A Systematic Summary of Systematic Reviews on the Topic of the Rotator Cuff

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Background: The number of systematic reviews and meta-analyses published on the rotator cuff (RC) has increased markedly.

Purpose: To quantify the number of systematic reviews and meta-analyses published on the RC and to provide a qualitative summary of the literature.

Study Design: Systematic review; Level of evidence, 4.

Methods: A systematic search for all systematic reviews and meta-analyses pertaining to the RC published between January 2007 and September 2017 was performed with PubMed, MEDLINE, and the Cochrane Database of Systematic Reviews. Narrative reviews and non–English language articles were excluded.

Results: A total of 1078 articles were found, of which 196 met the inclusion criteria. Included articles were summarized and divided into 15 topics: anatomy and function, histology and genetics, diagnosis, epidemiology, athletes, nonoperative versus operative treatment, surgical repair methods, concomitant conditions and surgical procedures, RC tears after total shoulder arthroplasty, biological augmentation, postoperative rehabilitation, outcomes and complications, patient-reported outcome measures, cost-effectiveness of RC repair, and quality of randomized controlled trials.

Conclusion: A qualitative summary of the systematic reviews and meta-analyses published on the RC can provide surgeons with a single source of the most current literature.

Keywords: rotator cuff; repair; systematic review; meta-analysis

There has been an upsurge in the number of systematic reviews and meta-analyses pertaining to the rotator cuff (RC) over the past decade. These articles are published with the intent of providing busy surgeons with the most current information on a single condition by synthesizing all the available evidence with rigorous methods. However, with the steady increase in these types of studies, it can be difficult for providers to even stay up to date with this literature. A basic PubMed search for RC repair returned 430 articles in 2016 alone. To aid researchers and providers as they strive to remain current on this topic, we sought to quantify the number of systematic reviews and meta-analyses published on the RC in the past decade and provide a summary of this literature for easy reference.

METHODS

A literature search was performed to identify all RC-related systematic reviews and meta-analyses published in English between January 2007 and September 2017. The search engines used were PubMed, Medline, and the Cochrane Database of Systematic Reviews. The search terms included *RC*, *supraspinatus*, *infraspinatus*, or *subscapularis* in combination with *systematic review* or *meta-analysis*. All systematic reviews and meta-analyses that examined research topics pertaining to the RC were included (eg, anatomy, epidemiology, diagnosis, treatment). Exclusion criteria were narrative reviews that did not report a systematic literature search, studies that did not separate RC tears from other RC pathology, and studies

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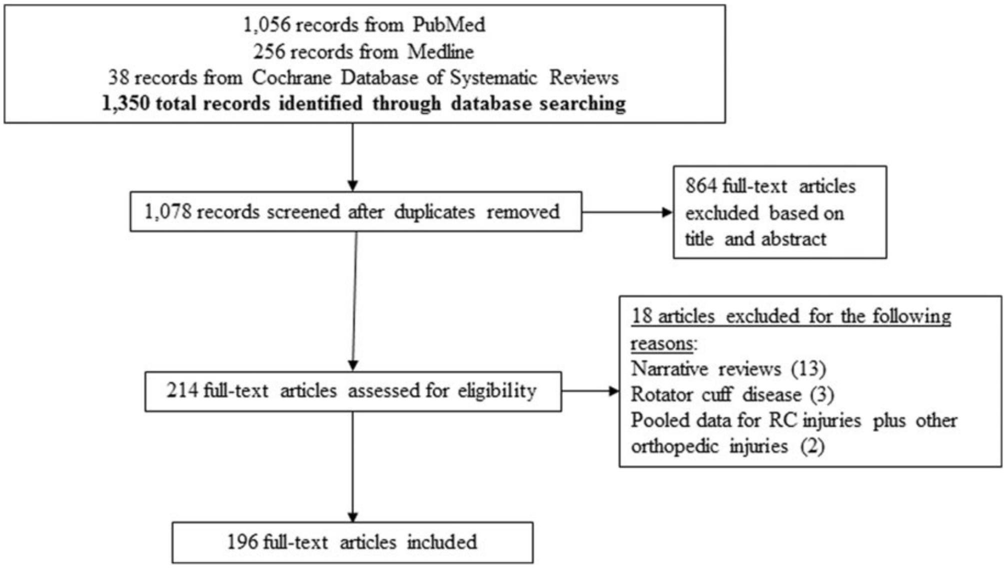

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart. RC, rotator cuff.

that pooled data pertaining to RC injuries with those of other orthopaedic injuries. Four authors (J.J., J.M., T.M., M.A.K.) independently reviewed the results of the literature search and compared their findings. Three authors (J.J., J.M., T.M.) reviewed each study in detail and summarized the study results. The articles were divided into 15 topics: anatomy and function, histology and genetics, diagnosis, epidemiology, athletes, nonoperative versus operative treatment, surgical repair methods, concomitant conditions and surgical procedures, RC tears after total shoulder arthroplasty, biological augmentation, postoperative rehabilitation, outcomes and complications, patient-reported outcome (PRO) measures, cost-effectiveness of RC repair, and quality of randomized controlled trials. A few articles were categorized under more than 1 topic because they examined multiple study aims (<5% of included papers).

RESULTS

Figure 1 presents the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart. A total of 1078 articles were identified by the literature search, of which 196 met the inclusion criteria. The number of articles included for each RC topic are presented in Table 1.

TABLE 1
Number of Articles by Rotator Cuff Topic[a]

Topic of Systematic Review	Articles Found, n
Anatomy and function	5
Histology and genetics	4
Diagnosis	19
Epidemiology	8
Rotator cuff tears in athletes	5
Nonoperative vs operative treatment	14
Surgical repair methods	43
Concomitant conditions and surgical procedures	9
Rotator cuff tears after total shoulder arthroplasty	2
Biological augmentation	29
Postoperative rehabilitation	21
Outcomes assessment	37
Patient-reported outcome measures and their psychometric properties	6
Cost-effectiveness of rotator cuff repair	1
Quality of randomized controlled trials	2

[a]Topics are not mutually exclusive.

Anatomy and Function

Sangwan et al[195] systematically reviewed 20 studies that examined the function of RC muscles as dynamic stabilizers of the glenohumeral joint. Several studies indicated that RC muscles can inhibit joint translation, contribute to joint stiffness, have shorter moment arms for some movements, and activate prior to global muscles on electromyography with respect to certain shoulder movements. In a systematic review, Edouard et al[46] indicated that the most reliable position for internal rotation (IR) and external rotation (ER) strength assessment was to be seated with 45° of shoulder abduction in the scapular plane. Berckmans et al[16] systematically reviewed 14 studies that examined isokinetic RC strength assessment among healthy overhead athletes and concluded that greater IR force resulted in lower functional deceleration ratio (ER/IR) on the dominant side as compared with the nondominant side. In their systematic review of studies that examined electromyography activity of the shoulder muscles, Spall et al[215] ascertained that RC tears were associated with longer duration of muscle activity in the upper trapezius during glenohumeral movements and greater fatigability of the anterior and middle deltoid during isometric hand gripping and overhead lifting. The activation ratio of only the latissimus dorsi was decreased for the RC tear group versus the control group (mean difference = –1.31; 95% CI, –2.36 to –0.25; $P = .02$), which suggests greater co-contraction of the latissimus dorsi during isometric abduction. Abe et al[2] cited good reliability and validity for measuring muscle thickness on ultrasound (US) in the supraspinatus, biceps, and triceps when compared with cross-sectional area on magnetic resonance imaging (MRI) as well as manual measurement on cadavers. This suggests that muscle thickness may be predictive of muscle function.

Histology and Genetics

Dean et al[38] systematically reviewed 101 studies that examined cellular and molecular changes in RC disease, as well as the pathogenesis of RC disease (Tables 2 and 3). To summarize, degenerative RC disease demonstrated histologic features consistent with inflammation and tendon healing. The progressive formation of collagen fibers, mainly types II and III, are associated with loss of the normal tendon structure and myxoid degeneration. Proinflammatory cytokines accelerate remodeling, amplify biomechanical adaptivity, and promote tenocyte apoptosis, which subsequently creates an imbalance between the catabolic and anabolic systems. In the catabolic state, there is a decrease in tissue inhibitors of metalloproteinases (TIMPs), resulting in higher levels of metalloproteinase, a matrix-remodeling protein. Furthermore, TIMPs may play a role in the degradation of proinflammatory cytokines, and their relative decrease may contribute to the local inflammatory state. As the total collagen content decreases, smaller and more disorganized fibrils form. The increase in tenascin-C and fibronectin is consistent with the wound-healing process.

Hegedus et al[69] cited that hypervascularity was associated with RC tears, although it tended to decrease with increasing tear size. The initial response to tendon injury or degeneration involved neovascularization and hyperemia, whereas hypovascularity contributed to degenerative lesions and aging. Nutrition and genetics could also play a role in vascular changes, but further research is needed. Two systematic reviews examined gene expression and protein composition in RC tendons.[34,202] Dabija et al[34] documented that RC tears were significantly associated with haplotypes in *DEFB1*, *FGFR1*, *FGF3*, *ESRRB*, and *FGF10* and 2 single-nucleotide polymorphisms within *SAP30BP* and *SASH1*. Sejersen et al[202] found that RC tears were associated with increased BNip3 in 1 study and increased expression of hypoxia inducible factor 1α, vascular endothelial growth factor, and metalloproteinases 1 and 9 in 4 studies. Moreover, the authors found that 2 studies cited no correlation between apoptotic and cytokine gene expression and tear size or histologic grade among patients with supraspinatus tears, while 1 study did not find a correlation between tear size and apoptotic markers.

TABLE 2
Changes to the Extracellular Matrix Components and Enzymes in Rotator Cuff Disease[a]

Matrix Components	Matrix Enzymes
Type I collagen ↑[116]	MMP-1 ↑[19,63,89,103,105,156,234] ↓[108]
Type II collagen ↑[57,161]	MMP-2 ↑[156] ↑ (ftRCT vs ptRCT[224])
Type III collagen ↑[10,87,100,116,180,182] ↑ (RCT vs non-RCT[82])	MMP-3 ↑[87,156] ↓[103,105,108,117] ↑ (ftRCT vs ptRCT[247])
Type X collagen ↑[161]	MMP-9 ↑[19,103,105,209,234] ↑ (ftRCT vs ptRCT[224])
Type I collagen α1 ↓[8] ↑ (ftRCT vs ptRCT[209])	MMP-13 ↑[83,108,117,156,209]
Type I collagen α2 ↓[6,85]	TIMP-1 ↓[117]
Type II collagen α1 ↑[6,8,85]	TIMP-2 ↓[117]
Type III collagen α1 ↑[8,231] ↓[6]	TIMP-3 ↓[6,85]
Type VI collagen ↑[7] α1 ↑[8]	ADAM10 ↓[6]
Collagen crosslinking ↑[10]	Transglutaminase 2 ↓[152]
Total collagen content ↓[10,180,182]	**Other Enzymes**
Calcium phosphate ↑[180]	COX-1 ↑[19,234]
Aggrecan ↑[6,8,85,116]	COX-2 ↑[19,169,209,234]
Biglycan ↑[8]	Cathepsin D ↑[63]
Decorin ↑[8]↓[6,116]	iNOS ↑[209,222]
Clusterin ↑[6,135]	eNOS ↑[222]
Elastin ↓[6]	**Transcription Factors**
Fibronectin ↑ (RCT vs non-RCT[230])	SOX9 ↑[6,8]
Osteopontin ↑[225]	FOXO1A ↑ (massive tears[199])
Tenascin-C ↑[57,80]	FOXO3A ↑ (in tears greater than one-third[199])
Versican ↑[8]	
GAG content ↑[8,180]	
Chondroitin sulphate ↑[7,57,180,181]	
Dermatan sulphate ↑[7,180,181]	
Hyalauronan ↑[181]	
Hyaluronic acid ↑[181]	
α-Skeletal muscle actin and of myosin heavy polypeptide 1 ↑[55]	

[a]Includes changes to other enzymes and transcription factors. ↑, increased; ↓, decreased. Used with permission from Dean et al.[38] ADAM, a disintegrin and metalloproteinases; COX, cyclooxygenase; FOX, forkhead box protein; ftRCT, full-thickness rotator cuff tear; GAG, glycosaminoglycan; MMP, matrix metalloproteinase; NOS, nitric oxide synthase; ptRCT, partial-thickness rotator cuff tear; RCT, rotator cuff tear; SOX9, sex-determining region Y-box 9 protein; TIMP, tissue inhibitor of metalloproteinase.

Diagnosis

Predictors of RC Diagnosis. Raynor and Kuhn[177] systematically reviewed 21 studies to determine which patient history factors were predictive of anatomic diagnoses among patients with atraumatic shoulder pain. Predictors of a diagnosis of an RC tear included history of hypercholesterolemia, family history of RC disease, excessive lifting, above-shoulder work, handheld vibration work, or age >60 years.

Physical Examination Tests. Several systematic reviews and meta-analyses examined the diagnostic accuracy of physical examination tests for diagnosing RC tears; however, there is substantial heterogeneity among these studies, and none replicated the same findings.[13,58,66,70,73,78] The most accurate tests for diagnosing an RC tear are a positive painful arc test (likelihood ratio = 3.7; 95% CI, 1.9-7.0),[73] a positive ER lag test (likelihood ratio = 7.2; 95% CI, 1.7-31),[73] and possibly the lateral Jobe test.[70] Hughes et al[78] concluded that suspicion of an RC tear might

TABLE 3
Changes to Cytokines, Growth Factors, Neuronal Factors, Apoptosis/Cell Cycle–Related Factors, and Other Factors in Rotator Cuff Disease[a]

Cytokines/Growth Factors	Apoptosis/Cell Cycle Related
IL-1α ↑[19,234]	HIF-1α ↑[15,103,135] ↓[136,137,140]
IL-1ra ↑[60-62]	BNIP-3 ↑[15]
IL-1β ↑[18,19,60-62,99,191,209,234]	BCL-2 ↑[135]
IL-2 ↓[136,140]	Caspase 3 ↑[136,137]
IL-6 ↑[18,19,99,136,209,234]	Caspase 8 ↑[136,137,140]
IL-11 ↑[136,140]	Heat shock protein 27 ↑[136,137,140]
IL-15 ↑[136]	Heat shock protein 70 ↑[136,137,140]
IL-18 ↑[136]	Poly(ADP-ribose) polymerase ↑[136,140]
Stromal derived factor 1α ↑[18,94]	Type-2 angiotensin II receptor ↓[136,140]
TNFα ↑[19,99,191,209,234]	cFLIP ↑[137]
VEGF ↑[103,104,135,169,209] ↑ (associated with motion pain[242])	cFLIP receptor ↑[137]
IGF-1 ↓[6,85]	p-53 induced gene I, cell division cycle 25A, Max protein, meiotic recombination 11 homolog A ↑[140]
TGF-β ↑[161,191]	Peroxiredoxin 5 ↑[237]
bFGF ↑[161,191]	P53 ↑[121,140]
FGF 18 ↑[140]	P53 inhibitors ↓[121]
BMP2 and BMP7 ↑[161]	NF-KB ↓[121]
Small inducible cytokines ↑[19]	Receptor activator of NF-KB ↑[121]
Macrophage inhibitory factor ↑[136]	
Heparin affinity regulatory peptide ↑[8]	
Five-lipoxygenase activating protein ↑[169]	
Hepatocyte growth factor ↓[140]	

Neuronal Factors	Others
Substance P ↑[89] (higher in nonperforated RCTs vs perforated[62])	Ubiquitin proteasome pathway UBE2A and UBE3A ↑ (massive tears vs small/controls[199])
β-endorphin ↑[89]	Calpain (CAPN1) and CTSB (lysosomal enzyme) ↑ (massive tears vs small/controls[199])
Anti-NGF30 ↑[136,140]	vWF ↑[169]
PGP9.5, GAP43 ↑[241]	T-cell receptor variable βchain ↑[136]
Glutamate receptor 5, glutamate receptor metabotropic 6, glutamate receptor inotropic 3A, GABA receptor α1 ↑[140]	Ig chain, T-cell receptor α chain ↓[136]
AMPA1, glutamate receptor interacting protein 1/2 ↓[140]	GATA binding protein, PAF acetylhydrolase, Attractin, IgG-2b chain ↑[136,140]
	Insulin induced gene 1, FGFr1, nuclear receptor coactivator 2, G protein coupled receptor 54, Ephrin A1, Thyrotroph embryonic factor, Odd Oz/ten-m homolog 2, POU domain, TNF 11, TGF-β binding protein 3, T-cell receptor β chain, cytochrome b-245, CD3 γ chain, polyprotein 1-microglobulin, Fc receptor IgE, solute carrier family 2, adenosine deaminsae, integrin-linked kinase ↑[140]
	Dynein, nuclear receptor subfamily 2 group F member 1, Homeobox A1, FGF receptor 3, MHC class I-like sequence, T-cell receptor β chain, killer cell lectin-like receptor, strain T-cell receptor ↓[140]
	T-cell receptor ↓[136,140]

[a]↑, increased; ↓, decreased. Used with permission from Dean et al.[38] AMPA, alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid; ADP, adenosine diphosphate; BCL, B-cell lymphoma; BMP, bone morphogenetic protein; cFLIP, cellular FLICE (FADD-like IL-1beta-converting enzyme)-inhibitory protein; CTSB, cathepsin B; FGF, fibroblast growth factor; GABA, gamma-aminobutyric acid; GAP43, growth-associated protein 43; HIF, hypoxia-inducible factor; IGF, insulin-like growth factor; IL, interleukin; NF-KB, nuclear factor kappa light chain enhancer of activated B cells; NGF, nerve growth factor; PGP9.5, protein gene product 9.5; RCT, rotator cuff tear; TGF, transforming growth factor; TNF, tumor necrosis factor; UBE, ubiquitin conjugating enzyme; VEGF, vascular endothelial growth factor; vWF, Von Willebrand factor.

be (1) increased by positive palpation, combined Hawkins–painful arc–infraspinatus test, Napoleon test, lift-off test, belly-press test, or drop-arm test and (2) decreased for negative palpation, empty can test, or Hawkins-Kennedy test; however, the authors determined that most tests were inaccurate and could not be recommended for clinical use. Full-thickness tears were most accurately diagnosed by a positive lag test (likelihood ratio = 5.6; 95% CI, 2.6-12).[73] Gismervik et al[58] and Beaudreuil et al[13] reported the Jobe and empty can tests to be most accurate for diagnosing supraspinatus tears. The Patte test, resisted ER with the elbow at the side flexed at 90°, and resisted lateral rotation from neutral position were shown to be most accurate for diagnosing infraspinatus tears.[13,66] The IR lag sign, belly-off, and modified belly-press tests were shown to be accurate for diagnosing subscapularis tears.[66,70] Pugh et al[174] systematically reviewed 5 studies that investigated various physical examination tests (ie, Hawkins, drop-arm, empty can, Patte, and bear-hug tests), concluding that they were not accurate and that they produced variable findings.

Imaging. A meta-analysis of 44 studies found high sensitivity (SE) and specificity (SP) for MRI when diagnosing RC tears: partial thickness (SE = 80%, SP = 95%) and full thickness (SE = 91%, SP = 97%).[213] Also, higher–field strength MRI (3 T vs 1 T and 1.5 T) provided the highest diagnostic accuracy. Two meta-analyses estimated the pooled SE and SP for US when diagnosing RC tears: partial thickness (SE = 72%-84%, SP = 89%-93%) and full thickness (SE = 95%-96%, SP = 93%-96%).[158,212] Smith et al[212] also indicated that the diagnostic accuracy of US was higher for lower transducer frequency (7.5 vs ≥10 MHz) and readings by musculoskeletal versus general radiologists. Baombe[11] concluded that US was accurate for diagnosing full-thickness RC tears but less accurate for diagnosing partial-thickness tears.

In a meta-analysis of 14 studies, McGarvey et al[134] discovered that (1) 3-T MRI and 3-T magnetic resonance arthrogram (MRA) showed excellent diagnostic accuracy for full-thickness supraspinatus tears, (2) 3-T 2-dimensional MRA was more sensitive (86.6% vs 80.5%, $P = .01$) but less specific (95.2% vs 100%, $P < .001$) than 3-T MRI for diagnosing partial-thickness tears, and (3) there was a trend toward 3-T MRA as the most accurate for diagnosing subscapularis tears. Two meta-analyses cited no differences in SE and SP for US, MRI, and MRA for diagnosing full-thickness RC tears.[109,185] Alternatively, 2 meta-analyses determined that MRA was more sensitive and specific than US and MRI for diagnosing partial- and full-thickness tears.[35,185] Kelly and Fessell[91] ascertained higher SE and SP for diagnosing full- versus partial-thickness tears on US, MRI, and MRA but did not compare diagnostic accuracy among these imaging modalities.

Seitz and Michener[201] systematically reviewed 5 case-control studies and indicated that acromiohumeral distance is less on US for patients with full-thickness RC tears versus healthy controls and those with subacromial impingement. Measuring the subacromial space with a linear measurement of the acromiohumeral distance for patients with an RC tear may be helpful in determining diagnosis and prognosis.

Indications for Surgery. On the basis of their systematic review, Oh et al[151] concluded that (1) early surgical management may be warranted for traumatic acute tears and in the presence of weakness and substantial functional disability; (2) nonoperative management is often successful when symptom duration is <3 months but may be unsuccessful for symptoms that last >1 year; and (3) the influence of age and sex on operative prognosis is unclear, although workers' compensation claims are associated with worse prognosis.

Epidemiology

According to a systematic review of 9 studies, patients with RC tears were 55 years old on average (range, 34-61 years), primarily male (77%), and most often injured by a fall onto an outstretched arm.[126] Furthermore, the mean time to surgery was 9 weeks (range, 3-48 weeks); the most commonly torn tendon was the supraspinatus (84%); and most tears were <5 cm (58%). Eljabu et al[48] discovered that asymptomatic RC tears increased in size, were associated with diminished muscle quality, and led to symptom development over the course of 3 years. In their review of the natural history of RC tears, Abdul-Wahab et al[1] determined that atraumatic tears were associated with muscle weakness and minor discomfort that did not appear to increase with increasing tear size.

Risk factors of RC tears included the dominant arm (odds ratio [OR], 2.30; 95% CI, 1.01-5.25) and age ≥60 years (OR, 5.07; 95% CI, 2.45-10.51), according to a meta-analysis of 10 studies.[198] As shown in Table 4, Teunis et al[226] conducted a meta-analysis of 30 studies and determined that the prevalence of RC abnormalities increased from 9.7% at ≤20 years old to 62% at ≥80 years old ($P < .001$). Vincent et al[233] also discovered more RC tears among older patients; however, this systematic review did not present prevalence rates, and the samples for the 2 clinical studies were primarily female and from a single country. Two systematic reviews of basic science and clinical studies ascertained that smoking is associated with increased prevalence of larger RC tears, degenerative changes, decreased tendon quality, reduced biomechanics, and increased stiffness.[17,196] The association between smoking and RC tears was also shown to be time and dose dependent.[17]

Athletes

Harris et al[67] indicated that the rate of return to play (RTP) after RC repair was 55% to 73% among Major League Baseball pitchers and that about 25% of players never pitched in the league again. The rate of RTP was only 8% in 1 study; however, 66% of players had concurrent procedures, such as SLAP (superior labrum anterior and posterior) repair, which may have affected RTP. On the basis of pooled data from 12 articles, Plate et al[172] discovered that the rate of RTP was 91% for contact sports, 40% for professional overhead athletes (although RC debridement was more common than RC repair for this group), and 83% for recreational overhead athletes. Berckmans et al[16] determined that greater IR force resulted in a lower functional deceleration ratio (ER/IR) on the dominant side as compared with the nondominant extremity for healthy overhead athletes; however, the most effective exercise program for increasing RC strength could not be determined. Papalia et al[165] systematically reviewed 22 studies of shoulder trauma among rugby players and cited 3 studies that ascertained the prevalence of RC tears in this population (2.1%-43%), and the most common mechanisms of injury included tackling and falling onto the arm. In a meta-analysis of 23 studies, Klouche et al[95] reported that the overall rate of RTP for

TABLE 4
Prevalence of Rotator Cuff Abnormalities Overall and Among Asymptomatic and Symptomatic Patients, in the General Population, and After Shoulder Dislocation[a]

	Age in Decades, y							
	<20	20-29	30-39	40-49	50-59	60-69	70-79	>80
Overall[b]								
Shoulders, n	299	434	481	933	1531	1134	1032	268
Prevalence cuff abnormality, % (n)	9.7 (29)	6.9 (30)	13 (60)	13 (117)	19 (285)	30 (338)	41 (427)	62 (166)
P value				*<.001*				
Odds ratio (95% CI)	Reference value	0.69 (0.41-1.2)	1.3 (0.83-2.1)	1.3 (0.87-2.1)	2.1 (1.4-3.2)	4.0 (2.6-5.9)	6.6 (4.4-9.8)	15 (9.6-24)
P value		.18	.24	.19	*<.001*	*<.001*	*<.001*	*<.001*
Asymptomatic								
Shoulders, n	0	75	70	470	807	495	468	59
Prevalence cuff abnormality, % (n)		6.7 (5)	21 (15)	4 (18)	9.5 (77)	16 (77)	28 (130)	56 (33)
P value				*<.001*				
Odds ratio (95% CI)	—	Reference value	3.8 (1.3-11)	0.56 (0.20-1.5)	1.5 (0.58-3.8)	2.6 (1.0-6.6)	5.4 (2.1-14)	18 (6.3-50)
P value			.014	.26	.42	*.048*	*<.001*	*<.001*
General population[c]								
Shoulders, n	2	12	140	254	473	442	394	164
Prevalence cuff abnormality, % (n)	0	0	2.9 (4)	7.9 (20)	14 (67)	31 (138)	50 (196)	65 (106)
P value				*<.001*				
Odds ratio (95% CI)	—	—	Reference value	2.9 (0.97-8.7)	5.6 (2.0-16)	15 (5.6-43)	34 (12-93)	62 (22-177)
P value				.056	*.001*	*<.001*	*<.001*	*<.001*
Symptomatic								
Shoulders, n	264	193	212	123	163	120	109	8
Prevalence cuff abnormality, % (n)	9.9 (26)	4 (8)	14 (29)	40 (50)	61 (163)	68 (81)	63 (69)	50 (4)
P value				*<.001*				
Odds ratio (95% CI)	Reference value	0.40 (0.18-0.89)	1.5 (0.83-2.55)	6.2 (3.6-11)	15 (8.7-24)	19 (11-33)	16 (9.0-28)	9.2 (2.2-39)
P value			.20	*<.001*	*<.001*	*<.001*	*<.001*	*.003*
Dislocations								
Shoulders, n	33	154	59	85	88	77	61	37
Prevalence cuff abnormality, % (n)	9 (3)	11 (17)	20 (12)	34 (29)	47 (41)	55 (42)	53 (32)	62 (23)
P value				*<.001*				
Odds ratio (95% CI)	Reference value	1.2 (0.34-4.5)	2.6 (0.66-9.8)	5.2 (1.5-18)	8.7 (2.5-31)	12 (3.4-43)	11 (3.0-40)	16 (4.2-64)
P value		.74	.17	.011	*.001*	*<.001*	*<.001*	*<.001*

[a]Italic text indicates statistically significant difference. Used with permission from Teunis et al.[226]
[b]Overall sums asymptomatic, general population, symptomatic, and dislocations.
[c]General population includes cadavers.

professional and recreational athletes was 84.7% (95% CI, 77.6%-89.8%) at 4 to 7 months after RC repair and that 65.9% (95% CI, 54.9%-75.4%) returned to an equivalent level of play. The rate of RTP for professional and competitive athletes was 49.9% (95% CI, 35.3%-64.6%).

Nonoperative vs Operative Treatment

Hawk et al[68] systematically reviewed 8 studies of nonoperative management for RC tears and found that (1) physical therapy had a negative effect on pain and activities of daily living in comparison with RC surgery (2 studies), (2) extracorporeal shockwave therapy (1 study) or low-level laser therapy (1 study) was associated with greater improvement in pain and function than that of sham therapy, and (3) there was no difference in pain or function for subacromial corticosteroid injections versus diathermy (1 study). Bury et al[23] determined that, as compared with general physical therapy for managing RC-related shoulder pain, scapula-focused approaches (including exercise therapy, stretches, and/or manual therapy) were associated with less disability at 6 weeks but not at 3 months after therapy. Abdul-Wahab et al[1] discovered that 73% to 80% of patients with full-thickness atraumatic tears and 68% with traumatic RC tears could be treated with physical therapy, especially if there were no signs of impingement yet good active ER, integrity of the intramuscular tendon of the supraspinatus, and little to no atrophy of the supraspinatus. Ainsworth and Lewis[4] systematically reviewed 10 studies that cited improved outcomes following rehabilitation for RC tears; however, none of these studies included a control group. Kamioka et al[88] identified 1 study reporting that aquatic therapy plus land-based rehabilitation after RC repair resulted in greater improvement in passive flexion range of motion (ROM) measured at 3 and 6 weeks after surgery as compared with land-based rehabilitation alone. One systematic review that examined the effectiveness of manual and exercise therapy concluded that (1) exercise was superior to manual therapy but not to surgery, (2) there were no differences in pain or function for exercise and/or manual therapy versus glucocorticoid injection or subacromial decompression, and (3) exercise was associated with greater improvement in function over advice to maintain normal activities.[159] On the basis of a systematic review of 5 studies, Braun et al[21] was unable to identify a prognostic model to predict outcomes among patients who underwent physical therapy for RC disorders (subacromial impingement and/or RC tear).

Ryosa et al[187] conducted a meta-analysis of data from 3 randomized controlled trials and documented greater improvement in pain following RC repair versus conservative management (mean difference = –0.93; 95% CI, –1.65 to –0.21; $P = .01$), although the observed difference in pain score was below the level of the minimal clinically important difference and there was considerable variation in conservative management among studies. Two systematic reviews cited support for operative versus nonoperative treatment of RC tears; 1 of these reviews also indicated improved function with rehabilitation versus no rehabilitation.[79,200] According to a systematic review of 11 studies, injection of hyaluronic acid for RC tear was associated with improved pain and function as compared with corticosteroid injection, physical therapy, or saline.[157] Only minor complications were found for hyaluronic acid, including vagal reaction and persistent pain at the injection site. Two overlapping systematic reviews cited 1 study that documented no difference in outcomes following hyaluronic acid versus corticosteroid injection.[43,79] Abdul-Wahab et al[1] determined that only 40% of patients who had corticosteroid or hyaluronate injection for RC tears were satisfied at 24 weeks. Given the findings of their systematic review, Robb et al[183] concluded that nonsteroidal anti-inflammatory drugs and subacromial corticosteroid injections can be used with caution in addition to supervised exercise. Huisstede et al[79] discovered 2 studies that did not observe a difference in pain or function for suprascapular nerve block with dexamethasone versus placebo for treating RC tears in the short term. Curtis[33] systematically reviewed clinical, animal, and in vitro studies that examined the effect of nutrients on treating tendon injuries, concluding that there is limited evidence for consuming vitamin D, a multifaceted supplement (Tenosan), or cyanidin (a phytochemical in fruits and vegetables) to improve tendon healing.

Surgical Repair Methods

Double- vs Single-Row Repairs. Wall et al[236] performed a systematic review of 15 cadaveric and animal studies that compared biomechanical properties for double-row (DR) versus single-row (SR) repairs. Nine studies favored DR repair with regard to tensile strength, construct failure, and gap formation, and 5 studies demonstrated that DR repairs increased native footprint coverage. Their review concluded that (1) DR repair restores more of the anatomic RC footprint and (2) SR repair is not biomechanically superior to DR repair.

Several overlapping systematic reviews reported up to 6 studies that documented improvement in PROs for DR and SR repairs, but there were no statistically significant differences between groups.[‡] Five overlapping meta-analyses also cited no statistically significant differences in PROs between DR and SR repairs.[31,39,138,171,205] Chen et al[31] determined that for tears >3 cm, DR repairs had better PROs than did SR repairs. Three meta-analyses found that in comparison with SR repairs, DR repairs had better PROs and/or increased ROM overall and especially for tears measuring >3 cm.[240,246,249]

Several overlapping systematic reviews identified 2 studies that documented better healing rates for DR versus SR repair.[147,167,173,197] DeHaan et al[39] identified 4 studies that examined structural healing and indicated a borderline significant trend toward a higher retear rate for SR versus DR repairs (43.1% vs 27.2%, $P = .06$). Millett et al[138] discovered an increased risk of retears for SR versus DR repairs (relative risk [RR], 1.76; 95% CI, 1.25-2.48), and this association was strongest for partial-thickness tears (RR, 1.99; 95% CI, 1.40-3.82). Several meta-analyses revealed that DR repairs have better structural healing versus SR repairs for tears measuring >3 cm.[31,240,246] Zhang et al[249] performed a meta-analysis of 8 studies and determined that the retear rate was less for DR versus SR repairs for partial-thickness tears; however, the rate of retear did not differ between repair methods for full-thickness tears. Two overlapping meta-analyses cited lower retear rates for DR and suture-bridge repairs versus SR repairs for tears measuring >1 cm.[45,71] Additionally, Duquin et al[45] discovered that retear rates did not differ between SR repair methods (transosseous vs SR suture anchor) or between arthroscopic and nonarthroscopic repairs (open + mini-open [MO]) for any tear size with SR or DR repair. Hein et al[71] indicated that retear rates did not differ between DR and suture-bridge repairs for any tear size.

Mascarenhas et al[130] and Spiegl et al[217] systematically reviewed meta-analyses that compared DR and SR repairs,

‡References 79, 147, 167, 173, 197, 200, 235.

and both concluded that PROs were improved for DR versus SR repairs for tears measuring >3 cm and that structural healing was greater for DR versus SR repairs for tears of any size and tears >3 cm. Mascarenhas et al[130] used the Jadad et al[84] decision algorithm to identify the highest-quality meta-analyses, which were those by Chen et al,[31] Zhang et al,[249] and Millett et al.[138]

Brown et al[22] performed a meta-analysis of 13 studies to evaluate the effect of suture configuration, repair method, and tear size on structural healing after RC repair. Retear rates did not differ by suture configuration (simple, mattress, and modified Mason-Allen sutures) or tear size for SR repairs, and the retear rates did not differ between DR suture anchor and suture-bridge repairs for any tear size, which were all performed with mattress sutures.

Transosseous-Equivalent Repairs. Mall et al[127] systematically reviewed 5 biomechanical studies, of which 4 indicated better biomechanical properties when the medial-row anchors were tied before the lateral-row anchors. One study demonstrated no significant differences in contact pressure, mean failure load, and gap formation for a standard suture-bridge repair with knots tied at the medial row versus knotless repairs.

Transosseous Repairs. Coghlan et al[32] identified 1 study that documented no statistically significant differences in PROs and retear rates for transosseous repair with Ethibond via the modified Mason-Allen suture technique versus transosseous repair with polydioxanone cord via the modified Kessler technique.

Arthroscopic vs MO Repairs. Nho et al[146] performed a systematic review of 17 studies, of which only 4 directly compared arthroscopic with MO repairs and none ascertained a statistically significant difference in PROs between the groups. The complication rate was 3% for arthroscopic repair and 6.6% for MO repairs. Lindley and Jones[114] performed a systematic review of 10 studies and found only 1 that indicated lower pain at 6 months after arthroscopic versus MO repair ($P = .03$); in addition, tears >3 cm had a higher retear rate when repaired arthroscopically ($P = .04$). Huang et al[77] performed a meta-analysis of 18 studies and determined that the Constant score was better for MO versus all-arthroscopic repair (standardized mean difference = 0.87; 95% CI, 0.11-1.62; $P = .03$). Three meta-analyses did not find any statistically significant differences in PROs, ROM, or retear rates for arthroscopic versus MO repair.[86,142,203] Gurnani et al[65] conducted a meta-analysis of 16 studies and cited improvement in PROs after arthroscopic or MO RC repair, but they did not perform any statistical comparisons between these 2 repair methods.

Repair of Articular-Sided Partial-Thickness RC Tears. Bollier and Shea[20] systematically reviewed 14 studies that assessed PROs after debridement with or without acromioplasty, completion and repair, or transtendon repair of a symptomatic partial articular-sided RC tear, of which only 1 retrospective nonrandomized study compared these procedures and indicated improved long-term results and decreased reoperation rates in the tear completion + MO repair group. Two overlapping meta-analyses compared tear conversion and repair versus transtendon repair for partial articular-sided RC tears. Sun et al[221] performed a meta-analysis of 5 studies and did not find a statistically significant difference in American Shoulder and Elbow Surgeons (ASES) scores; however, the retear rate was higher for tear conversion and repair versus transtendon repair (11.3% vs 4.3%, $P < .05$). Ono et al[155] conducted a meta-analysis of 3 studies and cited no statistically significant differences in Constant, ASES, and visual analog scale (VAS) scores as well as ROM and retear rates for tear conversion and repair versus transtendon repair.

Repair of Isolated Subscapularis Tears. Mall et al[125] systematically reviewed 3 arthroscopic-repair and 6 open-repair level 4 noncomparative studies of patients with isolated subscapularis tears. They reported that (1) Constant scores and pain improved after arthroscopic or open repairs, (2) biceps tenodesis was the most commonly performed concomitant procedure, and (3) postoperative healing was good (90%-95%).

Surgical Management of Partial-Thickness RC Tears. Strauss et al[220] discovered that 29% to 93% of patients had excellent outcomes after repair of a partial-thickness tear in 16 studies. Furthermore, debridement of partial-thickness tears <50% of the tendon's thickness with or without acromioplasty resulted in good outcomes, although 7% to 35% of partial-thickness tears progressed to full-thickness tears. Katthagen et al[90] reported (1) good outcomes following arthroscopic repair of partial-thickness tears >50% thickness and (2) no difference in outcomes for in situ repair versus repair of the tendon after completion to full-thickness tear. However, Pedowitz et al[168] determined that repair of partial-thickness tears >50% thickness failed and concluded that there was weak evidence for the 50% rule for arthroscopic surgery. Papalia et al[162] systematically reviewed 23 studies and generally reported improvement in ROM and PROs following repair of partial-thickness tears; however, treatment options and PRO measures varied greatly among studies, which limited comparisons.

Surgical Management of Massive and Irreparable RC Tears. Henry et al[72] pooled data from 18 studies of arthroscopic repair of chronic massive RC tears and determined that the rate of retear was 79% and that there was an improvement in postoperative VAS (5.9 to 1.7), active ROM (125° to 169°), and the Constant score (49 to 74). Two overlapping systematic reviews examined postoperative PROs for latissimus dorsi tendon transfer (LDT-T) among patients with irreparable tears.[118,145] Namdari et al[145] reviewed 10 noncomparative studies and cited improvement in clinical scores, pain, ROM, and strength following LDT-T. Longo et al[118] reported 19 studies that demonstrated restoration of active ER after LDT-T; they also discovered 3 studies that showed increased active ER and anterior elevation for LDT-T plus teres major transfer versus LDT-T alone. Tendon transfers for irreparable tears can be technically challenging and associated with neurovascular risks; thus, techniques involving a graft or synthetic patch have been developed to aid in bridging the gap and to allow the tendon to reconnect to the anatomic footprint. Lewington et al[112] found increased structural integrity on MRI for biceps tendon autograft (58% vs 26%,

P = .04) and fascia lata autograft (79% vs 58%, P < .05) when compared with partial primary repairs for irreparable tears. High structural healing rates for allografts (74%-90%), xenografts (73%-100%), and synthetic materials (60%-90%) for bridging reconstruction were also found.

Concomitant Conditions and Surgical Procedures

Two overlapping meta-analyses compared outcomes of full-thickness RC repairs with concomitant acromioplasty versus without acromioplasty.[50,214] Song et al[214] indicated that ASES scores were higher for RC repairs with acromioplasty versus without acromioplasty; however, no other statistically significant differences in pain, ROM, or retear rates were cited in either meta-analysis.[50] Redondo-Alonso et al[178] determined that 22% to 78.5% of patients in 5 studies had chronic pathology of the supraspinatus and the long head of the biceps tendon. Leroux et al[110] conducted a meta-analysis of 12 studies and discovered that biceps tenodesis was associated with higher postoperative Constant scores (92.8 vs 90.6, P < .01) and fewer biceps deformities (15.5% vs 3.9%, P < .01) than tenotomy when performed concurrently with RC repair. In a meta-analysis of 903 patients undergoing RC repair, Shang et al[204] also indicated that tenotomy was associated with worse Constant scores (standard mean difference = –0.23, P = .03) and increased odds of Popeye deformities (OR, 2.78; P < .0001) than tenodesis. Among patients with SLAP tears and concomitant RC tears, Erickson et al[49] cited no difference in PROs after tenotomy for patients aged ≥40 versus <40 years. Gombera and Sekiya[59] discovered that persistent pain and dysfunction after shoulder dislocation were often associated with an RC tear. Surgical repair of acute RC repairs after shoulder dislocation was typically associated with better PROs than nonoperative management. Two systematic reviews cited no statistically significant differences in PROs following RC repair with subacromial decompression versus without.[26,32]

RC Tears After Total Shoulder Arthroplasty

Levy et al[111] performed a meta-analysis of 1259 patients from 15 studies that examined the incidence of RC tears after total shoulder arthroplasty, and they reported that 11% of patients had superior cuff tears, 3% had subscapularis tears, and 1% underwent reoperation for RC tear after total shoulder arthroplasty. Horner et al[74] systematically reviewed 11 studies that examined indications for shoulder arthroscopy after total shoulder arthroplasty, and they determined that 19% of patients underwent arthroscopy for evaluation of the RC and/or associated impingement and 4% for RC tear.

Biological Augmentation

Platelet-Rich Plasma. Given the low intrinsic healing potential of tendon tissue and its degenerative nature, augmentation for tissue regeneration is an expanding area of research. Platelet-rich plasma (PRP) is a common augmentation strategy for both conservative and operative management of RC tears.[53] PRP is rich in soluble growth factors that may be involved in tissue regeneration and vascularization.[54] PRP can also stimulate angiogenesis and increase cell migration, differentiation/proliferation, and extracellular matrix production.[244] Five overlapping systematic reviews evaluated the effectiveness of PRP for conservative management of RC tears or in combination with arthroscopic RC repair.[5,53,123,139,164] Miranda et al[139] reported 10 laboratory studies that indicated positive or partially positive results in favor of PRP; however, 70.6% of 7 clinical studies and 75% of 8 meta-analyses did not find a statistically significant difference in clinical outcomes for PRP use versus control. Filardo et al[53] found that 5 of 8 studies reported improved function and pain with PRP use for chronic RC tears managed conservatively, but only 5 of 18 studies cited improved PROs and lower retear rates with the use of PRP at the time of arthroscopic RC repair. Maffulli et al[123] systematically reviewed 3 evidence level 1 or 2 studies and determined that the only PRO that differed between the PRP group and controls was postoperative pain score. Andia and Maffulli[5] discovered 1 study that documented lower retear rates with PRP use for small and medium RC tears and 1 study that cited increased retears for PRP use for massive tears, suggesting that tear size is influential. Papalia et al[164] found that 1 of 7 studies indicated decreased retears and better Rowe scores with the use of PRP versus control and that 1 other study indicated increased retears when PRP was used.

Five of 11 overlapping meta-analyses reported no statistically significant differences in PROs and/or retear rates for PRP use versus control among patients undergoing arthroscopic RC repair.[§] Two meta-analyses cited no overall differences in retear rates and postoperative PROs for PRP use versus control.[193,248] However, Saltzman et al[193] performed subgroup analyses and demonstrated that PRP use was associated with lower retear rates for (1) DR repairs of small- or medium-sized versus large or massive tears, (2) PRP application at the tendon-bone interface, (3) application of a solid PRP matrix versus liquid, and (4) DR versus SR repairs. Zhang et al[248] also determined that PRP use was associated with a lower retear rate for small- and medium-sized tears versus large- and massive-sized tears. Yang et al[244] performed a meta-analysis of 8 studies and discovered that PRP use was associated with better Constant, Simple Shoulder Test, and VAS scores, although there were no statistically significant differences in ASES and UCLA (University of California, Los Angeles) scores and overall retear rates for PRP use versus control. Also, stratifying by tear size and length of follow-up had no statistically significant effect on the association between PRP use and PROs. In a meta-analysis of 5 studies, Cai et al[24] indicated that PRP use was associated with a lower retear rate overall (RR, 0.05; 95% CI, 0.31-0.83) and a lower retear rate for mild to moderate versus severe to massive tears (RR, 0.35; 95% CI, 0.14-0.90). Similarly, Vavken et al[232] discovered that PRP use was associated with a lower retear rate for tears <3 cm versus >3 cm (RR, 0.60; 95% CI, 0.37-0.97); however, PRP use was not found to be cost-effective.

[§]References 24, 27, 54, 113, 141, 193, 232, 238, 244, 248, 250.

Stem Cells. Mesenchymal stem cells (MSCs) are capable of differentiating into multiple cell lines, and they provide a twofold mechanism of repair: MSCs (1) are capable of differentiating into new tenocytes and directly forming new tendon tissue and (2) can modulate the local immune response to stimulate surrounding cells for growth factor and cytokine production.[25,37,64,148,170] Ahmad et al[3] reviewed 27 preclinical and 5 clinical studies that demonstrated that MSCs were able to survive and differentiate into tenocytes when placed in tendon environments, increase collagen fiber density, enhance tissue architecture, and restore a nearly normal tendon-bone interface. Only 1 randomized controlled trial was cited, which noted that skin-derived tendon cells produced better clinical results than autologous plasma. Obaid and Connell[150] determined that MSCs can autopopulate allografts in vitro and indicated promising results for using MSCs with tendon repairs in animal models; however, more in vivo human trials are needed. Pas et al[166] systematically reviewed 2 nonrandomized studies that evaluated bone marrow–derived stem cells as an additive for RC repair, and both studies demonstrated fewer retears; however, 1 study did not have a control group, and neither study assessed PROs in a blinded fashion. A systematic review of 10 animal studies and 7 human studies cited (1) improved healing rates and load to failure with the use of MSCs in the animal studies, (2) several potential sources for harvesting MSCs for treating RC pathology (RC tendon, subacromial bursa, long head of the biceps tendon, and the proximal humerus), and (3) 1 case series that reported good repair integrity at 1 year after RC repair with MSCs but did not include a control group.[14] Imam et al[81] identified 1 laboratory-based study that discovered a superior number of progenitor cells from the iliac crest versus the tibia and calcaneus and 4 clinical studies that indicated improved outcomes and good structural integrity (approximately $\geq$90%) for RC repairs augmented with bone marrow aspirate concentrate, although 2 of these studies did not include a control group.

Scaffolds. Scaffolds for augmentation of RC repairs, including xenografts, allografts, and synthetic matrices, can facilitate cellular growth and collagen deposition. Thangarajah et al[227] systematically reviewed 11 clinical studies and 6 animal studies that evaluated scaffold use for augmentation of RC repairs. Two studies cited improved clinical outcomes for augmentation with an acellular dermal matrix and a nonabsorbable polypropylene patch versus control; 1 study determined that augmentation with porcine small intestinal mucosa was associated with less muscle strength versus control; the remaining 8 clinical studies either found no statistically significant differences between the augmentation and control groups or did not include a control group. The animal studies showed native cell infiltration; 3 separate studies demonstrated a higher load to failure for augmentation with porcine intestinal submucosa, an acellular dermal matrix, and an electrospun fibrous membrane versus control; and 1 study indicated better tensile strength for MSCs versus augmentation with polyglycolic acid. Longo et al[119] concluded that the benefits of extracellular matrix grafts include the capability to decrease in vivo mechanical forces on the tendon repair during healing and prevent gap formation while the host cells infiltrate and heal; furthermore, biologic scaffolds have type I collagen and higher affinity for host cells as compared with synthetic scaffolds but higher risk of immunogenicity. Papalia et al[164] cited good clinical results for autograft augmentation in 3 uncontrolled studies, worse clinical results and more complications for porcine xenografts in 4 of 5 studies, good clinical results for allografts in 5 of 9 studies (2 controlled, 3 uncontrolled), and good clinical results for synthetic devices in 6 of 7 uncontrolled studies. Ono et al[153] determined that repairs for large to massive tears with grafts had increased healing (OR, 2.48; 95% CI, 1.58-3.90) and better PROs ($P \leq .02$) versus repairs without grafts; however, statistical significance was reached only when 1 or 2 studies were excluded for practical or statistical reasons. Bridging grafts were associated with lower VAS pain scores (1 vs 3, $P = .01$) versus graft augmentation for large to massive tears, although healing rates did not differ for bridging versus augmentation (77.9% vs 64%, $P = .21$).[154] In a systematic review of 10 studies, Ferguson et al[51] reported that allograft augmentation was associated with more intact repairs as compared with primary repair controls in 4 studies and that polypropylene patches were associated with improved structural (83% vs 59% and 49%, $P < .01$) and functional outcomes as compared with controls and xenograft augmentation, respectively.

Gene Therapy. Rotini et al[184] found that gene therapy with adenovirus in vitro demonstrated capabilities of transferring genes to fibroblasts; however, genes that can be transcribed for tendon healing have yet to be identified.

Postoperative Rehabilitation

Types of Postoperative Rehabilitation Programs. The American Society of Shoulder and Elbow Therapists conducted a systematic review of 117 studies to develop a consensus statement regarding rehabilitation after arthroscopic RC repair.[228] The society recommended a 2-week period of immobilization, followed by performance of protected passive ROM during weeks 2 to 6, re-establishment of active ROM after 6 weeks, progression to strengthening at week 12, and finally the return to sport or work when appropriate.

Dickinson et al[41] reported greater improvement in postoperative PROs for supervised versus unsupervised therapy in 1 of 5 studies and cryotherapy versus no cryotherapy in 2 of 5 studies. In a systematic review by Du Plessis et al,[44] continuous passive motion was associated with greater ROM in 2 studies, less pain in 1 study, and increased strength in 1 study as compared with physical therapy. Baumgarten et al[12] conducted a systematic review of 4 studies to determine an optimal rehabilitation program after RC repair. Overall, outcome scores were improved for all types of therapies but did not significantly differ for (1) continuous passive motion versus physical therapy or manual passive motion and (2) supervised versus unsupervised physical therapy. Two other systematic reviews also cited no statistically significant differences in PROs for continuous passive motion versus manual therapy.[79,245] Thomson et al[229] systematically reviewed 11 studies and discovered improved postoperative PROs overall but did not find any single rehabilitation program to be superior to another. Marik and Roll[128] indicated (1) strong evidence to support postoperative rehabilitation involving progressive tendon forces plus standard rehabilitation and (2) inconclusive evidence regarding other types of postoperative rehabilitation (ie, continuous passive motion, supervised vs unsupervised therapy, and land-based vs aquatic-based therapy).

Early vs Delayed Postoperative Rehabilitation. Edwards et al[47] systematically reviewed 22 studies that examined electromyography activity during rehabilitation exercises in normal shoulders to determine which exercises met a cut point of ≤15% maximal voluntary isometric contraction and were not likely to result in excessive loading in the early postoperative rehabilitation period. They identified 19 active-assisted exercises that met the aforementioned criteria and would be appropriate for loading the supraspinatus or infraspinatus.

Several overlapping meta-analyses and systematic reviews compared outcomes for early versus delayed postoperative rehabilitation.[28,29,115,128,131,245] The definitions of early and delayed rehabilitation varied greatly across these studies, with early ROM beginning immediately after surgery to 6 weeks postoperatively and with delayed ROM beginning 3, 4, or 6 weeks postoperatively. Four meta-analyses and 1 systematic review documented no statistically significant differences in functional outcomes, ROM, and retear rates for early versus delayed rehabilitation.[28,29,115,131,245] A few meta-analyses found some evidence for better ER[30,56,207] and forward elevation[56,179] for early ROM but better function[30,56] and healing[30] for delayed ROM. When making comparisons with delayed passive ROM (3-6 weeks after surgery), Kluczynski et al[98] discovered (1) fewer retears for early passive ROM (within 1 week of surgery) for tears ≤3 cm repaired by transosseous or SR methods and (2) increased retears for early passive ROM for tears >5 cm repaired by DR or any other method. When making comparisons with delayed active ROM (≥6 weeks), Kluczynski et al[97] found increased retears in small (≤3 cm) and large (>3 or 5 cm) tears for early active ROM (<6 weeks). Three systematic reviews of overlapping meta-analyses determined that early ROM is associated with better ROM, but there is no difference in functional outcomes, pain, or healing rates between early and delayed ROM.[75,131,194] However, there is some evidence that larger tears may be associated with more retears for early versus delayed ROM.[75,194] The meta-analyses with the highest-quality rankings were those by Chan et al[28] and Riboh and Garrigues.[75,179]

Outcomes and Complications

Surgical Repair. Two systematic reviews reported significant improvement in ROM and PROs after RC repair.[126,251] Zuke et al[251] found that within 6 months of surgery, all indicated complications, the majority of postoperative improvement in strength and ROM, and the majority of retears had occurred. Spennacchio et al[216] systematically reviewed 10 articles that examined long-term (≥5 years) outcomes of arthroscopic RC repair and discovered that all of the studies demonstrated improvement in PROs and satisfactory results. In a meta-analysis of 6 studies, Shen et al[206] determined that DR repairs had decreased risk of retears overall (RR, 1.71; 95% CI, 1.18-2.49) and partial-thickness retears (RR, 2.16; 95% CI, 1.26-3.71) versus SR repairs; however, there were no statistically significant differences in PROs between DR and SR repairs. Two meta-analyses and 1 systematic review reported that retears were associated with worse PROs and/or reduced strength after SR, DR, or all-arthroscopic RC repairs versus intact RCs.[186,211,243] DiSilvestro et al[42] indicated that patients returned to driving at a mean of 2 months after RC repair.

Standard assessment and reporting of complications, especially shoulder stiffness, after arthroscopic RC repair are lacking, as demonstrated in a systematic review by Audige et al.[9] Sixteen definitions of the terms "frozen shoulder," "shoulder stiffness," and "stiff painful shoulder" were identified; diagnostic criteria for stiffness varied greatly among studies; and 12 definitions of restricted ROM were cited. Randelli et al[176] found that 73% of 56 studies reported complications after RC repair, with retears (11%-94%) and stiffness (2%-11%) being the most common. Less commonly, anesthetic, neurovascular, thromboembolic, and septic complications were indicated. Two overlapping systematic reviews identified risk factors for postoperative stiffness, including workers' compensation status, age <50 years, calcific tendinitis or adhesive capsulitis, concomitant labral repair, tear size, subscapularis tears, biceps tears, preoperative ROM, diabetes, open repairs, single-tendon repairs, and partial articular supraspinatus tendon avulsion repair.[40,163]

Revision Surgery. Ladermann et al[101,102] performed 2 overlapping systematic reviews of 10 evidence level 3 or 4 studies that examined outcomes following revision arthroscopic RC repair. Improvement in ROM and function after revision repair was found, and predictors of worse outcomes included female sex, tear recurrence after revision repair, preoperative active forward flexion <135°, and preoperative VAS pain score >5.[102] Furthermore, the authors concluded that most recurrent tears could be treated conservatively but revision surgery may be warranted for younger patients, a tear involving 3 tendons, and tears involving the subscapularis.[101]

Surgical Repair With Stiffness. Sabzevari et al[188] reported that preoperative stiffness is associated with decreased preoperative ROM among patients undergoing RC repair; however, postoperative outcomes did not differ between those with and without preoperative stiffness. Papalia et al[163] also cited strong evidence for arthroscopic capsular release among patients with shoulder stiffness secondary to RC repair.

Surgical Repair With Augmentation. Steinhaus et al[219] systematically reviewed 24 studies that examined outcomes after patch use with RC repair and discovered similar improvement in ROM, strength, and PROs for all augmentation and interposition techniques—except xenografts, which demonstrated less improvement in outcome scores versus the other techniques. Retear rates were 44% for xenografts, 23% for allografts, and 15% for synthetic grafts.

Repair of Subscapularis Tears. In a systematic review of 8 studies, Saltzman et al[192] indicated improvement in PROs, ROM, and strength after arthroscopic repair of isolated subscapularis tears, and the retear rate ranged from 4.8% to 11.8%. Shin et al[208] systematically reviewed 8 studies that examined outcomes following pectoralis major tendon transfer for irreparable subscapularis tendon ruptures. They reported a low incidence of postoperative nerve palsy (1%) and overall improvement in Constant and pain scores; however, Constant scores were significantly greater after subcoracoid transfer versus supracoracoid transfer of the pectoralis major tendon ($P < .001$).

Predictors of Postoperative Outcomes. Several overlapping systematic reviews and meta-analyses examined predictors of retears and worse outcomes after RC repair.[||] Predictors of retears included older age,[52,106,133,144,190] smoking,[196] increased tear size,[52,106,133,144,175,190] additional biceps or acromioclavicular procedures,[52,106] preoperative fatty infiltration,[52,93,133,175] multiple tendon involvement,[52,175] diabetes,[175] DR repairs,[175] increased retraction of the tendon,[52] and decreased bone mineral density.[52] Predictors of worse outcomes included older age,[52] female sex,[52] smoking,[17,196] diabetes,[52] lower baseline scores,[190] workers' compensation status,[92,106,175,190] decreased preoperative muscle strength,[52,175] increased tear size,[52] preoperative fatty infiltration,[93] <3 months between injury and surgery,[143] decreased sports activity,[52] preoperative shoulder stiffness,[52] and obesity.[52,96] Two reviews also determined that patients with a workers' compensation claim took longer to return to work and were less satisfied after RC repair.[36,92] Weinheimer et al[239] indicated that low surgeon volume (<12 surgical procedures per year) predicted increased length of stay, increased operating time, and an increase in reoperation rate. Raman et al[175] evaluated the strength of each predictive factor and discovered preoperative fatty infiltration to be the strongest predictor of retears (Figure 2).

Silva et al[210] systematically reviewed 14 studies of patients aged ≥65 years who underwent arthroscopic, MO, or open surgical repair of a symptomatic RC tear, and all studies demonstrated significant improvement between pre- and postoperative outcomes, with an overall postoperative patient satisfaction rate >90% and a healing rate of 78%. Downie and Miller[43] reported improved outcomes after surgery among patients >60 years old. MacKechnie et al[122] systematically reviewed 7 studies of open or arthroscopic repair of full-thickness RC tears of patients <55 years old and found that 81% of patients had traumatic tears; all studies that evaluated postoperative strength and pain showed improvement; and 82% of patients had satisfactory results. Lazarides et al[107] systematically reviewed 12 studies of patients <40 years old and determined that RC etiology was of traumatic origin in 8 studies and due to chronic overuse among elite throwers in 4 studies; 11 of these studies indicated good outcomes, although many elite throwers had difficulty returning to play (25%-97%).

Marx et al[129] systematically reviewed 86 articles from 6 major orthopaedic journals to determine how many reported indications for RC surgery (eg, duration of symptoms), which can subsequently influence patient outcomes. Of the retrieved articles, 44% did not report the duration of symptoms; <50% did not report a history of trauma or limitations of activities of daily living; and 48% failed to describe attempts at nonoperative management before surgery.

PRO Measures

Standardization of measures for assessing outcomes after operative and nonoperative treatment for RC tears is lacking, which makes it difficult to compare studies and may account for inconsistent findings across studies. Makhni et al[124] systematically reviewed 156 studies from 6 orthopaedic journals with a high impact factor and found that 63% reported ROM, 38% indicated quantitative strength measurements, 65% evaluated tendon integrity via imaging, and 16% to 61% included at least 1 of the 5 most common functional scores: Constant (61%), ASES (59%), UCLA (35%), Simple Shoulder Test (28%), and adjusted Constant (16%). Page et al[160] systematically reviewed the outcome domains and instruments used in 171 randomized controlled trials that examined the effectiveness of physical therapy interventions for shoulder pain, including 101 studies of patients with pain associated with RC disease. The outcome domains that were assessed included shoulder pain (87%), function (72%), ROM (67%), adverse events (27%), global assessment of treatment success (24%), strength (18%), health-related quality of life (18%), work disability (4%), and referral for surgery (2%). VAS was the most commonly reported measure of shoulder pain, and the Constant score and the Shoulder Pain and Disability Index were the most commonly used measures of shoulder function. Saccomanno et al[189] systematically reviewed 120 studies to determine the reliability of MRI for assessing repaired RCs. Structural integrity was the most commonly used criterion, and the dichotomized Sugaya classification had the highest reliability (kappa = 0.80-0.91).

Many PROs are available for assessing pain and function associated with RC tears; however, it is important to select high-quality PROs that demonstrate good psychometric properties (valid, reliable, and responsive). As shown in Table 5, Huang et al[76] systematically reviewed 73 studies to examine the psychometric properties of 16 PROs used among patients with RC tears. The Western Ontario Rotator Cuff Index (WORC) had the best overall quality, followed by the Disabilities of the Arm, Shoulder and Hand (DASH) score, Shoulder Pain and Disability Index, and Simple Shoulder Test; however, the most commonly cited PROs (ASES and Constant scores) demonstrated the lowest quality. In a systematic review of 120 articles that reported on 11 PROs, St-Pierre et al[218] indicated that (1) only the ASES and Upper Limb Functional Index had a measurement error <10% of the global score and (2) the minimum detectable change and minimal clinically important difference ranged from 6.4% to 20.8% and 8% to 20%,

[||]References 17, 36, 52, 92, 93, 96, 106, 133, 143, 144, 175, 190, 196, 239.

Figure 2. Flowchart of predictors. Pre-op, preoperative; WCB, Workers' Compensation Board. Used with permission from Raman et al.[175]

respectively. Longo et al[120] examined the psychometric properties of the WORC and the Rotator Cuff Quality of Life Measure (RC-QOL) in 16 studies and determined that the methodological quality was adequate on some properties (construct validity, reliability, responsiveness, internal consistency, and translation) but needed improvement on others. Makhni et al[124] created metrics to evaluate 16 PROs with respect to comprehensiveness (the total number of pain, functional, and quality-of-life/satisfaction metrics included in each study) and efficiency (the comprehensiveness score divided by the number of survey components). The most comprehensive PROs were the RC-QOL and Penn Shoulder Score, and the most efficient was the UCLA, DASH, and Constant score.

Cost-effectiveness of RC Repair

In 2015, Nwachukwu et al[149] systematically reviewed 3 studies and reported that (1) the lifetime age-weighted mean societal savings was US$13,771 per RC repair, (2) the mean lifetime gain in quality-adjusted life years for RC repair was 0.81 based on the Health Utility Index, and (3) SR repairs were more cost-effective than DR repairs.

TABLE 5
Quality of Measurement Properties per Questionnaire: Summary[a]

	Internal Consistency	Reliability	Measurement Error	Content Validity	Structural Validity	Hypothesis Testing	Criterion Validity	Responsiveness
ASES	–	++	–	?	?	– –	?	?
Constant	?	++	?	NA	NA	– –	?	+
DASH	?	++	– –	NA	++	+	NA	++
KSS	?	NA	NA	?	NA	?	?	?
L'Insalata	?	?	NA	?	NA	?	?	?
OSS	?	–	NA	?	NA	+	NA	?
Penn	?	+	?	?	NA	?	NA	?
RC-QOL	?	?	NA	?	NA	–	NA	?
SAL	NA	+	NA	NA	NA	?	NA	NA
SDQ	?	?	NA	NA	NA	–	NA	?
SPADI	+++	++	– –	NA	+++	–/+	?	+
SST	+++	++	–	?	NA	+/+	?	+
SSV	NA	NA	NA	NA	NA	–	NA	NA
UCLA	?	+	?	NA	NA	+	?	?
WOOS	NA	+	NA	NA	NA	?	NA	?
WORC	++	++	?	+++	NA	++	NA	+

[a]A plus sign (+) indicates positive evidence; a question mark (?), indeterminate evidence; and a negative sign (–), negative evidence. Used with permission from Huang et al.[76] ASES, American Shoulder and Elbow Surgeons shoulder outcome score; Constant, Constant-Murley score; DASH, Disabilities of the Arm, Shoulder and Hand score; KSS, Korean Shoulder Scoring System; L'Insalata, L'Insalata Shoulder Rating Questionnaire; NA, no information available; OSS, Oxford Shoulder Score; Penn, Penn Shoulder Score; RC-QOL, Quality-of-Life Outcome Measure for Rotator Cuff Disease; SAL, Shoulder Activity Level; SDQ, Shoulder Disability Questionnaire; SPADI, Shoulder Pain and Disability Index; SST, Simple Shoulder Test score; SSV, Subjective Shoulder Value; UCLA, University of California, Los Angeles shoulder score; WOOS, Western Ontario Osteoarthritis Shoulder index; WORC, Western Ontario Rotator Cuff Index.

Quality of Randomized Controlled Trials

Tadjerbashi et al[223] evaluated the quality of 50 randomized controlled trials involving shoulder arthroscopy, of which 22 involved the RC. The Jadad quality score was 3 of 5 (highest quality) for all shoulder studies, although the authors did not stratify by type of shoulder arthroscopy. McCormick et al[132] also reported a mean Jadad score of 3 for their systematic review of 54 randomized controlled trials involving RC disorders, although 63% of these studies were nonoperative. Furthermore, they determined that these studies were often lacking in the following CONSORT criteria (used for standard reporting of clinical trials): trial design descriptions (66%), descriptions of randomization type (65%), and power analysis (46%).

CONCLUSION

This systematic review offers a comprehensive summary of all systematic reviews and meta-analyses published on various topics related to the RC. There is a substantial body of literature pertaining to the RC; however, for some topics, evidence is lacking or flawed, or the results are conflicting. There is substantial evidence indicating that the most accurate physical examinations for diagnosing RC tears are a positive painful arc and positive ER lag test and that the most accurate diagnostic imaging tools are US, MRI, and MRA. However, further research is needed to determine which of these imaging modalities is the most accurate for diagnosis. There is considerable evidence showing that rehabilitation is better than no rehabilitation for nonoperative management of RC tears, although RC repair was shown to be superior to rehabilitation alone. Moreover, there is no evidence to support the use of injections for nonoperative management of RC tears. With respect to operative management, the consensus is that DR repairs result in better outcomes and fewer retears than SR repairs, especially for tears >3 cm. The most commonly reported complications after RC repair are retears and stiffness, although standard reporting and consistent definitions of postoperative complications are lacking. Predictors of retears and poor postoperative outcomes were examined in many studies and include older age, female sex, smoking, increased tear size, preoperative fatty infiltration, preoperative shoulder stiffness, diabetes, workers' compensation claim, decreased preoperative muscle strength, and concomitant procedures.

Multiple studies examined the effectiveness of various types of biological augmentation for RC treatment, including PRP, stem cells, and scaffolds. Laboratory studies tended to report favorable findings for PRP use, although the results of clinical studies are inconsistent. There is some evidence suggesting that PRP is beneficial for conservative management of RC tears, but there is less evidence for the use of PRP at the time of RC repair. Also, increased retears were found for massive tears following PRP use, which suggests that tear size may be influential. A few studies demonstrated fewer retears and good outcomes following the use of stem cells, although most of these studies did not include a control group. Several studies also demonstrated good outcomes for repairs with various types of grafts, including autografts, allografts, and bridging grafts;

however, more research is needed to determine which of these specific grafts is superior to the others.

A large body of literature examined postoperative rehabilitation strategies. There is little to no evidence to support the use of continuous passive motion, supervised (vs unsupervised) therapy, and cryotherapy. There is conflicting evidence with regard to early versus delayed postoperative rehabilitation, which may in part be due to variation in the timing of rehabilitation among studies. However, there is some evidence suggesting that early rehabilitation may be beneficial for smaller tears but harmful for larger tears.

Standardization of outcome measurement is lacking in the literature. Only 63% of studies included measures of ROM; 65% evaluated tendon integrity; and 38% measured strength. Despite being ranked as having low quality, the most commonly used outcome measures include the Constant (61%), ASES (59%), and UCLA (35%) scores. The WORC, DASH, Shoulder Pain and Disability Index, and Simple Shoulder Test were reported to have the highest quality. The quality of operative and nonoperative randomized controlled trials involving RC disorders was found to be moderate (Jadad score, 3 of 5), suggesting that higher-quality trials are needed. Also, only 50% to 60% of randomized controlled trials adhered to the CONSORT criteria for standard reporting of randomized controlled trials. In conclusion, this summary of systematic reviews and meta-analyses on the RC provides surgeons with a single source of the most current literature.

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