOI**	**Long-Term**	**%MOI**	**P value short vs long-term**
DASH	38.25 ± 19.5	13.72 ±16.72	61.15±55.80	16.05±19.15	45.78±83.39	0.31
SST	5.15±3.34	10.00 ±3.08	70.24±46.78	9.13±3.53	33.14±154.89	**0.03***
VAS Pain	5.77±2.12	2.03±2.47	51.83±103.29	1.48±2.70	73.31±44.59	0.49
ASES	NA	NA	NA	81.09±23.62	NA	NA
SF-36 PF (% age adjusted)	86.49±22.76	97.70±23.37	NA	105.91±36.98	NA	0.62
SF-36 PCS	39.0±8.63	45.12±10.93	NA	44.51±10.96	NA	0.36

%MOI= Percent maximal outcome improvement
*=statistical significance

Table 5: Percentage of patients who achieved MCID, SCB, and PASS for each PROM and at short and long-term outcome.

	MCID		SCB		PASS	
	Short-Term	**Long-Term**	**Short-Term**	**Long-Term**	**Short-Term**	**Long-Term**
DASH	76%	68%	NP	NP	NP	NP
SST	64%	54%	NP	NP	NP	NP
VAS Pain	86%	77%	81%	73%	83%	77%
ASES	NA	NA	NA	NA	NA	65%

NA= not available as ASES score was not determined at preoperative and short-term follow up
NP= no published values

Table 6: Univariable model of associations of preoperative factors with PROMs at long-term follow-up. Statistically significant values highlighted in bold font. (B=Beta value, se=standard error)

	VAS pain B (se) (95% CI)	SST B (se) (95% CI)	DASH B (se) (95% CI)	ASES B (se) (95% CI)	SF-36 PF age adjusted B (se) (95% CI)	SF-36 PCS B (se) (95% CI)
Patient age	NS	NS	NS	**-1.03 (0.50) (-2.04, -0.03)***	NS	**-0.55 (0.28) (-1.10, 0.01)***
Male sex	**-20.52 (9.78) (-40.41, -0.83)***	**22.23 (9.50) (3.09, 41.37)***	**-12.75 (6.42) (-25.69, 0.19)***	**17.53 (8.56) (0.29, 34.78)***	**31.81 (11.58) (8.47, 55.15)***	**7.79 (3.59) (0.58, 15.01)***
# comorbidities	NS	**-5.18 (2.61) (-10.43, 0.07)***	**4.53 (1.96) (0.59, 8.47)***	-4.68 (2.75) (-10.22, 0.86)	**-13.51 (2.80) (-19.16, -7.87)***	**-3.52 (0.86) (-5.25, -1.78)***
Traumatic injury	**-13.48 (7.25) (-28.08, 1.12)***	**17.36 (7.69) (1.88, 32.84)***	-9.05 (5.17) (-19.46, 1.36)^	NS	**21.40 (9.57) (2.12, 40.68)***	**6.25 (2.91) (0.41, 12.11)***
Subscapularis involvement	**-18.14 (4.51) (-27.23, -9.05)***	NS	NS	NS	NS	NS
Preoperative Tear size†	**0.04***	0.08^	**0.03***	0.15		

* P<0.05
^ 0.05<p<0.10
† Small tear size associated with worse PROMs

Table 7: Analysis of association between initial rotator cuff tear size and long-term follow-up PROMs. Tear sizes 1=small, 2=medium, 3=large, 4=massive. (F= F statistic). Statistically significant values highlighted in bold font.

Outcome	**Preoperative Tear Size**	**Mean Score ±std dev**	**F(3,43)**	***P***
DASH	**1**	24.0±23.0	3.26	**0.03***
	2	11.9±16.5		
	3	7.9±10.4		
	4	31.83±22.3		
SST	**1**	63.7±36.9	2.44	0.08
	2	80.0±22.6		
	3	90.1±17.6		
	4	60.0±41.0		
ASES	**1**	71.4±32.9	1.84	0.15
	2	87.7±17.0		
	3	88.8±13.8		
	4	72.8±28.5		
PAIN	**1**	3.2±3.5	3.05	**0.04***
	2	1.1±2.3		
	3	0.3±0.7		
	4	1.7±3.7		

Table. 8: Analysis of association of preoperative and intra-operative factors with full thickness recurrent rotator cuff tears. (OR=odds ratio; CI=confidence interval). Statistically significant values highlighted in bold font

Factor	Univariable Models		Multivariable Model	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Age	1.09 (0.98, 1.21)	0.13		
Male	2.40 (0.54, 10.69)	0.24		
Inj. Dominant arm	2.60 (0.59, 11.47)	0.20		
Married	1.07 (0.17, 6.63)	0.94		
# comorbidities	1.06 (0.74, 1.52)	0.75		
Traumatic injury	1.15 (0.30, 4.39)	0.83		
Workman's Comp	6.67 (1.33, 33.55)	**0.02**	4.96 (0.54, 45.44)	0.15
Critical shoulder angle	1.05 (0.91, 1.22)	0.47		
Acromial tilt	1.08 (0.97, 1.19)	0.15		
Tear length	1.39 (0.74, 2.59)	0.30		
Tear width	2.86 (1.22, 6.72)	**0.02**	1.32 (0.43, 4.07)	0.62
Subscap involvement	5.00 (0.97, 25.87)	0.055	0.27 (0.01, 11.52)	0.48
Size of tear		**<0.0001**		**<0.0001**
1	<0.01 (<0.01, <0.01)		<0.01 (<0.01, <0.01)	
2	REFERENCE		REFERENCE	
3	5.44 (0.99, 29.94)		6.99 (1.01, 48.49)	
4	18.67 (1.39, 249.88)		9.64 (0.31, 301.38)	

Table 9: Analysis of association of preoperative and intraoperative factors with rotator cuff tear arthropathy. Statistically significant values highlighted in bold font.

Factor	Univariable Models		Multivariable Model	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Age	1.0 (0.90, 1.10)	0.92		
Male	2.95 (0.67, 12.95)	0.15		
Inj. Dominant arm	1.26 (0.34, 4.64)	0.73		
Married	1.30 (0.21, 7.92)	0.77		
# comorbidities	0.92 (0.63, 1.34)	0.66		
Traumatic injury	1.39 (0.38, 5.07)	0.61		
Workman's Comp	2.92 (0.64, 13.30)	0.16		
Critical shoulder angle	1.01 (0.89, 1.15)	0.88		
Acromial tilt	1.04 (0.95, 1.15)	0.38		
Tear length	1.23 (0.66, 2.30)	0.52		
Tear width	2.27 (1.003, 5.15)	**0.049**	3.01 (0.99, 9.17)	**0.053**
Subscap involvement	4.03 (0.79, 20.42)	0.09	0.50 (0.03, 9.93)	0.64
Size of tear		0.10		
1	REFERENCE			
2	0.71 (0.11, 4.52)			
3	2.86 (0.50, 16.23)			
4	13.33 (0.98, 182.19)			

Figure 1: Flow chart of patient inclusion and exclusion.

268 patients treated with rotator cuff repair performed between 1/1/1999 and 12/31/2001

99 excluded > age 60

169 patients

38 declined to participate
26 deceased
46 lost to follow-up
9 excluded
1 did not complete study protocol

49 patients in final study cohort

Figure 2: Comparison of short and long-term patient reported outcomes for DASH, SST and VAS pain. * indicates statistically significant difference for the change in SST from short to long-term follow-up.