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Management of irreparable massive rotator cuff tears: a systematic review and meta-analysis of patient-reported outcomes, reoperation rates, and treatment response

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This study was exempt from local institutional review board approval because of the study type (ie, systematic review and meta-analysis).

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Background: There is no consensus on the treatment of irreparable massive rotator cuff tears. The goal of this systematic review and meta-analysis was to (1) compare patient-reported outcome scores, (2) define failure and reoperation rates, and (3) quantify the magnitude of patient response across treatment strategies.
Methods: The MEDLINE, Embase, CENTRAL (Cochrane Central Register of Controlled Trials), and Scopus databases were searched for studies including physical therapy and operative treatment of massive rotator cuff tears. The criteria of the Methodological Index for Non-randomized Studies were used to assess study quality. Primary outcome measures were patient-reported outcome scores as well as failure, complication, and reoperation rates. To quantify patient response to treatment, we compared changes in the Constant-Murley score and American Shoulder and Elbow Surgeons (ASES) score with previously reported minimal clinically important difference (MCID) thresholds.
Results: No level I or II studies that met the inclusion and exclusion criteria were found. Physical therapy was associated with a 30% failure rate among the included patients, and another 30% went on to undergo surgery. Partial repair was associated with a 45% retear rate and 10% reoperation rate. Only graft interposition was associated with a weighted average change that exceeded the MCID for both the Constant-Murley score and ASES score. Latissimus tendon transfer techniques using humeral bone tunnel fixation were associated with a 77% failure rate. Superior capsular reconstruction with fascia lata autograft was associated with a weighted average change that exceeded the MCID for the ASES score. Reverse arthroplasty was associated with a 10% prosthesis failure rate and 8% reoperation rate.
Conclusion: There is a lack of high-quality comparative studies to guide treatment recommendations. Compared with surgery, physical therapy is associated with less improvement in perceived functional outcomes and a higher clinical failure rate.
Level of evidence: Level IV; Systematic Review

Keywords: Irreparable massive rotator cuff tear; systematic review; meta-analysis; patient-reported outcomes; response to treatment; failure rate; reoperation; complications

As the most common upper-extremity condition in persons aged > 50 years,[55] rotator cuff tear represents a significant clinical challenge in our aging population. The overall incidence of rotator cuff tears ranges from 5% to 40%,[53,54] with approximately 54% of individuals aged > 60 years having partial or complete rotator cuff tears.[64] Massive rotator cuff tears (MRCTs), commonly defined as full-thickness tears involving ≥2 tendons[10] or tears measuring >5 cm in the coronal plane,[23] are estimated to comprise approximately 20% of all rotator cuff tears and 80% of recurrent tears.[5,44]

Increasing rotator cuff tear size is associated with poor outcomes and high structural failure rates following surgical repair.[38,59] A review of 18 studies reporting outcomes after repair of massive tears found a retear rate of 78%. Despite the high rate of structural failure, much of the published literature supports an attempt at primary repair.[4] However, a number of these MRCTs are retracted or lack tendon length so that they cannot be reattached to their footprint and thus are irreparable. Numerous treatment strategies, such as physical therapy, débridement, partial repair, graft interposition, tendon transfer, superior capsular reconstruction (SCR), balloon arthroplasty, and reverse shoulder arthroplasty, have been proposed to treat irreparable MRCTs. The comparative efficacy of these treatments remains unclear.

The purpose of this systematic review and meta-analysis was to evaluate the highest-quality clinical evidence currently available to recommend either for or against the various treatment options for irreparable MRCTs. This was accomplished by (1) comparing patient-reported outcome (PRO) scores across treatment strategies, (2) reporting failure and reoperation rates, and (3) quantitatively evaluating the magnitude of patient response to treatment. We hypothesized that (1) there is a lack of a consistent definition of irreparable MRCTs, (2) operative treatment of irreparable tears leads to greater improvement in PRO scores when compared with nonoperative treatment, and (3) there is no single superior operative treatment strategy because of a lack of high-quality evidence.

Materials and methods

Search rationale

This systematic review and meta-analysis followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement guidelines. The MEDLINE, Embase, CENTRAL (Cochrane Central Register of Controlled Trials), and Scopus databases were searched in November 2019 for studies addressing 8 treatment methods for irreparable MRCTs: physical therapy, débridement, partial repair, graft interposition, tendon transfer, SCR, balloon arthroplasty, and reverse shoulder arthroplasty. Separate searches were carried out for each treatment. Search terms included ‘‘massive rotator cuff tear’’ AND terms associated with each treatment: (‘‘physical therapy OR rehabilitation’’)/‘‘debridement’’/‘‘partial repair’’/(‘‘scaffold OR patch OR graft interposition OR platelet rich plasma OR augmentation OR stem cell’’)/(‘‘tendon transfer OR latissimus dorsi tendon transfer OR lower trapezius tendon transfer’’)/(‘‘superior capsular

reconstruction OR superior capsule reconstruction'')/(''(sub-acromial OR sub-acromial) AND (balloon OR spacer)) OR balloon arthroplasty'')/(''reverse total shoulder arthroplasty OR reverse shoulder arthroplasty OR reverse shoulder prosthesis''). Titles, abstracts, and full texts were screened to identify potentially relevant studies.

Study eligibility

The eligibility criteria were determined a priori. The inclusion criteria were studies of any level of evidence with minimum 2-year clinical follow-up with criteria defining MRCTs and reporting of validated PROs and/or range-of-motion data. The exclusion criteria were studies that included patients with repairable rotator cuff tears, rotator cuff tear arthropathy with Hamada stage ≥ 3 (glenohumeral arthritis),[28] fractures, rheumatoid arthritis, or instability, as well as case reports, biomechanical studies, reviews, surgical techniques, or studies written in a language other than English. Studies that included patients with or without glenohumeral arthritis were included if data for patients without glenohumeral arthritis were reported separately.

Data abstraction

Extrapolated data were recorded using a standardized data-collection spreadsheet for all sections. This included study design and patient demographic characteristics (Supplementary Tables S1-S9); MRCT diagnosis criteria (Supplementary Tables S10-S18); and clinical outcomes before and after treatment intervention, including visual analog scale pain scores (range, 0-10), range of motion, PRO scores, radiographic analysis, failure and revision rates, and complications (Supplementary Tables S19-S27). All continuous variables were reported as mean $\pm$ standard deviation, unless the standard deviation was unavailable, in which case range was reported if available.

Assessment of study quality

Two reviewers (R.J.S. and D.K.) independently assessed the methodologic quality of all included studies with the Methodological Index for Non-randomized Studies (MINORS) scoring system.[65] Studies with a MINORS score $< 75\%$ were excluded.

Response to treatment

To determine variation in the magnitude of response to treatment for the Constant-Murley score (CMS) and American Shoulder and Elbow Surgeons (ASES) score, we compared pre- to post-treatment score changes with the minimal clinically important difference (MCID) thresholds determined by previous rotator cuff studies.[21,33] The CMS and ASES score were chosen because they were the most frequently reported PROs among included studies. The change in ASES score and CMS for each study reporting either PRO, as well as the weighted average change in score for each treatment modality, was graphically compared with previously reported MCID thresholds. The weighted average change in PRO score was influenced by sample size. For the CMS, we used MCIDs of 15 for nonoperative treatment and 30 for operative management.[32] For the ASES score, we used MCIDs of 17 for nonoperative treatment and 39 for operative management.[20] All selected MCID threshold values were calculated by prior studies via an anchor-based approach, in which the change in PRO score is anchored to a separate global rating-of-change questionnaire that determines overall patient improvement with the treatment outcome at final follow-up.

Results

Search strategy and data aggregation

We identified 120 relevant studies, with 77 not meeting the inclusion criteria, leaving 43 studies included in this review (Fig. 1). All 43 studies were included in the qualitative synthesis, and 37 studies were included in the quantitative synthesis. The most common reasons for exclusion were insufficient follow-up, inclusion of rotator cuff tear sizes other than massive (without a subgroup analysis of massive tears), and failure to define the criteria for MRCTs. For each treatment strategy, the data were aggregated and pooled where appropriate, such that Table I provides a summary of study design and demographic characteristics; Table II includes criteria for defining MRCTs; and Table III outlines clinical outcomes, failure rates, and reoperation rates.

Physical therapy

Study design and patient demographic characteristics

All 3 studies addressing physical therapy were of level III or IV evidence, with 2 prospective studies and 1 retrospective study; the average follow-up period was 32 months.[11,70,71] The rate of patients lost to follow-up ranged from 0% to 35%. The number of patients ranged from 19 to 45 (total, 94). Nonoperative treatment strategies varied among studies. One study used a home-based 3-month anterior deltoid rehabilitation program,[70] a second restored passive range of motion and strength without a described duration,[71] and a third focused on periscapular and intact rotator cuff muscles and described deltoid muscle coaptation only when the arm was elevated.[11]

Definition of MRCT

All 3 studies defined MRCTs as the involvement of ≥ 2 tendons and defined irreparable tears as those with fatty muscle infiltration of grade ≥ 3.[11,70,71]

Clinical outcomes

Complete PRO scores were available for 2 studies, with $+13$-point and $+23$-point mean changes in the CMS and ASES score, respectively.[9,70] Pain scores improved by 3 points after physical therapy.[70] Complete range-of-motion data were available from 2 studies,[11,70,71] with forward elevation improving by 25°. Meanwhile, Collin et al[11] demonstrated that 53% of patients (24 of 45) achieved

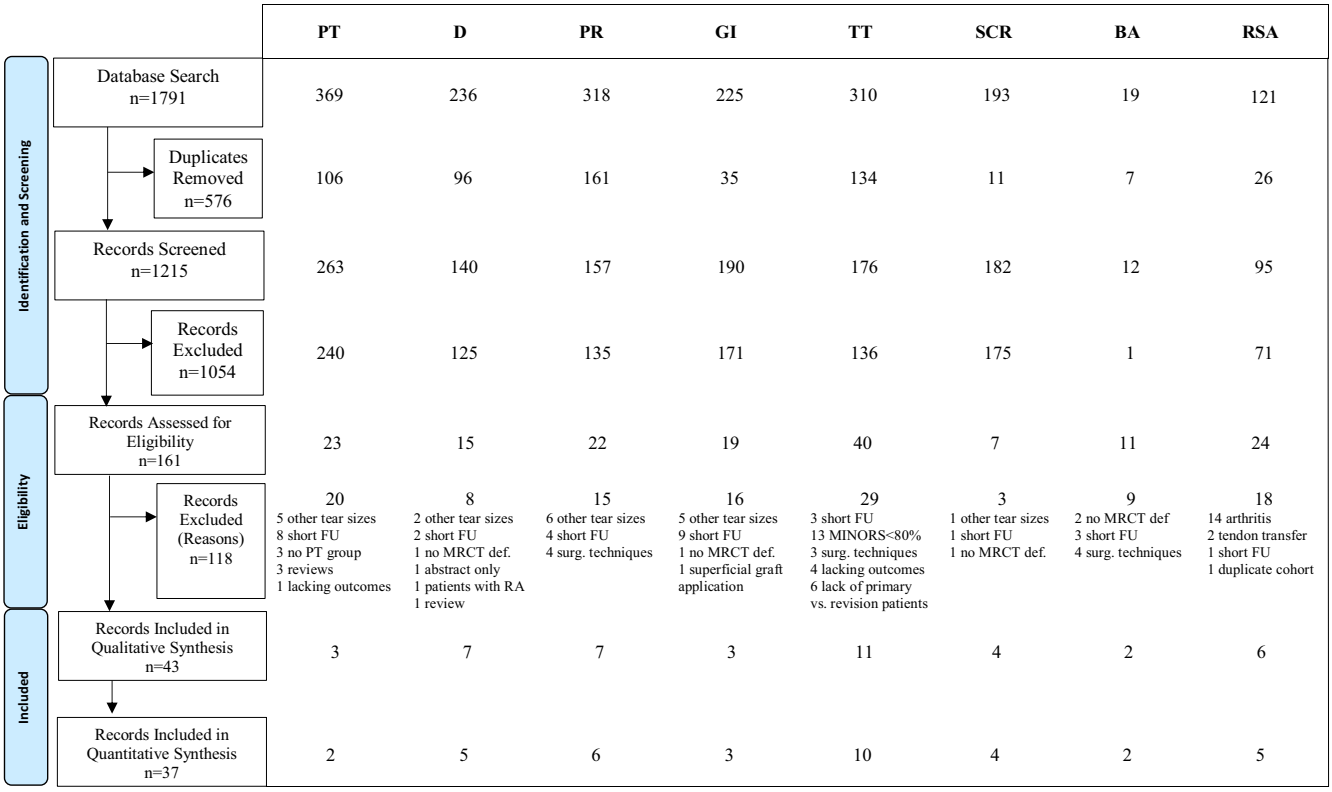

Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram representing search and screening process of studies reporting on nonoperative and operative treatment of irreparable massive rotator cuff tears *(MRCTs)*. *PT*, physical therapy; *D*, débridement; *PR*, partial repair; *GI*, graft interposition; *TT*, tendon transfer; *SCR*, superior capsular reconstruction; *BA*, balloon arthroplasty; *RSA*, reverse shoulder arthroplasty; *FU*, follow-up; *def*, definition; *RA*, rheumatoid arthritis; *surg*, surgical; *MINORS*, Methodological Index for Non-randomized Studies.

>160° of forward elevation after treatment. Tears with subscapularis involvement performed worse than posterosuperior rotator cuff tears. Strength improved from 1.1 kg to 1.9 kg.[70]

Survival and complications

For patients treated with anterior deltoid rehabilitation, 40% (12 of 30) had a successful outcome, 30% (9 of 30) chose surgery, and 30% (9 of 30) did not improve with the rehabilitation program in one study.[70] In another study, 18% of patients (7 of 40) elected to undergo surgery after nonoperative treatment failed.[71]

Débridement

Study design and patient demographic characteristics

All 7 articles addressing débridement were of level III or IV evidence, with 5 retrospective[22,30,36,39,42] and 2 prospective studies.[37,49] All articles had minimal loss to follow-up. The number of patients ranged from 23 to 57 (total, 256), with an average age of 65.7 years. The average follow-up period was 48 months, with 2 studies reporting follow-up ≥ 5 years.[22,39]

Definition of MRCT

There was variability in the criteria used for defining MRCTs. The most common were the involvement of ≥2 tendons or an anterior-posterior width > 5 cm. One study referenced either 2 torn tendons or retraction past the glenoid.[42]

Clinical outcomes

Five studies used the CMS, with a +26-point mean change in scores from before to after surgery,[22,30,36,37,42] whereas 2 studies used the ASES score, with a +37-point mean change in scores.[22,42] Three studies reported pain scores, with an average improvement of 4.5 points.[22,30,42] Range-of-motion data were available from 5 studies,[22,30,36,37,42] but only 2 measured motion both before and after surgery,[22,30] with forward elevation increasing by 32°.

Survival and complications

Complications were seldom reported. One study reported that type 1 complex regional pain syndrome developed in 4.9% of patients (2 of 41),[36] whereas another study reported that seromas and infections developed in 6.1% (2 of 33) and 3.0% (1 of 33), respectively.[22]

Table I Study design and patient demographic characteristics

Treatment	No. of studies	LOE	MINORS score, %	N (M/F)	Age, yr	Follow-up, mo
Physical therapy	3	III in 1 and IV in 2	89.6	94 (59/35)	68.3 (54-89)	32 (24-65)
Débridement	7	III in 1 and IV in 6	88.8	256 (160/96)	65.7 (33-82)	48 (24-120)
Partial repair	7	III in 1 and IV in 6	89.0	226 (122/93)*	62.7 (33-81)	45.2 (24-90)
Graft interposition	3	IV in 3	85.4	67 (39/28)	68.2 (51-85)	34.3 (24-86)
Tendon transfer	11	III in 1 and IV in 10	88.1	506 (319/187)	59.2 (53-64.2)	57.7 (24-147)
Arthroscopic assisted	4	IV in 4	89.1	144 (68/76)	61.7 (59-64.2)	70.2 (24-147)
Open	7	III in 1 and IV in 6	87.5	362 (251/111)	57.7 (53-61)	35.8 (24-77)
SCR	4	IV in 4	81.3	179 (12/11)*	64.7 (43-82)	44.5 (24 to ≥60)
HDA	1	IV	87.5	38	59.4	24.0
TFL	3	IV in 3	79.2	141 (12/11)*	66.4 (65.1-68.0)	51.4 (24-110)
Balloon arthroplasty	2	IV in 2	93.8	25	68.8 (54-85)	42.0 (24-60)
RSA	6	IV in 6	85.4	247 (48/74)*	67.5 (34-86)	39.4 (24-118)

LOE, level of evidence; *MINORS*, Methodological Index for Non-randomized Studies; *N*, total number of patients per treatment group reported; *M*, male; *F*, female; *SCR*, superior capsular reconstruction; *HDA*, human dermal allograft; *TFL*, tensor fascia lata autograft; *RSA*, reverse shoulder arthroplasty.
The MINORS score is presented as the weighted average for each treatment strategy.
Age and follow-up are reported as mean (range).
* Incomplete reporting of number of patients based on sex.

Partial repair

Study design and patient demographic characteristics

All 7 articles addressing partial repair were of level III[56] or IV evidence.[9,12,16,21,30,49,56] The study sample size ranged from 11 to 90 (total, 226), with an average age of 62.7 years. Two studies had >5% loss to follow-up.[12,21] The average follow-up period was 45.2 months, with 2 studies reporting follow-up ≥ 5 years.[12,21]

Definition of MRCT

All studies defined MRCTs by the number of tendons torn (2 torn tendons in 5 studies[12,16,21,49,56] and 3 torn tendons in 2 studies)[9,30]. Three studies included tear size (≥5 cm) as an additional criterion.[16,49,56] Three studies reported preoperative fatty infiltration,[9,30,56] 3 reported the acromiohumeral interval,[9,16,21] and 2 reported the Hamada classification,[9,12] demonstrating variability in the criteria used for defining MRCTs.

Clinical outcomes

Six studies reported PROs both before and after surgery. The mean change in the CMS[21,30,56] and ASES score[9,16,49] was +32 points and +35 points, respectively. Pain scores improved by about 4.5 points.[9,12,16,30] Three studies reported motion both before and after surgery, with forward elevation and external rotation improving on average by 30° and 11°, respectively.[12,16,30]

Survival and complications

Pooled rates for retear defined as rerupture on postoperative magnetic resonance imaging or ultrasound,[9,30] unsatisfactory outcomes,[12,21] and revision surgery[16,21,30,49] were 45% (25 of 55 patients), 14% (16 of 111), and 9.7% (16 of 165), respectively. The reasons for revision surgery included retear (12 of 16), infection (2 of 16), anchor loosening (1 of 16), or acromioclavicular joint cyst (1 of 16).

Graft interposition

Study design and patient demographic characteristics

The 3 articles addressing graft interposition were of level IV evidence, with 1 prospective study and 2 retrospective studies[2,45,52] (Supplementary Table S28). The number of patients ranged from 5 to 41 (total, 67), with an average age of 68.2 years and an average follow-up period of 34.3 months.

Definition of MRCT

There was variability in the criteria used for defining MRCTs, with the involvement of ≥2 tendons reported in 2 articles.[2,45,52] All 3 articles quantified tear size, with 2 reporting a tear size > 5 cm[45,52] and 1 reporting a tear size > 4 cm for the diagnosis of MRCTs.[2]

Clinical outcomes

Of the 3 studies, 2 used the CMS, with a +42-point mean change in scores from before to after surgery,[2,52] whereas 1 used the ASES score, with a +45-point mean change in scores.[45] Two studies reported pain scores, with an average improvement of 5 points.[45,52] Range of motion before and after surgery was reported in 2 studies, with forward

Table II Massive rotator cuff tear criteria

Treatment	No. of studies	Tear size	No. of tendons	Tendon retraction (Patte classification)	Goutallier fatty infiltration (SITS)	Hamada stage and/or AHI, mm
Physical therapy	3	NR	≥2 (3)	Stage 3 (1)	Grade 4 (1) Grade 3-4 (2)	AHI: 8.2 preop (1), 5.6 postop (1) Hamada: 1-2 (1)
Débridement	7	≥5 cm (5)	≥2 (5)	Stage 2 (1) Stage 3 (1) 4-5 cm (1) "Unable to reattach" (1)	Grade 3-4 (1) Grade 1.9 (1)	AHI: <5 preop (1), 5.1 preop (1)
Partial repair	7	≥5 cm (3)	≥2 (5) ≥3 (2)	Stage 2 (1)	Grade 3-4 (1) Grade 1.9 (1.5-2.2) (2)	AHI: <7 preop (1), 8.8 preop (1) Hamada: 1 (1), 1-2 (1)
Graft interposition	3	≥5 cm (2) ≥4 cm (1)	≥2 (2)	NR	Grade 3.75 (1)	AHI: 7.7 preop (1), 8.6 postop (1)
Tendon transfer	11	≥5 cm (5)	≥2 (7)	Stage 2-3 (2) Stage 3 (5) "Excessive" (2)	Grade 3-4 (11)	AHI: 4.2 (2.3-5.9) preop (4), 5.1 (4.7-5.7) postop (3) AHI: <5 preop (1) AHI: <7 preop (1) AHI: decrease by 1.5 (1) Hamada: 1.7 (0-2) preop (2), 2.2 (1-5) postop (2) Hamada: 1-2 preop (1) Hamada: 2-3 postop (1)
AA	4	≥5 cm (1)	≥2 (2)	Stage 2-3 (2) Stage 3 (1)	Grade 3-4 (4)	AHI: 3.13 preop (1), 5.7 postop (1) AHI: <5 preop (1) Hamada: 1-3 preop (1)
Open	7	≥5 cm (4)	≥2 (5)	Stage 3 (4) "Excessive" (2)	Grade 3-4 (7)	AHI: 4.6 (2.3-5.9) preop (3), 4.8 (4.7-4.9) postop (2) AHI: <7 preop (1) AHI: decrease by 1.5 (1) Hamada: 1.7 (0-2) preop (3), 2.2 (1-5) postop (3) Hamada: 1-2 preop (1) Hamada: 2-3 postop (1)
SCR	4	≥5 cm (1)	≥2 (3)	≥5 cm (1)	Grade 3-4 (1) Grade 2.6 (2.0-3.7) (3)	AHI: 4.9 (4.6-7.3) preop (4), 9.1 (8.1-9.9) postop (4)
HDA	1	≥5 cm	—	≥5 cm	Grade 3-4	AHI: 7.3 preop, 9.9 postop
TFL	3	—	≥2 (3)	—	Grade 2.6 (2.0-3.7) (3)	AHI: 4.1 (3.4-4.6) preop (3), 8.8 (8.1-9.7) postop (3)
Balloon arthroplasty	2	≥5 cm (2)	≥2 (1)	NR	Grade 3-4 (1) "Unsuitable for repair" (1)	AHI: 6.7 preop (1), 8.0 postop (1)
RSA	6	≥5 cm (1)	≥2 (6)	Stage 2 (1) Stage 3 (1)	Grade 3-4 (3)	AHI: <6 preop (1) AHI: <7 preop (1) Hamada: <4 preop (4)

SITS, supraspinatus, infraspinatus, teres minor, and subscapularis; *AHI*, acromiohumeral interval; *NR*, not recorded; *preop*, preoperatively; *postop*, postoperatively; *AA*, arthroscopic assisted; *SCR*, superior capsular reconstruction; *HDA*, human dermal allograft; *TFL*, tensor fascia lata autograft; *RSA*, reverse shoulder arthroplasty.

Table III Clinical outcomes, failure, and reoperation rates

Treatment	No. of studies	VAS		ROM		PRO		Failure and/or survival	Revision and/or reoperation
		Initial	Final	Initial	Final	Initial	Final		
Physical therapy	3	6.7 (1)	3.7 (1)	FF: 97 (76-115) (3) Abd: 118 (1) ER: 44 (1) IR: 76 (1)	FF: 133 (129-136) (2) Abd: 136 (1) ER: 39 (1) IR: 66 (1)	CMS: 43 (1) ASES: 39 (1) SSV: 45 (1)	CMS: 62.4 (56-69) (2) ASES: 62 (1) SSV: 64 (60-68) (2)	Success in 12 of 30 (40%) PT failure in 9 of 30 (30%)	Surgery in 9 of 30 (30%)
Débridement	7	7.6 (7-7.9) (3)	3.1 (2-4.3) (3)	FF: 106 (96-115) (2) Abd: 74 (57-90) (2) ER: 20 (1)	FF: 137 (118-155) (2) Abd: 118 (85-150) (2) ER: 42 (1) IR: T12 (1) Scapular-plane elevation: 111 (1)	CMS: 42.7 (31-72.2) (5) ASES: 25.5 (24-27) (2) UCLA: 11.5 (1) SSV: 35.2 (1) qDASH: 63.4 (1)	CMS: 63.9 (42.3-89) (6) ASES: 62.4 (55-69.8) (2) UCLA: 21 (1) SSV: 73.2 (1) DASH: 41.3 (1) qDASH: 24.1 (1) SPADI: 38.4 (1)	NR	1 of 23 (4.2%) (1)
Partial repair	7	6.3 (5.6-7) (4)	1.8 (1.5-2) (4)	FF: 126 (95-168) (3) Abd: 90 (1) ER: 34 (20-44) (3) IR: 84% (1)	FF: 160 (154-172) (4) Abd: 150 (120-169) (3) ER: 39 (27-54) (5) IR: T9 (2)	CMS: 39.6 (36.6-43.1) (3) ASES: 44.5 (41-46.6) (3) SSV: 34.7 (1) SST: 5.6 (1) qDASH: 52.5 (1) Oxford: 17.8 (1)	CMS: 71.5 (67.5-76.3) (3) ASES: 79.3 (78.6-80.1) (3) SSV: 74.0 (1) SST: 9.1 (1) qDASH: 55.8 (1) Oxford: 37.1 (1) SANE: 96 (1) SPADI: 29.5 (1)	Unsatisfactory outcome in 16 of 111 (14.4%) (2) Rerupture in 25 of 55 (45.4%) (2)	16 of 165 (9.7%) (4)
Graft interposition	3	6.9 (6.8-7) (2)	1.9 (1-2.8) (2)	FF: 67 (65-69) (2) Abd: 64 (60-68) (2) ER: 36 (32-39) (2) IR: 3.8 of 10 (3.4-4.2) (2)	FF: 128 (120-136) (2) Abd: 127 (120-134) (2) ER: 48 (38-57) (2) IR: 8.0 of 10 (7.5-8.4) (2)	CMS: 36.2 (25.7-46.7) (2) ASES: 29 (1) UCLA: 10.2 (1) SST: 2.4 (1)	CMS: 78.3 (72.1-84.5) (2) ASES: 74 (1) UCLA: 29.4 (1) SST: 7.8 (1)	Rerupture in 1 of 5 (20%) (1)	1 of 5 (20%) (1)
Tendon transfer	11	7.7 (7.5-7.8) (2)	2.6 (2.4-2.8) (3)	FF: 95 (58-134) (11) Abd: 84 (40-112) (11) ER: 18 (12-29) (11) IR: L3 (1)	FF: 137 (120-157) (11) Abd: 123 (90-154) (11) ER: 33 (23-50) (11) IR: L3 (1)	CMS: 35.9 (21-47.3) (10) ASES: 39.2 (30.1-48.3) (2) UCLA: 6.5 (1) SSV: 31.3 (19.3-54) (5) DASH: 52 (1)	CMS: 63.5 (58-69.5) (10) ASES: 71.7 (66.7-73.2) (3) UCLA: 27.5 (1) SSV: 66.8 (48.9-78) (5) SST: 7 (1) DASH: 18 (1)	LD rerupture in 29 of 184 (15.8%) (4) SSC insufficiency in 8 of 122 (6.6%) (2) Deltoid avulsion in 2 of 122	24 of 356 (6.7%) (6)

(*continued on next page*)

Table III Clinical outcomes, failure, and reoperation rates (*continued*)

Treatment	No. of studies	VAS		ROM		PRO		Failure and/or survival	Revision and/or reoperation
		Initial	Final	Initial	Final	Initial	Final		
								(1.6%) (2) Stiffness in 2 of 55 (3.6%) (1) LD insufficiency in 6 of 55 (10.9%) (1)	
AA	4	7.5 ± 1.0 (1)	2.7 (2.5-2.8) (2)	FF: 97 (58-134) (4) Abd: 64 (51-80) (4) ER: 19 (13-29) (4)	FF: 140 (130-157) (4) Abd: 115 (93-130) (4) ER: 33 (28-42) (4)	CMS: 30.1 (21-37) (4) UCLA: 6.5 (1) SSV: 22.7 (19.3-26) (2)	CMS: 60.5 (58-65.4) (4) ASES: 66.7 (1) UCLA: 27.5 (1) SSV: 60.0 (48.9-71.1) (2) SST: 7 (1)	LD rerupture in 28 of 129 (21.7%) (3)	10 of 115 (8.7%) (2)
Open	7	7.8 ± 1.5 (1)	2.4 ± 1.9 (1)	FF: 93 (70-118) (7) Abd: 87 (40-112) (7) ER: 19 (14-23) (7) IR: L3 (1)	FF: 136 (120-151) (7) Abd: 128 (90-154) (7) ER: 33 (23-50) (7) IR: L3 (1)	CMS: 39.8 (32-47.3) (6) ASES: 39.2 (30.1-48.3) (2) SSV: 37.0 (28-54) (3) DASH: 52 (1)	CMS: 65.4 (60-69.5) (6) ASES: 71.7 (70.2-73.2) (2) SSV: 71.4 (60-78) (3) DASH: 18 (1)	LD rerupture in 1 of 55 (1.8%) (1) SSC insufficiency in 8 of 122 (6.6%) (2) Deltoid avulsion in 2 of 122 (1.6%) (2) Stiffness in 2 of 55 (3.6%) (1) LD insufficiency in 6 of 55 (10.9%) (1)	14 of 241 (5.8%) (4)
SCR	4	5.6 (4.3-6.9) (2)	1.1 (0.9-1.2) (2)	FF: 97 (84-123) (4) Abd: 106 (1) ER: 27 (26-27) (3) IR: L3 (1)	FF: 154 (148-162) (4) Abd: 160 (1) ER: 41 (40-43) (3) IR: L1 (1)	ASES: 34.3 (23.5-49.5) (4) UCLA: 9.9 (1) JOA: 50.9 (48.3-53.0) (3)	ASES: 91.2 (85.3-94.3) (4) UCLA: 32.4 (1) JOA: 92.4 (91.4-93.2) (3)	Graft failure in 11 of 180 (6.1%) (4) Retear of ISP in 3 of 24 (12.5%) (1)	6 of 126 (4.8%) (2)
HDA	1	4.3	1.2	FF: 123 Abd: 106	FF: 162 Abd: 160	ASES: 49.5	ASES: 85.3	Graft failure in 3 of 38 (7.9%)	1 of 38 (2.6%)
TFL	3	6.9 (1)	0.9 (1)	FF: 89 (84-123) (3) ER: 27 (26-27) (3) IR: L3 (1)	FF: 152 (148-156) (3) ER: 41.4 (40-43) (3)	ASES: 29.2 (23.5-35) (3) UCLA: 9.9 (1) JOA: 50.9 (48.3-52)	ASES: 93.2 (92.3-94.3) (3) UCLA: 32.4 (1) JOA: 92.4	Graft failure in 8 of 142 (5.6%) (3) Retear of ISP in	5 of 88 (5.7%)

				IR: L1 (1)	(3)	(91.4-93.2) (3)	3 of 24 (12.5%) (1)		
Balloon arthroplasty	2	6.6 (1)	2.8 (1)	FF: 71 (1) Abd: 65 (1)	FF: 129 (1) Abd: 125 (1)	CMS: 38.0 (34.2-41.8) (2) SAS: 6.7 (1)	CMS: 67.1 (66.8-67.4) (2) SAS: 8.0 (1)	NR	1 of 20 (5%) (1)
RSA	6	5.9 (5.5-6.3) (2)	2.0 (1.9-2.0) (2)	FF: 69 (53-94) (3) ER: 29 (21-40) (3)	FF: 133 (122-143) (3) ER: 40.2 (29-51) (3)	CMS: 26.5 (23-27.8 (3) ASES: 37.5 (33.3-41.6) (2) SST: 1.0 (1.6-2.2) (2)	CMS: 59.4 (55-63.4) (3) ASES: 74.7 (74-75.4) (2) SST: 7.1 (6.5-7.6) (2)	Prosthesis failure in 16 of 159 (10.1%) (3) Fracture in 14 of 231 (6.1%) (4) Instability in 4 of 206 (1.9%) (3)	19 of 231 (8.2%) (4)

VAS, visual analog scale; *ROM*, range of motion; *PRO*, patient-reported outcome; *FF*, forward flexion; *Abd*, abduction; *ER*, external rotation; *IR*, internal rotation; *CMS*, Constant-Murley score; *ASES*, American Shoulder and Elbow Surgeons; *SSV*, Subjective Shoulder Value; *PT*, physical therapy; *UCLA*, University of California–Los Angeles; *qDASH*, short version of Disabilities of the Arm, Shoulder and Hand questionnaire; *DASH*, Disabilities of the Arm, Shoulder and Hand; *SPADI*, Shoulder Pain and Disability Index; *NR*, not reported; *SST*, Simple Shoulder Test; *SANE*, Single Assessment Numeric Evaluation; *SSC*, subscapularis; *AA*, arthroscopic assisted; *LD*, latissimus dorsi; *ISP*, infraspinatus; *SAS*, Shoulder Activity Scale; *SCR*, superior capsular reconstruction; *JOA*, Japanese Orthopaedic Association; *HDA*, human dermal allograft; *TFL*, tensor fascia lata autograft; *RSA*, reverse shoulder arthroplasty.

elevation and external rotation improving on average by 61° and 12°, respectively.[2,52]

Survival and complications

Pooled rates for retear and revision surgery were 20% (1 of 5 patients) and 20% (1 of 5), respectively.[2,52]

Tendon transfer

Study design and patient demographic characteristics

All 11 articles addressing tendon transfer were of level III[50] or IV evidence.[8,14,17,18,24,25,27,33-35,50] The study sample size ranged from 14 to 86 (total, 506), with an average age of 59 years. The average follow-up period was 57.7 months, with 2 studies reporting follow-up ≥ 9 years.[17,25] It is worth noting that there was overlap in the cohorts of patients reported by 2 separate pairs of studies[24,25,27,35] (Supplementary Table S29), which slightly skews conclusions drawn from analysis of all patients among the 11 studies.

All authors used the latissimus dorsi tendon[8,14,17,24,25,27,33-35,50] except Elhassan et al,[18] who transferred the lower trapezius. The latissimus transfer surgical procedures were performed using either the open 2-incision technique popularized by Gerber et al[26] or an arthroscopic-assisted approach.[14,27,34,35] Operative technique details are outlined in Supplementary Table S29.

Definition of MRCT

All studies defined MRCTs as either involving ≥2 tendons (ie, supraspinatus and infraspinatus)[17,18,24,25,34,35,50] or measuring ≥5 cm,[8,24,33,35,50] with 2 studies requiring both criteria.[24,50] Of the 11 articles, 9 reported tendon retraction to at least the level of the glenoid or medial to it,[5,11,17,18,27,34,35,45] and all studies observed fatty infiltration of Goutallier grade ≥ 3.[8,14,17,18,24,25,27,33-35,50]

Clinical outcomes

All but 1 study[18] reported the CMS, with a mean change of +28 points (+30 points for arthroscopic treatment and +26 points for open treatment). The mean change in the ASES score was +33 points.[17,50] Pain scores improved by about 5.1 points.[17,34] All studies reported motion both before and after surgery, with forward elevation and external rotation improving on average by 43° and 15°, respectively.

Survival and complications

Pooled rates for tendon transfer retear,[14,17,18,25,27,35] rotator cuff tear,[24,25,35] deltoid deficiency,[17,24,25] and revision surgery[17,18,24,25,27,35] were 14.6% (35 of 239 patients), 6.6% (8 of 122), 1.6% (2 of 122), and 6.7% (24 of 356), respectively. Of the 35 tendon transfer failures, 27 (77%) occurred due to humeral bone tunnel fixation with tendon tubularization compared with 8 failures (23%) with greater tuberosity footprint fixation.[27,35] Postoperative

complications included hematoma (8%, 23 of 286 patients),[17,18,27,33,35] greater tuberosity fracture (7.3%, 4 of 55),[27] deep infection (3.3%, 7 of 214),[14,18,27,33,35] stiffness (3.1%, 6 of 193),[17,25,33] and nerve dysesthesia (2.1%, 9 of 431).[14,17,24,25,27,33,35,50]

Superior capsular reconstruction

Study design and patient demographic characteristics

All 4 retrospective articles addressing SCR were of level IV evidence; they included 177 patients with an average age of 64.7 years and an average follow-up period of 44.5 months.[46-48,58] There was overlap in the cohorts reported by 3 studies,[46-48] which slightly skews conclusions drawn from analysis of patients receiving fascia lata autograft. Variability was noted concerning graft characteristics (ie, type, size, and thickness) and glenoid fixation (Supplementary Table S30).

Definition of MRCT

Pennington et al[58] defined MRCTs using a tear size $\geq$ 5 cm and further characterized muscle quality with the Goutallier grading classification, whereas Mihata et al[46-48] defined MRCTs as involving $\geq$2 tendons. All studies reported preoperative fatty infiltration and average changes in the acromiohumeral interval ranging from 3.4 mm preoperatively to 9.6 mm postoperatively.[46-48,58]

Clinical outcomes

All studies used the ASES score, with a +57-point mean change in scores from before to after surgery (+36 points for human dermal allograft and +64 points for tensor fascia lata autograft). Two studies reported pain scores, with an average improvement of 3.9 points.[46,58] Range of motion before and after surgery was reported in all studies, with forward elevation improving on average by 57°.

Survival and complications

Pooled rates for structural failure and revision surgery were 6.1% (11 of 180 patients) and 4.8% (6 of 126), respectively. Rates of graft tear and revision surgery were 7.9% (3 of 38) and 2.6% (1 of 38), respectively, with the use of human dermal allograft.[58] Rates of infraspinatus retear, graft tear, and revision surgery were 12.5% (3 of 24), 5.6% (8 of 142), and 5.7% (5 of 88), respectively, with the use of tensor fascia lata autograft.[46-48]

Balloon arthroplasty

Study design and patient demographic characteristics

Two articles, 1 retrospective case series and 1 prospective case series, addressing balloon arthroplasty were included, and both were of level IV evidence, including 25 patients, with an average age of 68.8 years and an average follow-up period of 42 months.[60,63]

Definition of MRCT

Both studies defined MRCTs using a tear size $\geq$ 5 cm. Ricci et al[60] also required $\geq$2 tendons to be torn and Goutallier grade $\geq$ 3, whereas Senekovic et al[63] noted the presence of substantial fatty infiltration deemed unsuitable for repair in all patients without qualitative assessment of its severity.

Clinical outcomes

Both studies used the CMS, with a +29-point mean change in scores from before to after surgery. One study reported pain scores, with an average improvement of 3.8 points.[60] Range of motion before and after surgery was reported in 1 study, with forward elevation improving on average by 58°.[63]

Survival and complications

No complications were noted, whereas 1 patient (5%, 1 of 20) needed eventual conversion to reverse shoulder arthroplasty within the 5-year follow-up period.[63]

Reverse shoulder arthroplasty

Study design and patient demographic characteristics

All 6 articles addressing reverse shoulder arthroplasty were retrospective case series of level IV evidence.[3,19,29,51,66,68] The number of patients included ranged from 17 to 64 (total, 247), with an average age of 67.5 years and an average follow-up period of 39.4 months. Age data were available from only 3 studies.[19,29,51]

Definition of MRCT

Tendon number was the most commonly referenced criterion for an MRCT, with a minimum 2-tendon tear.[3,15,29,51,66,68] All studies referenced either the acromiohumeral interval[3,19] or the Hamada classification,[27,29,51,61,68] but the Hamada classification was primarily used to exclude arthritis and not to diagnose MRCTs. Among the 3 studies that assessed tendon retraction,[3,19,66] a common value for the degree of retraction was not identified. Three studies used the Goutallier classification and considered grade $\geq$ 3 to be consistent with MRCTs.[3,19,68]

Clinical outcomes

Three studies reported the CMS, with a +32-point mean change in scores from before to after surgery,[3,19,68] whereas 2 studies reported the ASES score, with a +37-point mean change in scores.[29,51] Two studies reported pain scores, with an average improvement of 3.9 points.[29,51] Range of motion before and after surgery was reported in 3 studies, with forward elevation improving on average by 64°.[27,29,51,68]

Survival and complications

Pooled rates for prosthesis failure, fracture, instability, and revision surgery were 10.1% (16 of 159 patients), 6.1% (14

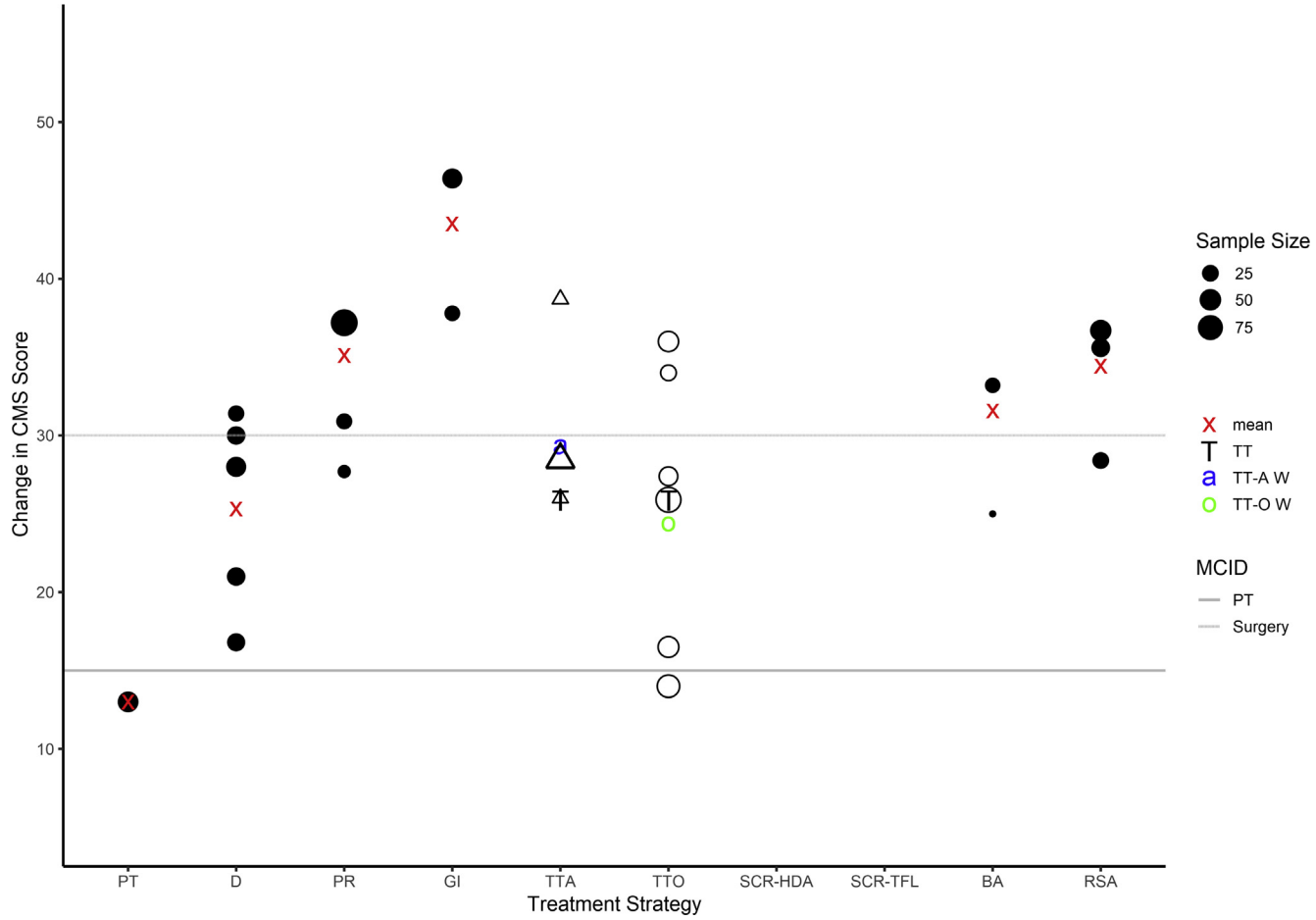

Figure 2 Change in Constant-Murley score *(CMS)* for each treatment strategy compared with minimal clinically important difference *(MCID)* threshold for either nonoperative or operative intervention. The sample size is directly proportional to the size of the *circle* (or *triangle* for arthroscopic tendon transfer). Influenced by the sample size, the *red x* denotes the weighted average change in the CMS for all treatment strategies except tendon transfer. The *T* denotes the weighted average change in the CMS for all tendon transfers *(TT)*. The *blue a* represents the weighted average change in the CMS for arthroscopic tendon transfer *(TT-A W)*. The *green o* represents the weighted average change in the CMS for open tendon transfer *(TT-O W)*. *PT*, physical therapy; *D*, débridement; *PR*, partial repair; *GI*, graft interposition; *TTA,* arthroscopic tendon transfer; *TTO*, open tendon transfer; *SCR-HDA*, superior capsular reconstruction with human dermal allograft; *SCR-TFL*, superior capsular reconstruction with tensor fascia lata autograft; *BA*, balloon arthroplasty; *RSA*, reverse shoulder arthroplasty.

of 231), 1.9% (4 of 206), and 8.2% (19 of 231), respectively.[3,19,29,51,66,68] One study provided an estimated 90.7% survival rate at 52 months, with the endpoint defined as component revision, removal, loosening, or a worsening ASES score.[51]

Response to treatment

The magnitudes of change in the CMS and ASES score for each treatment strategy compared with the MCID threshold for nonoperative and operative treatment are provided in Figures 2 and 3, respectively. Twenty-six studies reported sufficient data for CMS score comparison to the MCID. The weighted average change in the CMS was greater than the MCID for partial repair, graft interposition, balloon arthroplasty, and reverse shoulder arthroplasty. Fifteen studies reported sufficient data for ASES score comparison to the MCID. The weighted average change in the ASES score was greater than the MCID for physical therapy, graft interposition, and SCR with tensor fascia lata autograft.

Discussion

Our study findings clearly show the absence of high-quality literature on irreparable MRCTs. Of all 43 studies, only 9.3% (4 of 43) were of level III evidence, with the remaining studies of level IV evidence. As such, it is

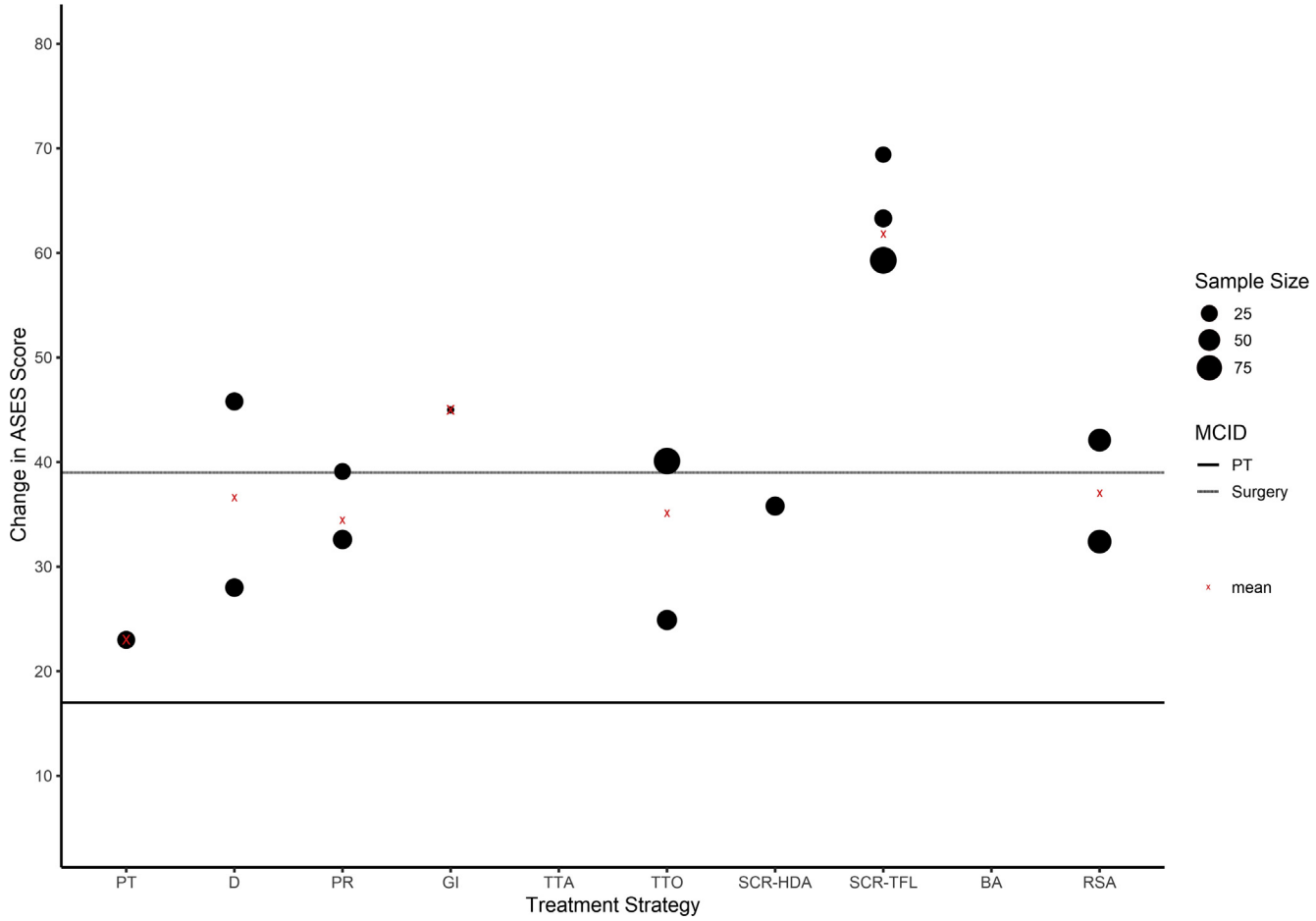

Figure 3 Change in American Shoulder and Elbow Surgeons *(ASES)* score for each treatment strategy compared with minimal clinically important difference *(MCID)* threshold for either nonoperative or operative intervention. The sample size is directly proportional to the size of the circle. The *red x* denotes the weighted average change in the ASES score for all treatment strategies, which is influenced by sample size. *PT*, physical therapy; *D*, débridement; *PR*, partial repair; *GI*, graft interposition; *TTA,* arthroscopic tendon transfer; *TTO*, open tendon transfer; *SCR-HDA*, superior capsular reconstruction with human dermal allograft; *SCR-TFL*, superior capsular reconstruction with tensor fascia lata autograft; *BA*, balloon arthroplasty; *RSA*, reverse shoulder arthroplasty.

difficult to definitively recommend either for or against one treatment strategy over another for the management of irreparable MRCTs. These findings agree with the recommendations provided by the American Academy of Orthopaedic Surgeons 2019 clinical practice guideline on the management of rotator cuff injuries.[1] The guideline authors found insufficient evidence to support the efficacy of physical therapy, partial repair, tendon transfer, SCR, débridement, allograft augmentation, or reverse shoulder arthroplasty in the treatment of irreparable tears, instead concluding, on the basis of consensus clinical opinion alone, that these treatments may improve PROs.[1]

Treatment decisions when the rotator cuff cannot be repaired will have to be made with professional judgment, surgeon experience, patient expectations and ability to complete postoperative rehabilitation, and a shared decision-making process between the surgeon and the patient. In such scenarios, appropriate-use criteria can provide guidance by considering clinical experience, patient factors (smoking status, workers' compensation, and so on), and disease type (tear size and fatty infiltration) to indicate the appropriateness of a given intervention for a specific clinical scenario.[57,61]

Our study suggests that compared with surgery, physical therapy may lead to high failure rates and inferior clinical outcomes for irreparable MRCTs. Physical therapy is promoted to be the first line of treatment when a patient is deemed medically unfit, does not wish to proceed with surgery, or demonstrates a positive response to nonoperative care.[61] However, with the numbers available, 60% of the patients (18 of 30) in this review did not respond to physical therapy or went on to undergo surgery.

Débridement and partial repair showed improvements in visual analog scale pain scores, functional range of motion, and PRO scores, with lower reoperation rates, compared with physical therapy. The majority of débridement studies

Table IV Superior capsular reconstruction graft failure rates

Graft type	N	No. with postoperative MRI	Timing of imaging, yr	Graft failure rate (%)
HDA				
Hirihara et al[31] (2017)	8	5	2	1 of 5 (20)
Denard et al[15] (2018)	59	20	1	11 of 20 (55)
Pennington et al[58] (2018)	88	4	2	3 of 4 (75)
Burkhart and Hartzler[6] (2019)	10	10	1	3 of 10 (30)
Woodmass et al[69] (2019)	34	NR	NR	22 of 34 (65) *
Burkhart et al[7] (2020)	41	26	1	4 of 26 (15)
Lacheta et al[40] (2020)	22	21	0.2	9 of 21 (43)
Total	262	86		32 of 86 (37)
TFL				
Mihata et al[48] (2013)	24	24	3	4 of 24 (17)
De Campos Azevedo et al[13] (2018)	22	22	0.5	2 of 22 (9)
Lee and Min[18] (2018)	36	36	1	13 of 36 (36)
Lim et al[43] (2019)	31	31	1	9 of 31 (29)
Mihata et al[47] (2018)	88	88	5	4 of 88 (5)
Mihata et al[46] (2019)	30	30	2.5	3 of 30 (10)
Total	231	231		35 of 231 (15)

N, total number of patients; *MRI*, magnetic resonance imaging; *HDA*, human dermal allograft; *NR*, not reported; *TFL*, tensor fascia lata autograft.
* Graft failure rate determined by clinical examination rather than advanced imaging.

did not meet the MCID threshold, and as such, débridement may not be a successful treatment strategy. However, Walch et al[67] investigated débridement with concomitant biceps tenotomy in 307 patients with full-thickness rotator cuff tears, finding that this combination of procedures led to significant clinical improvement. Although their study did not exclusively investigate MRCTs, this treatment strategy may be considered in the appropriate patient. A drawback to partial repair was the high retear rate (45%, 25 of 55 patients), and the majority of studies did not meet the MCID threshold.

Surgical reconstruction (graft interposition or tendon transfer) compared with physical therapy showed superior improvements in pain scores, forward elevation, and mean changes in the CMS and ASES score. The scores in all 3 graft interposition studies exceeded the MCID threshold, and as such, graft interposition should be investigated further. Arthroscopic-assisted tendon transfer using greater tuberosity fixation techniques is favored over humeral bone tunnel fixation techniques as the latter are associated with a high failure rate (77%, 27 of 35 patients). On the basis of the available evidence, open tendon transfer may not be a successful treatment strategy as the majority of studies did not meet the MCID for either the ASES score or CMS.

SCR and balloon arthroplasty are relatively new procedures with a paucity of data reporting clinical outcomes and rates of failure, revision surgery, and complications. With the numbers available, both SCR and balloon arthroplasty led to an improvement in pain scores, forward elevation, and PRO scores. However, of concern is the high structural failure rate of SCR using human dermal allograft, which has been reported to range from 15% to 75%,[6,7,15,40,58,69] compared with SCR using tensor fascia lata autograft, with reported failure rates ranging from 5% to 36%[13,41,43,46-48] (Table IV). On the basis of the available evidence, SCR using fascia lata autograft may be considered, and further studies are needed to determine the success of SCR with human dermal allograft and the efficacy of balloon arthroplasty.

Reverse shoulder arthroplasty was found to improve pain scores, functional motion, and PRO scores compared with physical therapy. However, this treatment strategy has an 8.2% reoperation rate (19 of 231 patients) and a 10.1% prosthesis failure rate (16 of 159). In light of this finding, we agree with the appropriate-use criteria that reverse arthroplasty should be considered only in a healthy elderly patient with pseudoparalysis from a chronic irreparable massive tear.[57,61]

We found considerable variability in the definition of MRCTs. Thirty-two studies required a minimum tear size for diagnosis (ie, $\geq$5 cm), and 23 studies required a minimum number of involved tendons (ie, 2). Meanwhile, 13 studies required both a minimum tear size and a minimum number of involved tendons, and 2 studies required either a minimum tendon retraction length or a minimum amount of fatty infiltration. Clearly, there is inconsistent reporting on what defines MRCTs. How to define MRCTs may depend on the treatment strategy and patient expectations (ie, pain relief, restoration of motion, or limitation of the progression of radiographic changes). A recent study using the Delphi method determined with 90% agreement that MRCTs should be defined as either axial or coronal tendon retraction to the glenoid rim and/or a tear with $\geq$67% of the tuberosity exposed in the sagittal plane.[62]

Regarding the limitations of this review, first, the major limitation is the lack of high-quality evidence available on the treatment of irreparable MRCTs. There were only 3 comparative studies, all of which compared débridement with partial repair, whereas the majority of studies were case series (72%, 31 of 43). Without better-quality studies, it is difficult to make evidence-based recommendations for clinical care. Second, we observed inconsistent reporting of PROs, pain scores, range of motion, strength, failure rates, revision surgery, and complication rates across all treatment strategies. There were 12 different PROs used, with the CMS (27 studies) and ASES score (17 studies) most commonly reported. Similarly, 6 of 43 studies (14%) reported motion data in 4 planes (forward flexion, internal rotation, external rotation, and abduction) before and after surgery. Third, we were unable to perform a comprehensive quantitative synthesis because of inconsistent outcome instrument selection. Standardized data collection and reporting are keys to data transparency, and instituting a minimum data set requirement could improve the quality of future studies. Fourth, the results of our quantitative analysis are highly dependent on MCID values selected from prior studies. Although separate MCIDs were chosen for operative and nonoperative treatments, the operative MCID available was calculated using data from patients undergoing complete rotator cuff repair only. It is highly likely that each treatment strategy will have a unique MCID threshold if separately determined by anchor-based methodology.

Further limitations of our quantitative analysis are those inherent to anchor-based MCID methods. First, MCID values are highly impacted by the patient population being studied, with less healthy cohorts having lower baseline scores and more opportunity for score improvement. This is particularly relevant when considering the functional impairment seen in patients with irreparable MRCTs. Second, anchor-based approaches are subject to recall bias. The results of the global rating-of-change questionnaire administered to patients at final follow-up are likely influenced by recent developments in each patient's health status and therefore may reflect a snapshot of health status at a single time point rather than the magnitude of change from baseline. Third, the timing of MCID determination influences the magnitude of recall bias, with a longer follow-up duration introducing more susceptibility to bias. Finally, many studies determining the MCID are limited by small subject numbers and wide confidence intervals. Gagnier et al[20] evaluated 222 patients with full-thickness rotator cuff tears, but only 22 patients had a minimal clinical improvement. This small subset was further evaluated to determine the MCID of the ASES score for surgical treatment, which was found to have a fragile confidence interval of –7.57 to 85.57. Robust MCID values for each treatment strategy matched for age, sex, and racial differences need to be determined through studies with larger sample sizes using a combination of anchor- and distribution-based approaches.

Conclusion

Because of the paucity of high-quality clinical studies available for guiding the management of irreparable MRCTs, it is currently not possible to recommend for or against any specific treatment strategy. Rather, clinical experience, patient factors, patient expectations, and rotator cuff tear characteristics should guide clinical decision making. Compared with surgical treatments, physical therapy may have inferior outcomes. Standardized data collection, reporting, and terminology are key to enhancing the quality of evidence-based medicine. There is a need to unequivocally define the MCID for various MRCT treatment strategies that will lead to improved interpretation of outcomes. Significant opportunities exist for multicenter research groups to embark on high-quality comparative clinical studies to improve our understanding and management of MRCTs.

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Supplementary Data

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