Systematic Review

Superior Capsular Reconstruction Provides Sufficient Biomechanical Outcomes for Massive, Irreparable Rotator Cuff Tears: A Systematic Review

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Purpose: To critically review the literature reporting biomechanical outcomes of superior capsular reconstruction (SCR) for the treatment of massive and/or irreparable rotator cuff tears. **Methods:** A systematic review was performed following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines using the PubMed, MEDLINE, and Cochrane Library databases in August 2020. Cadaveric studies were assessed for glenohumeral translation, subacromial contact pressure, and superior humeral translation comparing SCR with an intact cuff with reference to a torn control state. **Results:** A total of 15 studies (142 shoulders) were included in our data analysis. SCR showed improvements in superior humeral translation, subacromial contact force, and glenohumeral contact force when biomechanically compared with the massive and/or irreparably torn rotator cuff. No statistically significant differences were found between SCR and the intact rotator cuff regarding superior humeral translation (standard mean difference [SMD], 2.09 mm vs 2.50 mm; $P = .54$) or subacromial contact force (SMD, 2.85 mPa vs 2.83 mPa; $P = .99$). Significant differences were observed between SCR and the intact cuff for glenohumeral contact force only, in favor of the intact cuff (SMD, 1.73 N vs 5.45 N; $P = .03$). **Conclusions:** SCR may largely restore static restraints to superior humeral translation in irreparable rotator cuff tears, although active glenohumeral compression is diminished relative to the intact rotator cuff. **Clinical Relevance:** Investigating the biomechanical outcomes of SCR will help surgeons better understand the effectiveness of this treatment option.

The rotator cuff musculature acts to balance the forces across the glenohumeral joint and provide dynamic stability to the shoulder.[1] Disruption of this mechanism leads to unopposed pull of the deltoid, superior migration of the humeral head, and in some cases, progression to cuff tear arthropathy (CTA).[2] Massive rotator cuff tears, generally defined as greater than 5 cm in size or involving greater than 2 tendons, present a significant challenge to both the patient and the surgeon.[1,3] These tears are often associated with advanced muscle atrophy and fatty infiltration, and they are difficult to repair to the anatomic footprint under normal or nearly normal tension.[4,5] As such, treatment options for massive, irreparable rotator cuff tears vary widely.

Arthroscopic repair is an option; however, concerns exist regarding the high rates of structural failure.[6] Reverse shoulder arthroplasty (RSA) is another treatment option and has been shown to be more cost-effective than arthroscopic rotator cuff repair for massive, irreparable tears.[7] Despite the increasing popularity of RSA in the past 2 decades, the risks of poor functional outcomes and postoperative complications remain significant.[8-14] In a previous systematic review, Zumstein et al.[14] found global rates of complications, reoperations, and revisions at a mean of

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24 months' follow-up of 24%, 3.5%, and 10%, respectively. More specifically, complications and clinical outcomes in younger, active patients are especially problematic.[15-19] Other treatment options for massive and/or irreparable tears include arthroscopic debridement, partial rotator cuff repair, tendon transfer, and subacromial balloon spacer placement. Treatment algorithms for massive, irreparable rotator cuff tears have been proposed; however, existing literature does not convey a universally acceptable and evidence-based treatment algorithm.[11,20]

As described by Mihata et al.[21] in 2013, superior capsular reconstruction (SCR) is quickly gaining attention as a viable treatment option, and interest continues to build on the role of the superior capsule to glenohumeral mechanics and function. To this end, Adams et al.[22] described the superior capsule as the "essential lesion" to shoulder biomechanics and dysfunction, rather than the rotator cuff tendon tear itself. The superior capsule is intimately associated with the superior rotator cuff, spanning the undersurface of the supraspinatus and infraspinatus muscle—tendon unit and accounting for up to 30% to 61% of the greater tuberosity footprint.[22-25] In the setting of an irreparable rotator cuff tear, the superior capsule can be reconstructed in an attempt to prevent cephalad motion while restoring more functional glenohumeral biomechanics.

SCR was initially pioneered with use of a thicker, quadrupled fascia lata autograft (5-8 mm). Several authors have suggested improved shoulder stability with thicker grafts.[26,27] However, concerns over donor-site morbidity, increased operative time, and surgical complexity have motivated the search for alternative graft sources. Acellular dermal matrix allograft of 3 mm thickness or greater has been used in recent years as an alternative and has helped drive the popularity of SCR in the United States and Europe.[28-34] The body of evidence regarding the outcomes of SCR is limited to several small case series with short clinical follow-up and biomechanical studies.

The purpose of this study was to critically review the literature reporting biomechanical outcomes of SCR for the treatment of massive and/or irreparable rotator cuff tears. We hypothesized that SCR would restore glenohumeral biomechanics similarly to that of the intact rotator cuff.

Methods

A systematic review was registered with PROSPERO and performed following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines. A comprehensive literature search was performed using the PubMed, MEDLINE, and Cochrane Library electronic databases. The following terms were used as keywords and appeared in the title, abstract, or keyword fields: massive rotator cuff tear, irreparable rotator cuff tear, superior capsular reconstruction, and superior capsule reconstruction. Additionally, all references in the included studies were cross-referenced for inclusion if any were missed by the initial search. The final search was completed on August 16, 2020, independently by 2 authors (T.J.S. and L.K.). Trials were eligible for inclusion if they met the following criteria: human or cadaveric subjects with documented massive and/or irreparable rotator cuff tears undergoing biomechanical testing after SCR. Studies involving animals, operative techniques, partial rotator cuff tear, and rotator cuff repair were excluded, as were duplicates and nonrelevant studies. Case reports and abstracts without available full text were excluded. Non—English-language articles were excluded if direct translation was not possible. A full-text review was performed by 2 authors (T.J.S. and L.K.) to confirm appropriateness for inclusion. Any disagreement between authors during each step of the review process was resolved by a discussion between the 2 reviewers. If a consensus could not be reached, final inclusion was decided by a third reviewer (B.R.W.). A flow diagram outlining the selection process can be found in Fig 1.

Biomechanical studies were assessed for several outcomes including superior translation of the humerus, glenohumeral contact force, subacromial contact force or pressure, subacromial contact area, total rotational range of motion, abduction strength, maximum abduction angle, cumulative deltoid force, anchor pullout strength, and maximum load to graft failure. Owing to variations in study design and testing conditions, biomechanical outcomes were compared at 0° of glenohumeral abduction for a greater yield of pooled outcome measures. Descriptive statistics were calculated from each included study. For continuous data, weighted means and standard deviations were calculated for all subjects and outcome parameters. Standard mean differences were calculated between the SCR group and the intact rotator cuff group by comparing with the torn rotator cuff state as a shared control.

The Metafor package, as part of RStudio software (version 1.0.143; R Foundation for Statistical Computing, Vienna, Austria), was used for data analysis. Forest plots were created for superior humeral translation, glenohumeral contact force, and subacromial contact force (Figs 2-4). The I^2 index was used to measure heterogeneity of included studies.[35] Effect sizes were calculated using random-effects models with the DerSimonian-Laird estimator because high heterogeneity precluded use of a fixed-effects model.[36,37] All outcomes of analysis were reported as the weighted average or standard mean difference with the 95% confidence interval (CI). A funnel plot was created to assess publication bias (Fig 5). The estimated treatment effect for superior humeral migration was plotted on the x-axis, while effect sizes were plotted on the y-axis. Point

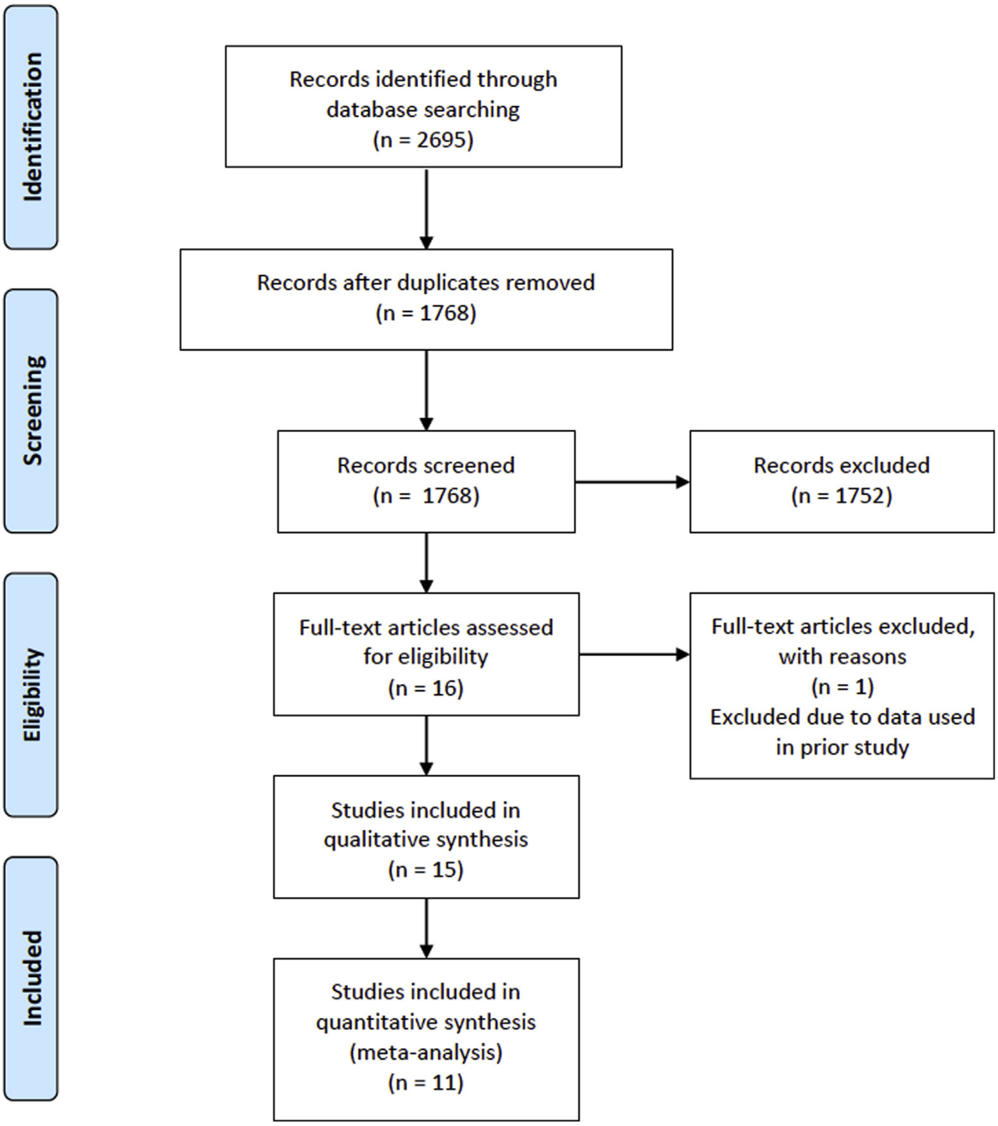

Fig 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart.

estimates were verified to be symmetrical around the real estimated treatment effect to show limited publication bias.[38]

Results

The initial keyword search returned 2,695 articles for review: 1,262 articles on massive rotator cuff tear, 577 articles on irreparable rotator cuff tear, 471 on superior capsular reconstruction, and 385 articles on superior capsule reconstruction. After screening for duplicate citations, 1,768 articles remained. After screening for appropriateness based on the title and abstract, 1,753 articles were excluded. Fifteen biomechanical articles, all of which involved cadaveric shoulders, were included for full-text review. A total of 142 cadaveric shoulders underwent SCR during biomechanical testing and were included in our analysis.[26,27,39-51] Graft types in the cadaveric samples were as follows: fascia lata in 51 shoulders,[26,27,39-42,46] dermal matrix in 71,[43-45,48,50,51] long head of the biceps (LHB) in 12,[39,47] and patellar tendon in 8.[49] Graft thickness was as follows: 8 mm in 22 shoulders,[26,40,41] 5 to 8 mm in 8 shoulders,[46] 5 mm in 8 shoulders,[42] 4 to 8 mm in 8 shoulders,[27] 4 to 6 mm in 8 shoulders,[43] 4 mm in 8 shoulders,[49] 3 to 6 mm in 8 shoulders,[51] 3 mm in 44 shoulders,[44,50] 2 to 4 mm in 11 shoulders,[45,48] and undisclosed in 17 shoulders.[39,47]

All 15 biomechanical studies performed SCR on cadaveric specimens in comparison to a simulated massive and/or irreparable rotator cuff tear state.[26,27,39-51] A control group, consisting of shoulders with an intact rotator cuff, was used for comparison in 13 of the 15 studies.[26,27,40-43,45,46,48-51] Surgical technique and experimental scenarios varied among studies and included SCR without acromioplasty, SCR with acromioplasty, SCR with subacromial resurfacing, SCR with additional posterior infraspinatus side-to-side

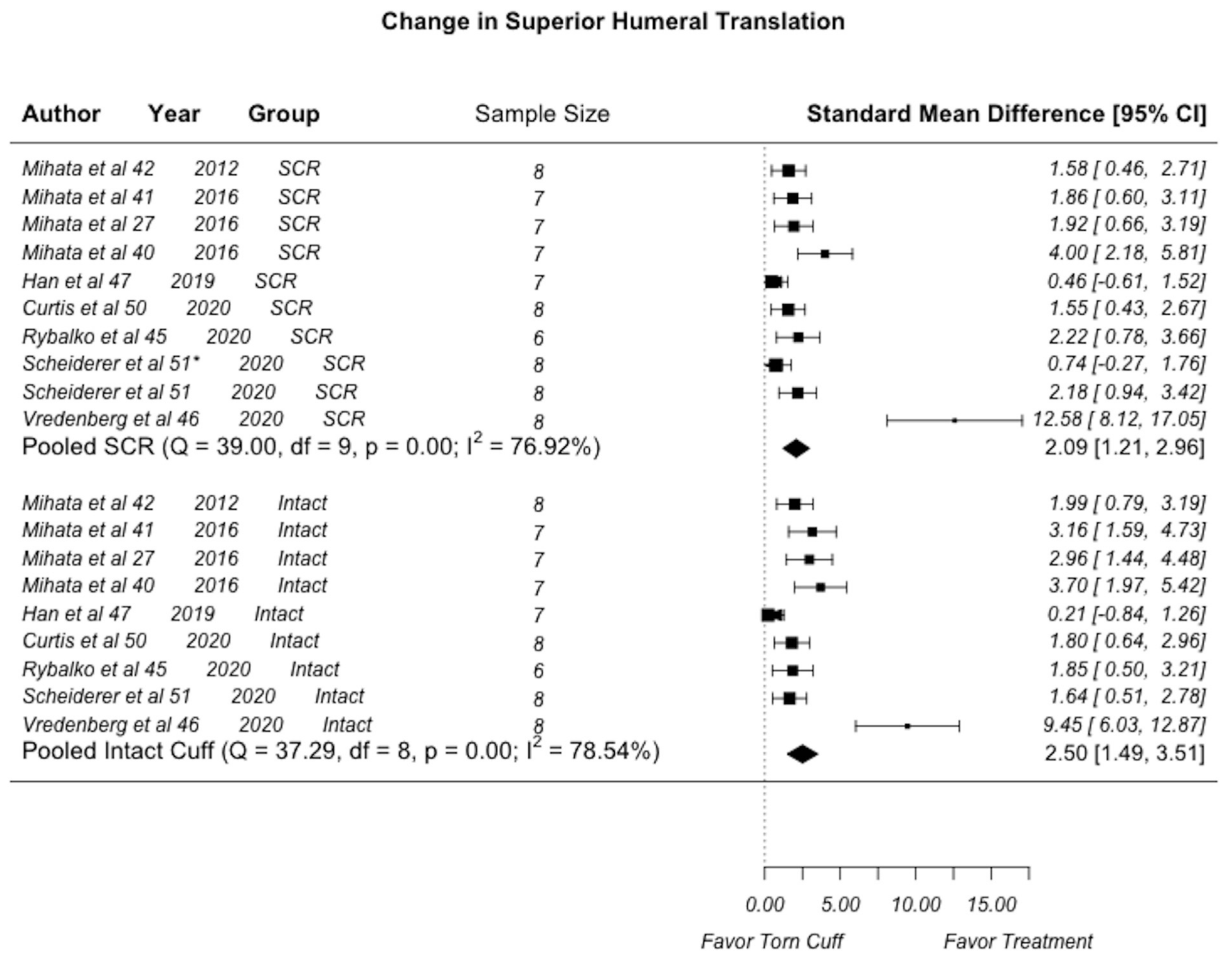

Fig 2. Forest plot showing change in superior humeral translation (in millimeters) between superior capsular reconstruction (SCR) and intact rotator cuff with reference to torn control state. Asterisk (*) indicates 3-mm thickness graft tendon was used. (CI, confidence interval.)

suturing, SCR with additional anterior and posterior side-to-side suturing, and various glenoid fixation techniques, as well as variations in graft types and thicknesses. Thirteen studies evaluated superior humeral translation and/or the force required to superiorly translate the humerus. All studies reported improvements after SCR compared with a torn control state.[26,27,39-43,45-51] Eleven studies evaluated subacromial contact force, and all showed improvements after SCR compared with a torn control state.[26,27,40-42,46-51] One study evaluated subacromial contact area in the torn state and reported improvements after SCR.[47] Three studies evaluated glenohumeral contact force and reported improvements after SCR in all scenarios.[26,41,42] Two studies evaluated shoulder abduction force between SCR and a torn control state and showed that the findings after SCR were comparable to the intact cuff state.[43,45] One study reported improvements in maximum abduction angle and cumulative deltoid force after SCR similar to the intact cuff state.[50] One study noted that fascia lata graft size remained constant after biomechanical testing whereas dermal allografts were found to elongate by approximately 15%.[26] Another study found no evidence of graft deformation with patellar tendon SCR grafts.[49]

Of the 15 biomechanical studies, 11 were included in the quantitative analysis.[26,27,40-42,45-47,49-51] Five studies were performed by the same group of authors, and all 11 studies used similar experimental conditions. Fresh frozen cadaveric shoulders were mounted on a custom shoulder testing system and analyzed under various conditions: with an intact rotator cuff, with an irreparably torn rotator cuff, and after SCR with both fascia lata and dermal allografts. For superior humeral translation, the standard mean difference between the experimental (either repaired or intact) and control (torn cuff) groups was 2.28 mm overall (2.09 mm for SCR vs 2.50 mm for intact; 95% CI, 1.62-2.91 mm; $P < .001$, $I^2 = 76.7\%$). For subacromial contact force, the standard mean difference was 2.81 mPa overall (2.85 mPa for SCR vs 2.83 mPa for intact; 95% CI, 1.85-3.78 mPa; $P < .001$, $I^2 = 88.9\%$); For glenohumeral contact force, the standard mean difference was 3.4 N overall (1.73 N for SCR vs 5.45 N for intact;

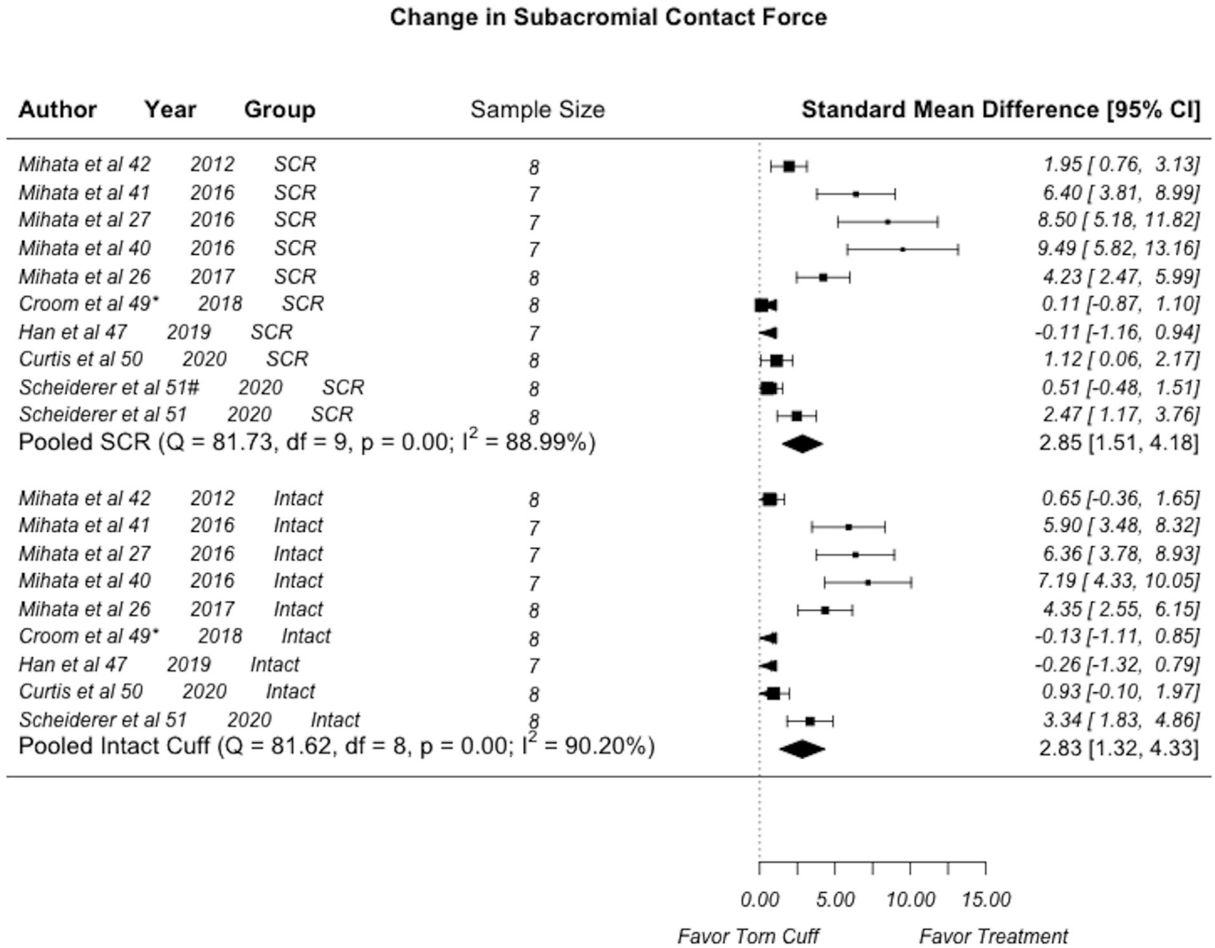

Fig 3. Forest plot showing change in subacromial contact force (in millipascals) between superior capsular reconstruction (SCR) and intact rotator cuff with reference to torn control state. Asterisk (*) indicates patellar tendon graft was used; hash (#) indicates 3-mm thickness graft was used. (CI, confidence interval.)

95% CI, 1.60-5.20 N; $P = .03$). The forest plots for superior humeral translation, subacromial contact force, and glenohumeral contact are shown in Fig 2, 3, and 4, respectively.

Discussion

SCR showed improvements in superior humeral translation, subacromial contact force, subacromial contact area, glenohumeral contact force, and shoulder

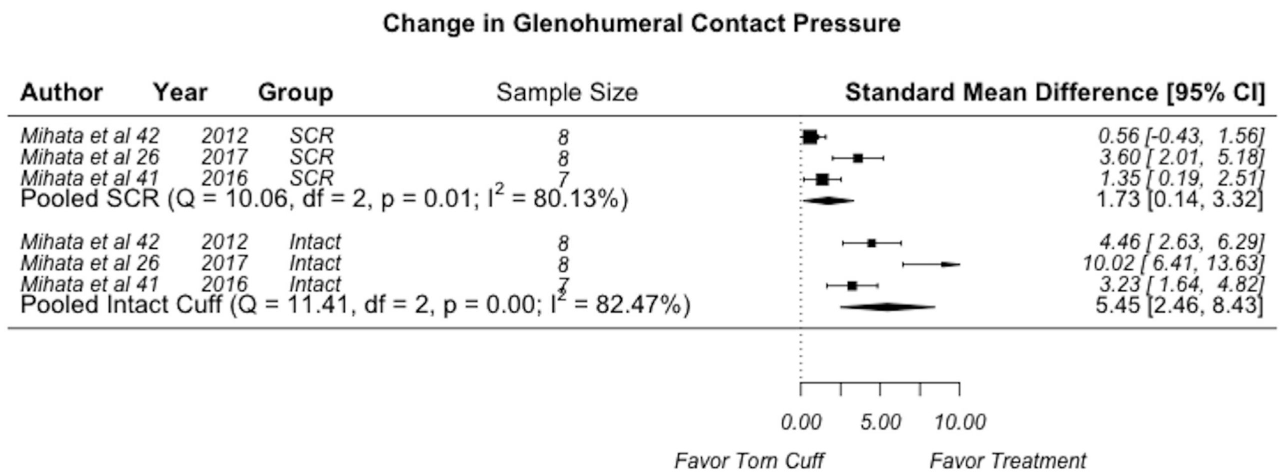

Fig 4. Forest plot showing change in glenohumeral contact pressure (in newtons) between superior capsular reconstruction (SCR) and intact rotator cuff with reference to torn control state. (CI, confidence interval.)

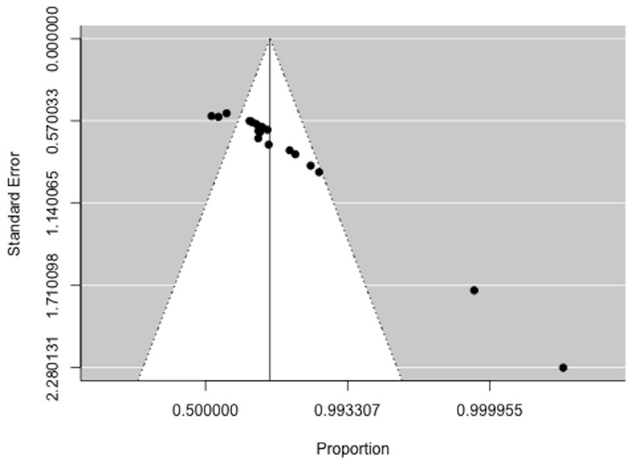

Fig 5. Funnel plot showing publication bias of all studies with respect to superior humeral migration.

abduction force when biomechanically compared with the massive and/or irreparably torn rotator cuff. Pooled analysis of the available biomechanical studies showed no appreciable difference between SCR and the intact rotator cuff regarding superior humeral translation or subacromial contact force. The only statistically significant biomechanical difference between the native rotator cuff and SCR related to glenohumeral contact force, which exhibited slightly higher values in favor of the intact rotator cuff. These findings may suggest that SCR confers sufficient stability to reconstitute low-demand physiological shoulder function comparable to an intact rotator cuff with respect to humeral translation and subacromial contact force. Therein, from a biomechanical standpoint, SCR may be a viable option for the treatment of massive, irreparable rotator cuff tears.

Massive rotator cuff tears cause derangement of the glenohumeral joint. Large tears create pain and loss of function within the rotator cuff, which leads to disuse, diffuse osteopenia, and potential fatty degeneration that propagates pathology within the rotator cuff.[2,52] Irreparable rotator cuff tears often present with concomitant tears of the superior capsule.[53] Authors have suggested that a competent superior capsule is essential to glenohumeral biomechanics.[22] The superior capsule spans the undersurface of the superior rotator cuff and additionally occupies a significant portion of the greater tuberosity footprint.[22-25] Furthermore, compromise of the superior capsule introduces extravasation of synovial fluid, alterations in intra-articular pressures, and impaired nutritional delivery to the glenohumeral cartilage.[52] Superior translation of the humerus leads to gross mechanical compromise; unbalanced muscular forces; and trauma to the glenoid, humerus, acromion, and coracoid. These factors may ultimately manifest clinically as pain and loss of function. Massive and/or irreparable tears may also result in subacromial impingement, which may serve as an additional pain generator.[42] Neer et al.[2] described the spectrum of glenohumeral pathology resulting from prolonged rotator cuff dysfunction as “cuff tear arthropathy.” CTA results in irreversible osseous changes to the glenoid and humerus, as described by Hamada et al.[54] Treatment options to prevent the development of CTA in massive, irreparable rotator cuff tears include debridement, tendon transfer, interpositional arthroplasty, subacromial spacer placement, RSA, or SCR.[55] SCR is advantageous because it has limited to no donor-site morbidity and shows improvements in glenohumeral biomechanics.[56] As such, SCR may be a valuable option for patients with massive, irreparable rotator cuff tears; low physiological demand; and limited arthropathy.[52,55] Continued long-term clinical studies are required to show whether SCR leads to an appreciable reduction in the development of CTA.

The findings from this review of the biomechanical evidence show that SCR may restore capsular integrity by reducing subacromial contact pressure and superior humeral head migration. From this perspective, SCR may hold promise in restoring shoulder function and reducing the incidence of CTA in well-indicated patients. However, the findings are limited by the paucity of biomechanical data on this subject. Of the 15 studies included in this review, 5 are from Mihata et al.[26,27,40-42] and 7 were performed at the same research site. These studies show significant similarities in terms of study design and experimental conditions. Additionally, it is unclear whether specimens may have been included in more than 1 study. These factors may potentially introduce bias, limiting the reliability of the pooled results and the generalizability of the findings.

Four additional biomechanical studies were included in the qualitative analysis but could not be included in the quantitative analysis because of a lack of common outcome measures. El-shaar et al.[39] tested 5 matched pairs of cadaveric shoulders after massive rotator cuff tear, SCR with fascia lata autograft, and SCR with LHB autograft. They reported improvements after SCR in the force required to superiorly translate the humerus 1.5 cm when compared with the torn control state, with a trend toward a stronger reconstruction in the LHB group. However, the results were not statistically significant ($P = .059$). The authors also noted no failures in either the LHB or fascia lata SCR group during biomechanical testing. Singh et al.[43] compared the biomechanical outcomes of SCR with the intact cuff state, irreparable tear state, and subacromial balloon spacer placement. They reported that both SCR and the balloon spacer restored superior humeral translation and functional abduction force similar to that of the intact cuff state. No significant differences were found between the balloon spacer and SCR ($P = .99$). Pogorzelski et al.[44] evaluated 36 cadaveric SCRs using dermal allografts with various glenoid fixation techniques. They concluded that there was no difference in graft elongation or stiffness between fixation techniques but reported that the pullout strength was greater with the use of 3 threaded anchors versus 4 push-in anchors. Smith et al.[48] reported improved superior humeral translation and subacromial contact force after SCR with both 2-mm and 4-mm dermal allografts when compared with the torn state. However, they noted biomechanical superiority of the double-layered 4-mm grafts in terms of superior humeral translation. Unfortunately, standard deviations were not reported, and these data were therefore excluded from quantitative analysis in our study.

Recently published systematic reviews have reported improvements in visual analog scale scores, range of motion, and clinical outcome scores after SCR for massive and/or irreparable rotator cuff tears.[56-59] However, only a few studies have compared the existing literature regarding biomechanical outcomes. Makovicka et al.[56] performed a qualitative clinical and biomechanical review by graft type in 2020 involving 8 of the same cadaveric studies included in our present review. They reported improvements in superior humeral translation and subacromial contact forces after SCR when compared with the irreparable tear state. However, no pooled biomechanical analysis was performed. Galvin et al.[59] published a qualitative review including 5 biomechanical studies in 2019. They summarized that SCR results in improved glenohumeral stability and decreased subacromial contact forces when performed with an 8-mm fascia lata graft versus a 4-mm acellular dermal allograft. In addition, they suggested the routine addition of a subacromial decompression, posterior side-to-side graft fixation to any residual infraspinatus, and graft fixation in 15° to 45° of abduction and 20° of internal rotation. These conclusions were drawn mainly from the biomechanical cadaveric studies by Mihata et al.[26,27,40-42]

The merits of our systematic review include a moderate sample size of 142 cadaveric shoulders. In addition, the included studies involved a variety of graft types (fascia lata allograft, fascia lata autograft, acellular dermal matrix, LHB tendon autograft, and patellar tendon allograft) and a variety of graft thicknesses (range, 2-8 mm). Finally, to our knowledge, this is the only review to include a quantitative biomechanical analysis of pooled cadaveric outcomes comparing SCR and the intact rotator cuff with reference to a torn control state. Of the 15 studies, 11 (73.3%) were able to be included in the quantitative analysis owing to similarities in experimental design, testing conditions, and outcome measures.

Limitations

We acknowledge that our analysis has several limitations. Five of the studies were performed by Mihata et al.,[26,27,40-42] and 7 studies were performed at the same laboratory site. As previously mentioned, the studies showed significant similarities in design and it is unclear whether specimens and/or data were included in more than 1 study. These factors may potentially introduce bias into the results, limiting the generalizability of the pooled findings. Most of the studies in the quantitative analysis involved thicker fascia lata grafts and may lack translational validity for the prevailing dermal grafts used in North America. In addition, grafts were tested immediately after fixation; thus, we are unable to account for any changes that may occur with graft healing (or lack thereof). Finally, biomechanical studies lack active muscular contraction, represent static rather than dynamic muscular forces, and do not necessarily correlate with clinical outcomes.

Conclusions

SCR may largely restore static restraints to superior humeral translation in irreparable rotator cuff tears, although active glenohumeral compression is diminished relative to the intact rotator cuff.

References

1. Burkhart SS. Arthroscopic treatment of massive rotator cuff tears. Clinical results and biomechanical rationale. *Clin Orthop Relat Res* 1991;267:45-56.
2. Neer CS, Craig EV, Fukuda H. Cuff-tear arthropathy. *J Bone Joint Surg Am* 1983;65:1232-1244.
3. Gerber C, Fuchs B, Hodler J. The results of repair of massive tears of the rotator cuff. *J Bone Joint Surg Am* 2000;82:505-515.
4. Bedi A, Dines J, Warren RF, Dines DM. Massive tears of the rotator cuff. *J Bone Joint Surg Am* 2010;92:1894-1908.
5. Rockwood CA, Williams GR, Burkhead WZ. Débridement of degenerative, irreparable lesions of the rotator cuff. *J Bone Joint Surg Am* 1995;77:857-866.
6. Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. *J Bone Joint Surg Am* 2004;86:219-224.
7. Makhni EC, Swart E, Steinhaus ME, et al. Cost-effectiveness of reverse total shoulder arthroplasty versus arthroscopic rotator cuff repair for symptomatic large and massive rotator cuff tears. *Arthroscopy* 2016;32:1771-1780.
8. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: A follow-up of a previous study. *J Bone Joint Surg Am* 2017;99:454-461.
9. Bohsali KI, Bois AJ, Wirth MA. Complications of shoulder arthroplasty. *J Bone Joint Surg Am* 2017;99:256-269.
10. Gerber C, Canonica S, Catanzaro S, Ernstbrunner L. Longitudinal observational study of reverse total shoulder arthroplasty for irreparable rotator cuff dysfunction: Results after 15 years. *J Shoulder Elbow Surg* 2018;27:831-838.
11. Groh GI, Groh GM. Complications rates, reoperation rates, and the learning curve in reverse shoulder arthroplasty. *J Shoulder Elbow Surg* 2014;23:388-394.

12. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. *J Bone Joint Surg Am* 2011;93:2249-2254.
13. Palsis JA, Simpson KN, Matthews JH, Traven S, Eichinger JK, Friedman RJ. Current trends in the use of shoulder arthroplasty in the United States. *Orthopedics* 2018;41:e416-e423.
14. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: A systematic review. *J Shoulder Elbow Surg* 2011;20:146-157.
15. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJP. Reverse shoulder arthroplasty as salvage for failed prior arthroplasty in patients 65 years of age or younger. *J Shoulder Elbow Surg* 2014;23:1036-1042.
16. Ek ETH, Neukom L, Catanzaro S, Gerber C. 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;22:1199-1208.
17. Muh SJ, Streit JJ, Wanner JP, et al. Early follow-up of reverse total shoulder arthroplasty in patients sixty years of age or younger. *J Bone Joint Surg Am* 2013;95:1877-1883.
18. Otto RJ, Clark RE, Frankle MA. Reverse shoulder arthroplasty in patients younger than 55 years: 2- to 12-year follow-up. *J Shoulder Elbow Surg* 2017;26:792-797.
19. Sershon RA, Van Thiel GS, Lin EC, et al. Clinical outcomes of reverse total shoulder arthroplasty in patients aged younger than 60 years. *J Shoulder Elbow Surg* 2014;23:395-400.
20. Gerber C, Wirth SH, Farshad M. Treatment options for massive rotator cuff tears. *J Shoulder Elbow Surg* 2011;20:S20-S29.
21. Mihata T, Lee TQ, Watanabe C, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthroscopy* 2013;29:459-470.
22. Adams CR, DeMartino AM, Rego G, Denard PJ, Burkhart SS. The rotator cuff and the superior capsule: Why we need both. *Arthroscopy* 2016;32:2628-2637.
23. Kordasiewicz B, Kiciński M, Pronicki M, Małachowski K, Brzozowska M, Pomianowski S. A new look at the shoulder anterior capsuloligamentous complex complementing the insertion of the subscapularis tendon—Anatomical, histological and ultrasound studies of the lesser tuberosity enthesis. *Ann Anat* 2016;205:45-52.
24. Nimura A, Kato A, Yamaguchi K, et al. The superior capsule of the shoulder joint complements the insertion of the rotator cuff. *J Shoulder Elbow Surg* 2012;21:867-872.
25. Pouliart N, Somers K, Eid S, Gagey O. Variations in the superior capsuloligamentous complex and description of a new ligament. *J Shoulder Elbow Surg* 2007;16:821-836.
26. Mihata T, Bui CNH, Akeda M, et al. A biomechanical cadaveric study comparing superior capsule reconstruction using fascia lata allograft with human dermal allograft for irreparable rotator cuff tear. *J Shoulder Elbow Surg* 2017;26:2158-2166.
27. Mihata T, McGarry MH, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical effect of thickness and tension of fascia lata graft on glenohumeral stability for superior capsule reconstruction in irreparable supraspinatus tears. *Arthroscopy* 2016;32:418-426.
28. Adams CR, Denard PJ, Brady PC, Hartzler RU, Burkhart SS. The arthroscopic superior capsular reconstruction. *Am J Orthop* 2016;45:320-324.
29. Burkhart SS, Denard PJ, Adams CR, Brady PC, Hartzler RU. Arthroscopic superior capsular reconstruction for massive irreparable rotator cuff repair. *Arthrosc Tech* 2016;5:e1407-e1418.
30. Denard PJ, Brady PC, Adams CR, Tokish JM, Burkhart SS. Preliminary results of arthroscopic superior capsule reconstruction with dermal allograft. *Arthroscopy* 2018;34:93-99.
31. Hirahara AM, Andersen WJ, Panero AJ. Superior capsular reconstruction: Clinical outcomes after minimum 2-year follow-up. *Am J Orthop* 2017;46:266-278.
32. Lee S-J, Min Y-K. Can inadequate acromiohumeral distance improvement and poor posterior remnant tissue be the predictive factors of re-tear? Preliminary outcomes of arthroscopic superior capsular reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2018;26:2205-2213.
33. Millett P, Pogorzelski J, Horan M, Fritz E, Katthagen J. Arthroscopic superior capsule reconstruction (ASCR) vs. latissimus dorsi transfer (LDT): A comparison of early clinical outcomes. *Arthroscopy* 2017;33:e3-e4.
34. Pennington WT, Chen SW, Bartz BA, Pauli JM. Arthroscopic superior capsular reconstruction with acellular dermal allograft using push-in anchors for glenoid fixation. *Arthrosc Tech* 2019;8:e51-e55.
35. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003;327:557-560.
36. DerSimonian R, Laird N. Meta-analysis in clinical trials revisited. *Contemp Clin Trials* 2015;45:139-145 (pt A).
37. Sidik K, Jonkman JN. A note on variance estimation in random effects meta-regression. *J Biopharm Stat* 2005;15:823-838.
38. Stuck AE, Rubenstein LZ, Wieland D. Bias in meta-analysis detected by a simple, graphical test. Asymmetry detected in funnel plot was probably due to true heterogeneity. *BMJ* 1998;316:469. author reply 470-471.
39. El-shaar R, Soin S, Nicandri G, Maloney M, Voloshin I. Superior capsular reconstruction with a long head of the biceps tendon autograft: A cadaveric study. *Orthop J Sports Med* 2018;6:232596711878536.
40. Mihata T, McGarry MH, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical effects of acromioplasty on superior capsule reconstruction for irreparable supraspinatus tendon tears. *Am J Sports Med* 2016;44:191-197.
41. Mihata T, McGarry MH, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical role of capsular continuity in superior capsule reconstruction for irreparable tears of the supraspinatus tendon. *Am J Sports Med* 2016;44:1423-1430.
42. Mihata T, McGarry MH, Pirolo JM, Kinoshita M, Lee TQ. Superior capsule reconstruction to restore superior stability in irreparable rotator cuff tears: A biomechanical cadaveric study. *Am J Sports Med* 2012;40:2248-2255.
43. Singh S, Reeves J, Langohr GDG, Johnson JA, Athwal GS. The subacromial balloon spacer versus superior capsular reconstruction in the treatment of irreparable rotator cuff tears: A biomechanical assessment. *Arthroscopy* 2019;35:382-389.

44. Pogorzelski J, Muckenhirn KJ, Mitchell JJ, et al. Biomechanical comparison of 3 glenoid-side fixation techniques for superior capsular reconstruction. *Am J Sports Med* 2018;46:801-808.
45. Rybalko D, Bobko A, Amirouche F, et al. Biomechanical effects of superior capsular reconstruction in a rotator cuff−deficient shoulder: A cadaveric study [published online June 9, 2020]. J Shoulder Elbow Surg. https://doi.org/10.1016/j.jse.2020.03.007.
46. Vredenburgh ZD, Prodromo JP, Tibone JE, et al. Biomechanics of tensor fascia lata allograft for superior capsular reconstruction [published online June 9, 2020]. J Shoulder Elbow Surg. https://doi.org/10.1016/j.jse.2020.04.025.
47. Han F, Kong CH, Hasan MY, Ramruttun AK, Kumar VP. Superior capsular reconstruction for irreparable supraspinatus tendon tears using the long head of biceps: A biomechanical study on cadavers. *Orthop Traumatol Surg Res* 2019;105:257-263.
48. Smith GC, Im HY, Lam PH. Effect of human dermal allograft thickness on glenohumeral stability for superior capsular reconstruction in irreparable supraspinatus tears: A biomechanical analysis of the superior capsular reconstruction—A cadaveric study [published online May 25, 2020]. Shoulder Elbow. https://doi.org/10.1177/1758573220925086.
49. Croom WP, Adamson GJ, Lin CC, et al. A biomechanical cadaveric study of patellar tendon allograft as an alternative graft material for superior capsule reconstruction. *J Shoulder Elbow Surg* 2019;28:1241-1248.
50. Curtis DM, Lee CS, Qin C, et al. Superior capsule reconstruction with subacromial allograft spacer: Biomechanical cadaveric study of subacromial contact pressure and superior humeral head translation. *Arthroscopy* 2020;36:680-686.
51. Scheiderer B, Kia C, Obopilwe E, et al. Biomechanical effect of superior capsule reconstruction using a 3-mm and 6-mm thick acellular dermal allograft in a dynamic shoulder model. *Arthroscopy* 2020;36:355-364.
52. Macaulay AA, Greiwe RM, LU Bigliani. Rotator cuff deficient arthritis of the glenohumeral joint. *Clin Orthop Surg* 2010;2:196-202.
53. Ciampi P, Scotti C, Nonis A, et al. The benefit of synthetic versus biological patch augmentation in the repair of posterosuperior massive rotator cuff tears: A 3-year follow-up study. *Am J Sports Med* 2014;42:1169-1175.
54. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. *Clin Orthop Relat Res* 1990:92-96.
55. Cvetanovich GL, Waterman BR, Verma NN, Romeo AA. Management of the irreparable rotator cuff tear. *J Am Acad Orthop Surg* 2019;27:909-917.
56. Makovicka JL, Chung AS, Patel KA, Deckey DG, Hassebrock JD, Tokish JM. Superior capsule reconstruction for irreparable rotator cuff tears: A systematic review of biomechanical and clinical outcomes by graft type. *J Shoulder Elbow Surg* 2020;29:392-401.
57. Catapano M, de Sa D, Ekhtiari S, Lin A, Bedi A, Lesniak BP. Arthroscopic superior capsular reconstruction for massive, irreparable rotator cuff tears: A systematic review of modern literature. *Arthroscopy* 2019;35:1243-1253.
58. Sochacki KR, McCulloch PC, Lintner DM, Harris JD. Superior capsular reconstruction for massive rotator cuff tear leads to significant improvement in range of motion and clinical outcomes: A systematic review. *Arthroscopy* 2019;35:1269-1277.
59. Galvin JW, Kenney R, Curry EJ, et al. Superior capsular reconstruction for massive rotator cuff tears: A critical analysis review. *JBJS Rev* 2019;7:e1.