J Shoulder Elbow Surg (2016) 25, 521–535

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

CONSENSUS STATEMENT

The American Society of Shoulder and Elbow Therapists' consensus statement on rehabilitation following arthroscopic rotator cuff repair

Charles A. Thigpen, PT, PhD, ATC[a,b,*], Michael A. Shaffer, MSPT, OCS, ATC[c], Bryce W. Gaunt, PT, SCS[d], Brian G. Leggin, PT, MS, OCS[e], Gerald R. Williams, MD[f], Reg B. Wilcox III, PT, DPT, MS, OCS[g]

[a]*ATI Physical Therapy, Greenville, SC, USA*
[b]*Center for Effectiveness in Orthopedic Research, University of South Carolina, Greenville, SC, USA*
[c]*Department of Rehabilitation Therapies, University of Iowa Hospitals and Clinics, Iowa City, IA, USA*
[d]*Human Performance Rehabilitation Centers at St Francis Rehabilitation Center, Columbus, GA, USA*
[e]*Good Shepherd Penn Partners, Penn Therapy and Fitness, Philadelphia, PA, USA*
[f]*Rothman Institute, Jefferson Medical College, Philadelphia, PA, USA*
[g]*Department of Rehabilitation Services, Brigham & Women's Hospital, Boston, MA, USA*

This is a consensus statement on rehabilitation developed by the American Society of Shoulder and Elbow Therapists. The purpose of this statement is to aid clinical decision making during the rehabilitation of patients after arthroscopic rotator cuff repair. The overarching philosophy of rehabilitation is centered on the principle of the gradual application of controlled stresses to the healing rotator cuff repair with consideration of rotator cuff tear size, tissue quality, and patient variables. This statement describes a rehabilitation framework that includes a 2-week period of strict immobilization and a staged introduction of protected, passive range of motion during weeks 2-6 postoperatively, followed by restoration of active range of motion, and then progressive strengthening beginning at postoperative week 12. When appropriate, rehabilitation continues with a functional progression for return to athletic or demanding work activities. This document represents the first consensus rehabilitation statement developed by a multidisciplinary society of international rehabilitation professionals specifically for the postoperative care of patients after arthroscopic rotator cuff repair.
Level of evidence: Level V; Expert Opinion

Keywords: Rotator cuff; tears; postoperative rehabilitation; physical therapy; therapeutic exercise; stiffness

The dilemma after rotator cuff repair: Balancing mobility and anatomic healing

Rotator cuff tears affect approximately 30% of the population aged older than 60 years, and the rate doubles to nearly

*Reprint requests: Charles A. Thigpen, PT, PhD, ATC, ATI Physical Therapy, 200 Patewood Dr, Ste 150 C, Greenville, SC 29615, USA.
E-mail address: Charles.thigpen@atipt.com (C.A. Thigpen).

1058-2746/$ - see front matter © 2016 Journal of Shoulder and Elbow Surgery Board of Trustees.
http://dx.doi.org/10.1016/j.jse.2015.12.018

60% of the population by age 80 years[115]. Rotator cuff pathology results in approximately 450,000 operations per year, with the direct medical costs in the United States exceeding $7 billion per year[12,70,81,90,111,116]. Although recent studies support conservative management for symptomatic full-thickness rotator cuff tears[63], arthroscopic rotator cuff repair (RCR) for full-thickness tears has actually become more prevalent, with the rate of arthroscopic RCR increasing by 600% over the past 10 years[18]. Arthroscopic repair has replaced open surgery and now comprises greater than 95% of all RCRs in the United States[17].

Despite positive clinical results, reports of structural failure after arthroscopic RCR can range from 16%-94%[17,23,34,44,77]. Recent studies have shown that, of those patients whose repair fail to heal, greater than 98% have failure to heal within the first 6 months after repair[50,82]. For larger tears (>4 cm), failure occurs even sooner, with as many as 78% of failures occurring within the first 3 months after repair[50]. These results suggest that rotator cuff healing is protracted and that protecting the repair from excessive loading, particularly early in the rehabilitation process, is vital. Judicious use of range-of-motion (ROM) exercises is supported by a recent meta-analysis that concluded that in patients with tears >2 cm, early ROM produced a 1.4-1.9 times greater risk of failure[14]. Yet, it is still unclear if incomplete healing of the repair results in worse long-term outcomes after arthroscopic RCR[117].

Recently, there have been a number of randomized controlled trials that have attempted to clarify the role of early, protected mobilization compared with unprotected mobilization regarding structural integrity and patient outcomes[2,31,53,58,59,65,88] (Table I). The studies to date have compared a mixture of strict immobilization (6-8 weeks), protected passive range of motion (PROM), and/or early, unprotected PROM after an arthroscopic RCR. The lack of consistent timelines for immobilization, ROM restrictions, and type of RCR precludes a clear, uniform recommendation. However, in general, a period of strict immobilization with graded rehabilitation shows improved rates of anatomic healing without associated stiffness when compared with an approach of early, unprotected ROM[19,25,53,61,88]. Taken as a whole, clinical trials comparing immediate ROM versus delayed initiation and protected, early ROM until 6 weeks postoperatively have shown shoulder ROM, pain levels, and patient self-reported outcomes that are equivocal at follow-up periods of 1 year or more[2,31,53,58,59,65,88]. Although early, unrestricted initiation of exercise does produce increased ROM, with gains of 7°-15° of forward elevation (FE) and 5°-10° of external rotation (ER) at 3 and 6 months postoperatively, respectively, these relatively small differences in ROM do not seem to improve patient function even during these early time frames[14]. In addition, any stiffness that arises from protected ROM and immobilization tends to moderate by 1 year after an arthroscopic RCR[88]. Although recalcitrant postoperative stiffness is not common after RCR, there are several factors associated with persistent ROM deficits: calcific tendinitis; adhesive capsulitis; partial articular surface tendon avulsion-type RCR; concomitant labral repair; or acute, single-tendon cuff repair[25,49,62,86]. However, a recent study has suggested that even for patients with these risk factors, stiffness can be minimized with the addition of an early, protected ER but unweighted FE ROM program, without restriction is effective in avoiding detrimental stiffness (>15° loss at 1 year)[62]. The intervention, which successfully mitigated loss of postoperative ROM, was simply the addition of an unweighted table slide into FE. The table slide is an excellent choice for early mobilization because it is easy for patients to perform yet produces only low levels of supraspinatus activity[36,110]. In this document, we will suggest specific therapeutic interventions that we believe, on the basis of the best available evidence, are safe and effective for patients after arthroscopic RCR. For early, protected self-mobilization activities, such as the table slide or what we have termed the "forward bow," we believe the crucial threshold is ≤15% electromyographic (EMG) activity of the supraspinatus[69].

In this document, we suggest a 2-week period of strict immobilization and a staged introduction of protected, PROM starting at 2 weeks postoperatively, followed by restoration of active range of motion (AROM) beginning at 6 weeks, with a gradual strengthening progression beginning at postoperative week 12. We acknowledge that some surgeons and scientists believe that a 6-week period of strict immobilization is preferable. We understand the attraction of this approach, but in our opinion, there is no clear human evidence to support strict immobilization versus early, protected ROM with limits of <90° of FE and <30° of ER within the first 6 weeks. In our opinion, an across-the-board recommendation of 6 weeks of strict immobilization for all sizes and types of RCRs is unnecessary and may lead to a false sense of security. To that point, 17.3% of patients became noncompliant with rehabilitation restrictions between weeks 6-12 postoperatively when they were limited to sling immobilization and only 1 ROM exercise for the first 6 weeks postoperatively[1]. When we surveyed members of the American Society of Shoulder and Elbow Therapists (ASSET) to help define patterns of practice, 96% of respondents began passive, limited ROM within the first 3-4 weeks after RCR. Each of the randomized controlled trials we reviewed in Table I represents level I evidence, which forms the basis of our recommendation that early, protected PROM within the first 6 weeks after RCR allows for appropriate healing of the repaired rotator cuff, reduces the chances of postoperative stiffness, and communicates to patients that they are active participants in their own recovery. In our opinion, the decision to initiate ROM at 2-3 weeks versus 6 weeks postoperatively should be weighed among the patient, surgeon, and therapist as they select an approach that is in line with a given patient's situation and goals. We do recommend the more conservative approach, a 6-week period of strict immobilization with delayed start of PROM activities, if there are concerns regarding tissue healing. Gaining PROM too quickly, particularly in repairs with poor tissue quality, is thought to unduly stress the suture-tendon interface. The risks for failure after arthroscopic RCR are well documented and include larger tear size[19,82], poor tissue

Table I Summary of primary outcomes from randomized controlled trials comparing ROM initiation after arthroscopic RCR

Author	Patients	Group 1	Group 2	Results	Conclusion
Koh et al[61], JBJS, 2014	Included: small- to medium-sized full-thickness tears Excluded: massive and concomitant stiffness or labral lesions	Immobilization for 4 wk; then gradual ROM return	Immobilization for 8 wk; then gradual ROM return	Rates of RC healing were similar between groups. Stiffness was more prevalent in 8-wk group (38% vs. 18%).	Immobilization for 1 more month did not enhance healing but was associated with more prevalent "stiffness."
Keener et al[53], JBJS, 2014	Included: small- to medium-sized full-thickness tears Excluded: massive and concomitant stiffness or labral lesions	Immediate, therapist-guided PROM	Immobilization for 6 wk; then therapist-guided PROM	ROM, pain measures, and frequency of healed repairs were equal.	Early PROM and immobilization for 6 wk are equally safe and effective after RCR.
Kim et al[58], AJSM, 2012	Included: small- to medium-sized full-thickness tears Excluded: massive and concomitant stiffness or labral lesions	Immediate PROM for 4 wk (up to 120° FE)	Immobilization for 4 wk	ROM, pain measures, and frequency of healed repairs were equal.	Early PROM and immobilization for 4 wk are equally safe and effective after RCR.
Cuff and Pupello[20], JSES, 2012	Included: full-thickness crescent-shaped supraspinatus tear repaired using transosseous-equivalent suture bridge with SAD Excluded: concomitant labral or biceps procedure; partial-thickness, L-shaped tears; reverse L–shaped tears extending into SubS or IS; glenohumeral arthritis; adhesive capsulitis; revision RTC repairs; workers' compensation	Immediate PROM (up to 120° FE)	Immobilization with Codman pendulums only for 6 wk (up to 90° FE)	Patient outcomes and ROM measures were equal at 1 y. Healing occurred in 91% of patients in pendulum-only group vs. 85% in immediate PROM group.	Restricting postoperative exercises to pendulums only did not adversely affect ROM and was associated with a higher percentage of patients with healed repairs.
Lee et al[65], *Arthroscopy*, 2012	Included: medium-sized (1-3 cm) or large-sized (3-5 cm) tears repaired without undue tension with single-row repair Excluded: partial, small, and massive tears; SLAP; AC arthritis; DCR; glenohumeral arthritis; workers' compensation; tenotomy or tenodesis	Immediate ROM (ER and FE) with no reported limits	Immobilization and 6 wk of protected FE ROM to 90°	Similar pain improvement from preoperative levels was reported. Group 2 showed slower recovery than group 1 regarding ER and IR ROM and muscle strength up to 6 mo, but there was no significant difference at 1 y. The retear rate was higher in group 1 than in group 2 (23.3% vs. 8.8%).	Aggressive early motion may increase anatomic failure at the repaired cuff; a gentle protocol with limited ROM would be better for tendon healing.
Arndt et al[2], *Orthopaedics & Traumatology*, 2012	Included: isolated, nonretracted supraspinatus tear, mobile shoulder; stage 2 or lower fatty infiltration; preserved acromiohumeral distance Excluded: extension of tear beyond supraspinatus	6 wk of preoperative therapy + immediate PROM (up to 120°)	6 wk of immobilization	Recovery of flexion and ER in group 1 that appeared to be "stabilizing over time" was reported. The mean Constant score was significantly higher in group 1. However, group 2 had a higher rate of complete healing, although this was not statistically significant.	The rehabilitation protocol that results in better tendon healing has not been identified; the results suggest that passive motion should be allowed because the functional results were better.

AC, acromioclavicular; *AJSM*, American Journal of Sports Medicine; *ER*, external rotation; *FE*, forward elevation; *IR*, internal rotation; *JBJS*, Journal of Bone and Joint Surgery; *JSES*, Journal of Shoulder and Elbow Surgery; *PROM*, passive range of motion; *RC*, rotator cuff; *RCR*, rotator cuff repair; *ROM*, range of motion; *SAD*, subacromial decompression; *SLAP*, superior labrum anterior-posterior; SubS, subscapularis.

quality[6,114], older patient age[42,84], fatty infiltration and atrophy[24,38,40,97,105], smoking[72], hypercholesterolemia[4,5], and diabetes[15]. These factors should be considered when modifying the proposed staged ROM goals (Table II) in consultation with the referring surgeon.

We have included our suggested rehabilitation guideline (Appendix S1) as a starting point for communication among the surgeon, physical therapist, and patient, and this should align with the surgeon's approach, concerns he or she may have about the compliance of the patient, and any specific limitations necessitated by tissue quality and healing potential. Our document is not intended to substitute for communication between therapist and surgeon. To the contrary, we offer this document as a glossary for therapist-surgeon communication as we attempt to clarify the necessity and safety of commonly used therapeutic interventions.

Methods of development

This guideline evolved after representatives from the American Shoulder and Elbow Surgeons (ASES) approached ASSET about the need for clarification of guiding principles for postoperative rehabilitation after arthroscopic RCR. In response, ASSET identified a panel of members with extensive experience treating patients after arthroscopic RCR to review the literature and begin developing a rehabilitation statement. This panel included members with clinical specialty certifications and terminal research degrees from different geographic regions.

In the development of this guideline, our goal was to cite the best available evidence, relying on randomized controlled trials when available. The panel searched for English-language clinical trials and basic science evidence from multiple databases (Cochrane, PubMed, CINAHL [Cumulative Index to Nursing and Allied Health Literature], and SportDiscus). We searched the following key terms: arthroscopic rotator cuff repair, rehabilitation, exercise, shoulder, scapula, post-operative, and physical therapy. Database searches resulted in 4714 articles; then abstracts were reviewed to merit inclusion as supporting evidence related to rehabilitation after RCR. After review of the evidence, articles were divided into two groups; the first group comprises 14 randomized controlled trials, systematic reviews, and meta-analyses comparing patient outcomes after RCR. The second group of articles (103) was composed of primarily basic science and mechanistic studies, which were included to guide specific interventions (modalities, exercise selection, and progression). Given the timeline for review, assimilation, and reaching a consensus, the references were updated through June 2015 using the same search process.

After the subpanel developed the major principles and time frames guiding rehabilitation, the recommendations were sent to all members of ASSET to review, provide feedback, and develop consensus. In addition, the more contentious aspects of the statement (immobilization time frames, when to initiate AROM, time to restore normal ROM, and so on) were openly debated at subsequent annual meetings of ASSET until consensus was reached. ASSET members also completed a short survey on practice patterns regarding the dosing of exercise, frequency of visits, and management of complications. Those survey results have been incorporated into the recommendations to provide a rationale for rehabilitation decisions not commonly studied in the literature. Finally, an ASES member with extensive experience performing arthroscopic RCR reviewed the statement to provide a surgeon's perspective. The final protocol (Appendix S1) represents an international consensus rehabilitation statement developed by a multidisciplinary society of rehabilitation professionals (physical therapists, athletic trainers, and occupational therapists) who are members of ASSET. This statement provides key recommendations that represent the best evidence and rationale for the key clinical decisions along the rehabilitation progression. This statement is intended to foster matched expectations among patient, surgeon, and therapist to provide a patient-centered rehabilitation strategy. To our knowledge, this is the first consensus statement developed for the rehabilitation of patients after arthroscopic RCR.

Key recommendations

The key recommendations are as follows:

- Protected PROM should be considered during the first 6 weeks after arthroscopic RCR of small to medium tears (<4 cm) to promote the best opportunity for early restoration of ROM without jeopardizing healing or long-term outcomes (evidence category [Strength of Recommendation Taxonomy (SORT)], A[2,13,14,20,53,58,61,65,94,98]).
- Anatomic failure (nonhealing or retear) after arthroscopic RCR is not uncommon (25%-60%) but is not consistently associated with poorer functional outcomes. Anatomic failure is associated with increasing age, poor tissue quality, fatty infiltration, atrophy, smoking, hypercholesterolemia, and diabetes. It tends to occur in the first 3-6 months after surgery. Therefore, with each decision, the rehabilitation clinician should weigh the stresses each intervention places on the rotator cuff relative to its potential value balanced against the implications for healing (evidence category [SORT], B[1,43,64,70,71,84,85,97,106,114]).
- Supervised rehabilitation should monitor ER in neutral abduction and FE ROM as indicators of progress (evidence category [SORT], A[2,20,53,58,61,65]).
- Stiffness after arthroscopic RCR at 1 year is not common (3%-10%), but individuals with diabetes, thyroid disorders, acute rotator cuff tears, partial-thickness tears, and adhesive capsulitis may benefit from additional focus on their PROM during the first 6 weeks (evidence category [SORT], B[16,25,49,62]).

Table II Suggested shoulder exercises categorized by time of initiation and phase of postoperative rotator cuff rehabilitation

	Postoperative weeks 1-6	Postoperative weeks 6-12	Postoperative weeks 8-16	Postoperative weeks 12-20	Postoperative week 20 and later
Initiation phase	Phase 1	Phase 2	Phase 2-3	Phase 3-4	Phase 4
EMG activity level	≤15%	≤15%	16%-29%	30%-49%	≥50%
Exercise goal	PROM	AAROM or AROM	AROM or resisted	Endurance	Strengthening
Exercises*	Pendulum[30,69,74]	Towel slide or horizontal dusting[36,113]	Pulley FE[30,36,74] Incline dusting[115]	High, middle, and low scapular rows[47,84]	Upright FE 3-4 lb, 10-rep max[93,94,108]
	Forward bow[113]	AAROM supine washcloth press-up[113]	Ball roll on wall[36] Upright wall slide[36,74,115]	Standing dumbbell ER at 0° abd, 10-rep max[93]	Side-lying dumbbell ER at 0°, 10-rep max[93]
	Therapist-assisted FE[30,74]	AROM supine press-up[113]	FE with upright T-bar AAROM elevation[36,74]	Standing dumbbell ER in scapular plane, 10-rep max[93]	Prone horizontal abd, 10-rep max[93,94]
	CPM in FE[30]	Side-lying supported active elevation[36]	Upright T-bar AAROM FE, active lowering[36]	Elastic resistance shoulder flexion[84]	Prone ER at 90° abd, 10-rep max[93]
	Self-assisted supine FE[30,74,113]	AROM reclined wedge press-up[113]	Upright active FE with no weight[36,113]	Elastic resistance throwing accelerate[84]	Seated military press[11]
	ER/IR self-assisted with stick[30,74]	Supine elastic band FE[36] Aquatic FE slow speed[55]	Upright active FE 1 lb[113] Aquatic FE fast speed[55]	Elastic IR at 90°[84]	Elastic resistance ER at 90°[84] Elastic resistance throwing decelerate[84]
			Side-lying dumbbell ER at 0°, resistance of 25% MVIC[3]		
			Prone dumbbell ER at 0°, resistance of 25% MVIC[3]		Standing dumbbell ER at 90° abd, 10-rep max[93]
			Elastic resistance ER, IR, and forward punch[21,47,84]†		

AAROM, active-assistive range of motion; *abd*, abduction; *AROM*, active range of motion; *CPM*, continuous passive motion; *EMG*, electromyographic; *ER*, external rotation; *FE*, forward elevation; *IR*, internal rotation; *max*, maximum; *MVIC*, maximum voluntary contraction; *PROM*, passive range of motion; *rep*, repetition.

* Exercises were grouped based on published supraspinatus EMG activity.

† Mean EMG activity levels for these exercises span from <15% to >50%, with the study by Hintermeister et al[48] being the only study showing mean values <15%. However, the maximum EMG activity level in their study ranged from 25%-48%; thus, these exercises are best categorized in the 16% through ≥50% categories depending on the resistance level.

- Muscle performance strategies should begin with AROM exercises with the upper extremity in a short-lever or gravity-minimized position with a ≤15% supraspinatus EMG activity level, followed by progressive stresses with a longer lever or higher loads (evidence category [SORT], C[36,56,69,99,108,110]).
- Patient education is important to success after arthroscopic RCR and should include short-term activity modifications, compliance with home exercises, and resolution of shoulder stiffness balanced with long-term healing of the rotator cuff (evidence category [SORT], B[1]).

ASSET postoperative RCR rehabilitation guideline: promoting healing of RCR through milestone-based patient progression

Appendix S1 contains the detailed rehabilitation guideline. The following information serves as the background and rationale for each phase of rehabilitation.

Typically, postoperative rehabilitation protocols describe the specific exercise or activity progression based on healing timelines after surgery. However, in addition to the passage of time from surgery, there are many other important variables that need to be considered to properly advance a patient's rehabilitation. A protocol that offers flexibility of progression based on when patients reach specific clinical goals or criteria may be more appropriate. Most rotator cuff tears arise not from an acute injury but as a result of gradual degeneration of the tendon. Given the fact then that rotator cuff tissue is degenerative, each rehabilitation program after RCR should be approached with caution. Therapists need to understand that, from a biomechanical standpoint, the repaired tendon does not approach normal levels of elasticity or strength until at least 6 months postoperatively[10,37]. Furthermore, due consideration should be given to variables that have been shown to affect healing such as age and activity level of the individual, duration of symptoms[6,46], extent of the tear[52], location of the tear[52], number of tendons involved[52], rotator cuff tissue quality, atrophy of muscles[24,38,40,43,52,97,104], associated shoulder pathology, and method of surgical repair[10,11,35,37,57,106]. Therefore, to plan an appropriate rehabilitation program, close communication with the surgeon is vitally important to discuss associated pathology, tissue quality, surgical technique, and integrity of the repair.

Most patients after arthroscopic RCR only need to complete the first 3 phases of rehabilitation (Appendix S1). These phases comprise phase 1, in which exercises are generally considered to be passive exercises that minimize loads across the repair; phase 2, in which expanded flexibility exercises, as well as the transition from active-assistive exercises to active exercises to very light resistive exercises, begin in a way that gradually increases but maintains controlled loads to the repair; and phase 3, in which the emphasis on resistive exercise increases to focus on muscle hypertrophy and achieving the absolute force production to perform basic functional tasks. However, a patient who is a laborer or active recreational or competitive athlete will require phase 4 to restore maximal strength and power, as well as the endurance needed to participate in higher-level activities.

Although the ultimate goal of surgery and rehabilitation is a return to optimal functional improvement,[12,111] clinician-rated impairments such as pain, ROM, strength, and movement quality help define the attainment of clinical milestones and are used to guide rehabilitation progression. Impairments should be quantified to the extent possible with the use of an inclinometer or goniometer to measure AROM and a hand-held dynamometer to assess muscle performance. Assessing muscle activation after RCR is necessary to determine the extent of recovery, especially in the later phases of rehabilitation. There are no studies declaring when it is safe to generate maximal effort after RCR. However, numerous authors have assessed muscle performance using a hand-held dynamometer beginning at 4 months, with no reports of injury[32,45,65,89,96]. Thus, it is reasonable to begin assessing submaximal muscle performance beginning at 4 months, with maximal muscle testing delayed until 9-12 months postoperatively. Pain should be assessed with a patient-rated numeric pain rating scale (NPRS)[80]. Function of the periscapular musculature can be screened with visual observation of active elevation or rehabilitation exercises[76,102,109]. Isolated testing of the periscapular muscles can be used to help make sense of an abnormality detected with visual observation.

In addition to monitoring impairment-based milestones, it is important to collect patient-rated outcome measures to comprehensively assess response to treatment. Region-specific scores such as the ASES form[60] or the more robust Penn Shoulder Score[66] have established measurement properties and are recommended for assessment after RCR. The disease-specific Western Ontario Rotator Cuff Index provides the most responsive tool after RCR but is cumbersome to use clinically[48,60,66,79,112].

Clinician-rated impairments are expected to improve every 1-2 weeks and will help to determine the rate of progression through this rehabilitation guideline. Patient-rated outcome measures should be assessed every 2-4 weeks to ensure symptoms and patient function are keeping pace with clinician measures.

Phase 1: 0-6 weeks

Patient education

Perhaps no component of postoperative management is more important than patient education. The first step in this process is open communication between the rehabilitation provider and the patient, family, and surgeon. Thorough and timely patient education is important to help empower patients so that they can share responsibility for rehabilitation decisions. Patients who exhibit poor compliance with postoperative restrictions in the first 6 weeks show a relative risk of retear or nonhealing that is 152 times higher than that of compliant patients[1]. Important points of emphasis in education include understanding the pathology and procedure, time frame for recovery, and associated precautions during each phase. The rehabilitation clinician should clearly communicate the expectations for patient compliance with restrictions, the identification of patient goals, the importance of a home exercise program, and the short- and long-term prognosis for the patient based on his or her pathology and situation. Specific education components for this time frame are detailed in Appendix S1.

Modalities

Although passive modalities have not been shown to alter the long-term outcome after shoulder surgery, cryotherapy and transcutaneous electrical neuromuscular stimulation have been shown to decrease opioid use in the first 72 hours and help control postoperative pain[26,27,68]. Cryotherapy has been shown to decrease pain over the first 24 hours postoperatively, with a better potential for sleep and reduced need for pain medication[87]. Furthermore, patients receiving cryotherapy in the first 10 days postoperatively reported diminished shoulder pain and swelling, less pain during therapy, and a more tolerable rehabilitation[87]. Neuromuscular electrical stimulation has been shown to improve posterior cuff function after RCR[91]. Therefore, transcutaneous electrical neuromuscular stimulation or neuromuscular electrical stimulation may be considered based on the individual patient's needs and resources; however, the impact of these modalities on long-term outcomes is not clear.

Passive range of motion

PROM has been suggested to be beneficial after RCR[14,58,59,112] and has been included as an early component of our rehabilitation program. Our analysis of recent randomized controlled trials leads us to conclude that if performed correctly, PROM exercises can be used to minimize any chance for postoperative ROM loss while simultaneously protecting the repair (Table I). To achieve these 2 competing goals, we recommend limiting the amount of ROM to the staged goals. Elevation of the arm in the scapular plane and ER with the arm in 20°-30° of abduction are the only planes of glenohumeral motion we recommend for this time frame. Even within the ranges and planes we consider "safe" for the repair, repeated cyclic loads can have potentially detrimental effects on the suture-tendon interface. Therefore, we recommend performing all exercises with only as many repetitions as necessary to achieve the staged ROM goals. In this first phase of rehabilitation, the exercises chosen for PROM should have levels of EMG muscle activity ≤15% (Table II) and should be performed only in a gentle, comfortable manner as detailed exercises that meet but do not exceed the staged ROM goals in Table III and Appendix S1.

Although the tension on the repair can only be estimated, muscle activity level, the plane of motion, the absolute degree of ROM, cyclic loading, and the weight and length of an individual's upper extremity are likely to affect the tension on the repair. Whereas all these factors are important, exercise prescription (passive and active) for the patient with an RCR should be primarily based on known muscle activity levels, when possible, because these are the best available estimate of stress placed on the rotator cuff tendon[7,22,30,41,47,51,78,92,93,108]. Yet, the correlation between EMG activity and tension in musculotendinous structures has only been established during isometric contractions, with extrapolation of these data to other types of motions[30,74,110]. Because even passive exercises show minimal muscle activation, the treating clinician needs to recognize that stress occurs on a sliding scale rather than in discrete levels as exercises are progressed from PROM to active-assistive range of motion (AAROM), AROM, and resisted exercises. Yet, because stress imparted by rehabilitation exercises cannot be measured clinically, EMG evidence does offer at least some ability to match the progression of therapeutic exercises' likely stress on the repaired rotator cuff.

Table III Immediate start to PT (postoperative day 1) staged ROM goals and approximate targets

	PFE	PER at 20° of abd	PER at 90° of abd	AFE
POW 2	60°-90°	0°-20°	NA	NA
POW 6	90°-120°	20°-30°	NA	NA
POW 9	130°-155°	30°-45°	45°-60°	80°-120°
POW 12	140°-WNL	30°-WNL	75°-WNL	120°-WNL

The presented data are targets and should not be exceeded. They may vary based on intraoperative tissue quality findings by the surgeon. When the initiation of PT is delayed, the entire progression is delayed by the same time frame. Interventions and range of motion (ROM) should not be forceful or painful. The larger ROM value is the maximum recommended ROM at a given time frame and represents the goal at that given time frame.

abd, abduction; *AFE*, active forward elevation; *PER*, passive external rotation; PFE, passive forward elevation; *POW*, postoperative week; *PT*, physical therapy; *WNL*, within normal limits.

Suggested exercises are divided into categories based on previous recommendations[28,69] and then subdivided and modified to match the milestones and suggested phases of rehabilitation (Table III)[39]. Exercises are classified using the EMG activity level of the supraspinatus to anticipate the projected stress on the RCR. These exercises can be used to select and progress in a manner consistent with the suggested phases of rehabilitation. Table III is not meant to be an exhaustive list of EMG-supported exercises; it includes only the most commonly used rehabilitation exercises, which have documented EMG data. Specific EMG percentages are not listed for each exercise because differences in study design, instrumentation, and experimental technique, including whether mean or maximum EMG values were reported, make comparisons of specific percentages between studies inappropriate. We hope grouping exercises into broad categories of EMG activity provides clinicians with an avenue to titrate the level of exercise intensity to match the desired RCR stress.

Phase 2: 6-12 weeks

During the postoperative time frame of 6-12 weeks, animal studies have shown that Sharpey fibers, which bind the healing tendon to the bone, are not present in any considerable number. Therefore, repair strength is likely only 19%-30% of normal at 6 weeks and 29%-50% of normal at 12 weeks[39]. Although tendon-bone healing is thought to be sufficient to withstand low levels of muscle activity or passive tension, moderate to large loads or repetitive activities are not recommended. As the patient completes this phase (approximately 12 weeks), he or she typically displays near full PROM without pain; active elevation of the arm to at least 120° without compensation; and the ability to perform light, nonrepetitive activities of daily living or work tasks below shoulder level without difficulty or pain. Primary rehabilitation objectives for phase 2 include expanded PROM and stretching, introduction of AAROM or AROM exercises, and continued patient education emphasizing compliance with postoperative restrictions.

In phase 2, PROM and stretching exercises are progressed regarding both EMG activity level and planes of motion. On the basis of progressive healing of the tendon-bone interface, stretching interventions can advance to the 16%-29% level of muscle activity. Hence, exercises such as pulley and cane-assisted exercises can be included in this phase if the patient can perform them comfortably without shrugging other scapular compensation. If ROM restrictions are identified, ROM exercises can expand to planes of motion such as ER in increasing angles of abduction, internal rotation in abduction, horizontal adduction, and functional internal rotation (behind the back). Because these motions and positions are thought to place tension directly on the repair, these stretches are typically included only in the latter half of phase 2 (after week 9), should be prescribed judiciously, and should be performed only to the level of a light "stretch" sensation.

Muscle performance exercises (ie, light "strengthening") should not begin until the patient's pain level is well controlled (<2 of 10 on NPRS) and sufficient passive mobility is achieved, as evidenced by reaching staged PROM goals. Similar to the continuum of PROM exercises, strengthening exercises likely apply a progressive continuum of passive and active stresses on the repair based on the applied load. Thus, we recommend that muscle performance exercises should initially target AAROM exercises and then AROM exercises. We recommend beginning with exercises with documented EMG activity levels ≤15% (Table III), consistent with the PROM exercises outlined in phase 1. In general, AROM and AAROM exercises within this category (≤15% muscle activity level) use slow-speed motions in an aquatic environment[55], gravity-minimized positions such as supine or side lying, and/or short lever arms to promote rotator cuff and deltoid balance[21,22,67].

Once the patient tolerates the introduction of active loading, elevation can be progressed to exercises that show EMG activity levels between 16% and 29% (Table II). In the early part of this progression, the patient is generally in the upright position, moving the upper limb with assistance and then advancing to independent, unsupported elevation later in this phase of rehabilitation. Because the repair is still not biomechanically mature, we suggest avoiding excessively loading the healing tendon, as indicated by fatigue, pain, or altered patterns of movement.

The wall slide or wall walk exercise is the only AAROM exercise that has conflicting evidence regarding its EMG category (Table II). We placed the wall slide and wall walk in the category of 16%-29% EMG activity level because 2 of 3 studies documented muscle activity at this level[36,74,113]. Clinically, we believe the wall slide or wall walk is not appropriate to use in the early stages of phase 2 but, instead, is more appropriately used at the end of this phase, once the patient can actively elevate the arm to at least 130° without pain. In other words, the wall walk or wall slide has some utility in this phase, but this utility is more to build endurance for active elevation rather than as an assist for improving elevation ROM.

As active elevation improves, light, directed muscle activation can begin below chest level for the deltoid, rotator cuff, and scapular muscle. In our opinion, 4 key exercises are ER (infraspinatus and teres minor), internal rotation (subscapularis), row (posterior deltoid and periscapular muscles), and short lever FE or forward reaching (anterior deltoid and supraspinatus). Although we recommend pain-free isotonic, elastic resistance, or closed-chain exercises in the 16%-29% EMG activity range for phase 2 strengthening activities, caution needs to be used because muscle activation can be as high as 50% based on the level of resistance and exercise technique that are used (Table III). For example, active elevation against gravity produces 16%-29% supraspinatus activity if 0-1 lb of resistance is used but ≥50% supraspinatus activity if 3-4 lb of resistance is added to the arm[3,36,73,107,110]. Likewise, the activation level of the supraspinatus can be quite variable for the motions of ER, internal rotation, and forward punching when performed against elastic resistance[22,47,83]. The difficulty level of these exercises is based primarily on how the elastic resistance is applied (elasticity of band, amount of pre-tension, and percent of band elongation during exercise). Therefore, we recommend caution when prescribing these exercises during phase 2 rehabilitation. To maintain supraspinatus activity within the 16%-29% level, elastic bands should provide no more than 2-3 lb of resistance and be used through only a small ROM.

Isotonic progressions actually begin with only gravity for resistance and progress to no more than 1-2 lb for resistance in this phase of rehabilitation to maintain supraspinatus activity in the ≤16%-29% category. We advocate using the thumb-up "full can" position for assistive, active, and resisted elevation exercises because it provides better subacromial clearance[33], better scapular mechanics[103], and equal rotator cuff activation[7] compared with the thumb-down "empty can" position. Closed-chain exercises at the 16%-29% EMG activity level including static quadruped and tripod positions may be useful in this phase to facilitate rotator cuff co-contraction and scapular muscle activation[108].

Irrespective of the type of muscle performance exercises that are chosen, the focus of these activities is trying to impart a stimulus for tendon healing by focusing on movement quality and endurance while working against relatively low loads. Unfortunately, there are no objective measures of the biomechanical effect of exercise on the rotator cuff tendon. Clinicians are reminded that overly aggressive loading can result in a retear, which—during this time frame—is most often attributed to the suture–rotator cuff interface as opposed to complete tendon failure[29,54].

Logically, it would seem that isometric exercises could be considered for restoring muscle function because there is no motion that would otherwise stress the repair. However, it is critical that patients and clinicians understand that maximal isometric exercises result in higher forces on the repair than AROM or concentric contractions. Thus, we recommend great caution when prescribing isometric rotator cuff exercises and only suggest their use if the patient understands the concept of submaximal activation. By contrast, isometric exercises for the periscapular muscles, deltoid, and trapezius are thought to be safe given the low levels of rotator cuff activity[99]. The therapist also needs to be alert for problems such as scapular dyskinesia, poor core stability, or spinal hypomobility. Specific interventions should be added as needed to target these problems as part of a comprehensive rehabilitation program.

Phase 3: 12-20 weeks

In animal studies, the repair had between 29% and 50% of normal strength at 12 weeks, and by 15 weeks, the bone-to-tendon healing was nearly mature[39,101]. However, it is important to remember that this information may not be directly applicable to humans and even so describes a "best-case" scenario. Patient factors such as poorer tissue quality, as well as the presence of comorbidities, slow the healing process, but in general, tendon-to-bone healing is considered sufficient to allow strengthening in this 12- to 20-week time frame as long as the addition of resistance is gradual and only commensurate with the patient's abilities, comfort level, and long-term goals[75]. Patients who have not yet met ROM milestones or are still having pain should not be progressed. The EMG studies we cite in this guideline represent levels of muscle activity in "normal" patients who have full ROM. Although there are no studies on the topic, trying to actively elevate a shoulder in the presence of restrictions of passive mobility likely produces levels of muscle activation well above the levels documented in normal patients. To that point, it is our experience that attempting to "strengthen" a "stiff" shoulder merely increases pain and actually results in more restricted ROM. Therefore, although strengthening is the primary activity of this phase, continued emphasis on maintaining PROM is crucial. Differentiating a shoulder with PROM restrictions (ie, "stiff") from a painful shoulder with associated muscle guarding is difficult. Furthermore, "stiff" versus "painful" situations require different therapeutic interventions. Because this is a common but difficult situation, this scenario is covered in more detail in the "Management of complications" section, as well as Appendix S2.

Evidence suggests that strengthening exercises in phase 3 can safely progress to the 30%-49% EMG activity level for most patients (Table II)[39,100]. Therefore, resistance can increase as appropriate for the strengthening exercises initiated in phase 2, below–chest level strengthening exercises, and full-can strengthening. To keep supraspinatus activity level <50%, resistance levels for elbow-extended or long-lever elevation should be limited to 0-2 lb. This level of resistance is generally complementary with many patients' functional demands, so higher levels of resistance are often unnecessary. Similar to our recommendation that sufficient passive elevation is the milestone indicator for the initiation of muscle performance exercises, we recommend that only those patients who show adequate tolerance to resisted elevation in the scapular plane ("full can") should attempt overhead strengthening. For most patients, phase 3 concludes their rehabilitation after arthroscopic RCR.

Phase 4: 20-26 weeks

Phase 4 comprises advanced strengthening exercises and is appropriate only for patients whose work or recreational demands require loads or positions not achieved during phase 3 strengthening (eg, patients who engage in heavy manual labor or routinely participate in overhead athletics). The rehabilitation clinician is reminded that very few patients recovering from arthroscopic RCR fall into this category. To help patients set realistic expectations, it is strongly recommended that time frames and ultimate recommendations for returning to demanding activities be clearly discussed early in the postoperative period and reinforced throughout the rehabilitation process.

It is generally believed that strengthening exercises that show ≥50% EMG activity levels can be safely initiated in this phase (Table II). This includes the progression of exercises begun previously but also includes new exercises that are meant to replicate the positions or forces the patients will encounter when they return to their job or sport. The rehabilitation clinician is reminded that caution should still be exercised during this phase of rehabilitation. For 2- to 4-cm tears, if a retear is going to occur, the retear happens most often during the first 6 months postoperatively[50,82]. Details on functional progressions are provided in Appendices S1 and S2.

Frequency and format of supervised rehabilitation

The ideal form and frequency of rehabilitation after RCR are still a matter of debate. Buker et al[9] showed that patient education and a program of home exercises resulted in similar outcomes at 1 year when compared with regular, supervised physical therapy visits after RCR. However, this program included a systematic education program for the patients in the study beyond a simple review of an exercise sheet. In addition, the literature suggests that videotaped exercises, which the patient can review as needed, may be an effective method of instruction for most patients and may be an appropriate model of rehabilitation, considering the continued pressures on the health care system[95]. However, in our opinion, given the complexity of rehabilitation after RCR, a formal physical therapy course is advised. As a method to combat the lack of compliance that one group of authors observed in patients after RCR, they suggested "constant reinforcement, advice, and monitoring during the rehabilitation period . . . particularly during the second 6 weeks."[1] Finally, when reviewing the recent randomized controlled trials examining RCR outcomes, we found that all of these studies included regular, supervised rehabilitation as a part of standard practice.

The frequency of physical therapy follow-up visits will vary based on many factors including patient health status, surgery specifics, resources, patient goals, and clinician preferences. To our knowledge, there is no direct research linking the number of rehabilitation visits to patient outcomes. However, published reports suggest that physical therapy visit totals range from 12-28 visits after RCR[8,19,31,88]. On the basis of a survey of usual practice among ASSET members, a visit frequency of 1 time a week during phase 1 (0-6 weeks) was most common. ASSET members then increase or decrease the frequency of follow-up visits based on patient progress balanced against factors such as pain, impairments in other regions, or risk factors regarding healing or stiffness. Overall, 90% of ASSET members who responded to the practice survey reported treating patients after uncomplicated RCRs for <25 total visits, with the vast majority (70%) of ASSET respondents scheduling 1-2 visits per week in phase 1 and then 2 visits per week for phases 2-4 as needed.

Management of complications

Phase-to-phase progression through our rehabilitation guideline is based on achievement of milestones. If impairment and criteria-based milestones are not reached, progressing to the next phase is likely not appropriate. If milestones are not being reached, collaboration with the referring surgeon should occur to adjust the rehabilitation program and goals accordingly. Signs and symptoms suggesting the patient is not ready to advance to the next phase include excessive complaints of pain (≥3 of 10 for phase 1 and ≥2 of 10 for phases 2-4), lack of achievement of the lower range of the staged ROM goals, noncompliance with the home exercise program, and failure to adhere to healing precautions.

Complications related to postoperative pain and stiffness are not unexpected after arthroscopic RCR, especially in the first 3 months. Addressing this challenge is a critical role for the rehabilitation professional. A patient who presents with ROM that does not meet the lower end of the staged goals should be evaluated in terms of his or her comprehension of the rehabilitation program, pain levels, and passive restrictions of ROM to provide a personalized adaptation of the guidelines to that patient's presentation. Appendix S2 provides a clinical decision-making model for managing the patient who presents with deficits in ROM. The primary clinical decision is to determine whether ROM deficits are due to excessive pain or true loss of motion. This assessment begins during the first postoperative visit and is continually reevaluated throughout the rehabilitation process. It is not uncommon to experience a slight decrease in ROM in the late phases of rehabilitation because of increased activity levels, a new focus on strengthening activities, and less time devoted to ROM exercises. For example, if at 12 weeks postoperatively, a patient is having greater than expected pain (4 of 10 on an NPRS) with less ROM than anticipated (110° of FE and 30° of ER), the focus should remain on basic PROM activities until the expected pain and ROM milestones are reached. When surveyed and presented with a situation such as this, ASSET members ranked "increasing the aggressiveness of the stretching" last when presented with strategies to address this clinical situation. Instead, the response selected most commonly by ASSET members was to "increase the frequency of home exercises" with the rationale that a patient with higher than expected levels of pain will only have even greater levels of pain if aggressive stretching is used. By contrast, stretching more often but less aggressively should simultaneously reduce pain and improve ROM. If a situation arises in which a patient is deviating from expected ROM targets, it is important to continually communicate with the patient and referring surgeon and work together to adjust the treatment plan, goals, and timelines for progression.

Another common complication during rehabilitation after arthroscopic RCR is the presence of a lag of active elevation behind PROM values for FE. Under the best of circumstances, this is simply a matter of timing as passive restrictions are targeted before the patient is expected to build muscle performance. However, a lack of power in elevation can also signify either poor muscle coordination or, more ominously, a retear of the rotator cuff. Perhaps one of the easiest ways to differentiate these two situations is to assess the ability of the patient to actively maintain end-range elevation when passively placed there by the therapist. If the patient can maintain this position, then the lag of active motion is likely related to poor coordination and the therapist should focus on neuromuscular strategies such as manual facilitation exercises or the use of gravity-minimized positions to target positional strength at end-range elevation. Conversely, inability of the patient to maintain end-range elevation after being passively placed there can signify a retear of the rotator cuff. In this scenario, the referring surgeon should be contacted, particularly if an active lag is also present for ER.

Finally, patients who have high expectations for their return to activity tend to push their rehabilitation progression and may need longer periods of supervised rehabilitation. The algorithm in Appendix S2 attempts to streamline advanced strengthening activities to the needs of the particular patient. Selectively promoting certain tasks while discouraging others often confuses the patient and necessitates repeated communication between therapist and patient to ensure that goals, milestones, and precautions are understood even in the late stages of rehabilitation.

Conclusion

Rehabilitation of the surgically repaired rotator cuff is a common challenge to the patient, surgeon, and rehabilitation professional. Recent randomized controlled trials have shed light on the transient nature of stiffness and the potential for nonhealing or retear of the repair with early, more aggressive mobilization. Yet, most ASSET members still work with surgeons who use passive, limited ROM within the first 6 weeks after surgery. In addition, there is no level I evidence for other decisions that rehabilitation clinicians must make after arthroscopic RCR. To that end, we have attempted to summarize the available scientific evidence and presented a consensus statement for postoperative rehabilitation after arthroscopic RCR from the members of ASSET.

The goals of postoperative shoulder rehabilitation are to re-establish full, symmetrical passive and active motion; to balance glenohumeral and scapulothoracic force couples; and to restore pain-free function to the shoulder. There are many factors that go into surgical and postoperative decision making that potentially influence the integrity of the repair and the ultimate outcome. Therefore, communication and coordination of care between surgeon and rehabilitation professional are essential to optimize outcomes. In addition, rehabilitation should be individualized, even beyond these guidelines, according to patient factors (age, expectations, and health status) and rotator cuff tear (size, chronicity, and tissue quality).

Within the purview of the rehabilitation clinician, the approach we put forth here focuses on controlled, protected additions of load to promote healing and remodeling of the repair. The key conflict of rehabilitation is promoting mobilization of the shoulder while avoiding excessive stress on the repair. In that vein, we favor passive, limited ROM starting within the first 6 weeks postoperatively. Once passive mobility is established and the repair begins to sufficiently heal, active motions can begin. Rehabilitation loads on the RCR progress from concentric motions with short levers and gravity-minimized positions to longer levers performed against the resistance of gravity. When the repair is sufficiently strong (approximately 12-16 weeks), progressive resistance training is the primary focus of rehabilitation. However, because most retears occur within the first 6 months postoperatively, the rehabilitation clinician is reminded that healing of the repair is paramount and loads that arise from positioning of the shoulder and active muscle contractions need to be carefully considered. Around 4-5 months postoperatively, work- and sport-specific rehabilitation activities can commence if they are in line with the patient's goals and situation. The guideline provides a progression and summative protocol in Appendix S1. Appendix S2 includes an algorithm to assist with clinical decision making to address postoperative complications or advanced functional progressions.

Acknowledgment

This manuscript contains the consensus statement on rehabilitation after arthroscopic rotator cuff repair. This statement was created by the membership of the American Society of Shoulder and Elbow Therapists (ASSET). The authors acknowledge the members of ASSET (www.asset-usa.org) for their expertise in the development of this international consensus statement.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Appendix
Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.jse.2015.12.018.

References

1. Ahmad S, Haber M, Bokor DJ. The influence of intraoperative factors and postoperative rehabilitation compliance on the integrity of the rotator cuff after arthroscopic repair. J Shoulder Elbow Surg 2015;24:229-35. http://dx.doi.org/10.1016/j.jse.2014.06.050
2. Arndt J, Clavert P, Mielcarek P, Bouchaib J, Meyer N, Kempf JF. Immediate passive motion versus immobilization after endoscopic supraspinatus tendon repair: a prospective randomized study. Orthop Traumatol Surg Res 2012;98:S131-8. http://dx.doi.org/10.1016/j.otsr.2012.05.003
3. Ballantyne BT, O'Hare SJ, Paschall JL, Pavia-Smith MM, Pitz AM, Gillon JF, et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther 1993;73:668-77, discussion 677-82.
4. Beason DP, Abboud JA, Kuntz AF, Bassora R, Soslowsky LJ. Cumulative effects of hypercholesterolemia on tendon biomechanics in a mouse model. J Orthop Res 2011;29:380-3. http://dx.doi.org/10.1002/jor.21255
5. Beason DP, Tucker JJ, Lee CS, Edelstein L, Abboud JA, Soslowsky LJ. Rat rotator cuff tendon-to-bone healing properties are adversely

affected by hypercholesterolemia. J Shoulder Elbow Surg 2014;23:867-72. http://dx.doi.org/10.1016/j.jse.2013.08.018
6. Bjorkenheim JM, Paavolainen P, Ahovuo J, Slatis P. Surgical repair of the rotator cuff and surrounding tissues. Factors influencing the results. Clin Orthop Relat Res 1988;236:148-53.
7. Blackburn TA, McLeod WD, White B, Wofford L. EMG analysis of posterior rotator cuff exercises. Athl Train 1990;25:40-7.
8. Brennan GP, Parent EC, Cleland JA. Description of clinical outcomes and postoperative utilization of physical therapy services within 4 categories of shoulder surgery. J Orthop Sports Phys Ther 2010;40:20-9. http://dx.doi.org/10.2519/jospt.2010.3043
9. Buker N, Kitis A, Akkaya S, Akkaya N. Comparison of the results of supervised physiotherapy program and home-based exercise program in patients treated with arthroscopic-assisted mini-open rotator cuff repair. Eklem Hastalik Cerrahisi 2011;22:134-9 [in Turkish].
10. Burkhart SS, Johnson TC, Wirth MA, Athanasiou KA. Cyclic loading of transosseous rotator cuff repairs: tension overload as a possible cause of failure. Arthroscopy 1997;13:172-6.
11. Carpenter JE, Thomopoulos S, Flanagan CL, DeBano CM, Soslowsky LJ. Rotator cuff defect healing: a biomechanical and histologic analysis in an animal model. J Shoulder Elbow Surg 1998;7:599-605.
12. Centers for Medicare & Medicaid Services. Chapter 15—covered medical and other health services, 220.3 documentation requirement for therapy services. In: Medicare benefit policy manual. Washington, DC: Government Printing Office; 2013.
13. Chan K, MacDermid JC, Hoppe DJ, Ayeni OR, Bhandari M, Foote CJ, et al. Delayed versus early motion after arthroscopic rotator cuff repair: a meta-analysis. J Shoulder Elbow Surg 2014;23:1631-9. http://dx.doi.org/10.1016/j.jse.2014.05.021
14. Chang KV, Hung CY, Han DS, Chen WS, Wang TG, Chien KL. Early versus delayed passive range of motion exercise for arthroscopic rotator cuff repair: a meta-analysis of randomized controlled trials. Am J Sports Med 2015;43:1265-73. http://dx.doi.org/10.1177/0363546514544698
15. Chen AL, Shapiro JA, Ahn AK, Zuckerman JD, Cuomo F. Rotator cuff repair in patients with type I diabetes mellitus. J Shoulder Elbow Surg 2003;12:416-21. http://dx.doi.org/10.1016/S1058-2746(03)00172-1
16. Chung SW, Huong CB, Kim SH, Oh JH. Shoulder stiffness after rotator cuff repair: risk factors and influence on outcome. Arthroscopy 2013;29:290-300. http://dx.doi.org/10.1016/j.arthro.2012.08.023
17. Cole BJ, McCarty LP III, Kang RW, Alford W, Lewis PB, Hayden JK, et al. Arthroscopic rotator cuff repair: prospective functional outcome and repair integrity at minimum 2-year follow-up. J Shoulder Elbow Surg 2007;16:579-85. http://dx.doi.org/10.1016/j.jse.2006.12.011
18. Colvin AC, Egorova N, Harrison AK, Moskowitz A, Flatow EL. National trends in rotator cuff repair. J Bone Joint Surg Am 2012;94:227-33. http://dx.doi.org/10.2106/jbjs.j.00739
19. Conti M, Garofalo R, Delle Rose G, Massazza G, Vinci E, Randelli M, et al. Post-operative rehabilitation after surgical repair of the rotator cuff. Chir Organi Mov 2009;93(Suppl 1):S55-63. http://dx.doi.org/10.1007/s12306-009-0003-9
20. Cuff DJ, Pupello DR. Prospective randomized study of arthroscopic rotator cuff repair using an early versus delayed postoperative physical therapy protocol. J Shoulder Elbow Surg 2012;21:1450-5. http://dx.doi.org/10.1016/j.jse.2012.01.025
21. Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784-91.
22. Decker MJ, Tokish JM, Ellis HB, Torry MR, Hawkins RJ. Subscapularis muscle activity during selected rehabilitation exercises. Am J Sports Med 2003;31:126-34.
23. DeFranco MJ, Bershadsky B, Ciccone J, Yum JK, Iannotti JP. Functional outcome of arthroscopic rotator cuff repairs: a correlation of anatomic and clinical results. J Shoulder Elbow Surg 2007;16:759-65. http://dx.doi.org/10.1016/j.jse.2007.03.020
24. Demirors H, Circi E, Akgun RC, Tarhan NC, Cetin N, Akpinar S, et al. Correlations of isokinetic measurements with tendon healing following open repair of rotator cuff tears. Int Orthop 2009;34:531-6. http://dx.doi.org/10.1007/s00264-009-0827-9
25. Denard PJ, Ladermann A, Burkhart SS. Prevention and management of stiffness after arthroscopic rotator cuff repair: systematic review and implications for rotator cuff healing. Arthroscopy 2011;27:842-8. http://dx.doi.org/10.1016/j.arthro.2011.01.013
26. DeSantana JM, Sluka KA, Lauretti GR. High and low frequency TENS reduce postoperative pain intensity after laparoscopic tubal ligation: a randomized controlled trial. Clin J Pain 2009;25:12-9. http://dx.doi.org/10.1097/AJP.0b013e31817d1070
27. DeSantana JM, Santana-Filho VJ, Guerra DR, Sluka KA, Gurgel RQ, da Silva WM Jr. Hypoalgesic effect of the transcutaneous electrical nerve stimulation following inguinal herniorrhaphy: a randomized, controlled trial. J Pain 2008;9:623-9. http://dx.doi.org/10.1016/j.jpain.2008.01.337
28. Digiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. J Shoulder Elbow Surg 1992;1:15-25.
29. Djurasovic M, Marra G, Arroyo JS, Pollock RG, Flatow EL, Bigliani LU. Revision rotator cuff repair: factors influencing results. J Bone Joint Surg Am 2001;83:1849-55.
30. Dockery ML, Wright TW, LaStayo PC. Electromyography of the shoulder: an analysis of passive modes of exercise. Orthopedics 1998;21:1181-4.
31. Duzgun I, Baltaci G, Atay OA. Comparison of slow and accelerated rehabilitation protocol after arthroscopic rotator cuff repair: pain and functional activity. Acta Orthop Traumatol Turc 2011;45:23-33. http://dx.doi.org/10.3944/AOTT.2011.2386
32. Ellenbecker TS, Elmore E, Bailie DS. Descriptive report of shoulder range of motion and rotational strength 6 and 12 weeks following rotator cuff repair using a mini-open deltoid splitting technique. J Orthop Sports Phys Ther 2006;36:326-35. http://dx.doi.org/10.2519/jospt.2006.2191
33. Flatow EL, Soslowsky LJ, Ticker JB, Pawluk RJ, Hepler M, Ark J, et al. Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. Am J Sports Med 1994;22:779-88.
34. Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K, Galatz LM, et al. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am 2004;86:219-24.
35. Galatz LM, Rothermich SY, Zaegel M, Silva MJ, Havlioglu N, Thomopoulos S. Delayed repair of tendon to bone injuries leads to decreased biomechanical properties and bone loss. J Orthop Res 2005;23:1441-7. http://dx.doi.org/10.1016/j.orthres.2005.05.005.1100230629
36. Gaunt BW, McCluskey GM, Uhl TL. An electromyographic evaluation of subdividing active-assistive shoulder elevation exercises. Sports Health 2010;2:424-32. http://dx.doi.org/10.1177/1941738110366840
37. Gerber C, Schneeberger AG, Beck M, Schlegel U. Mechanical strength of repairs of the rotator cuff. J Bone Joint Surg Br 1994;76:371-80.
38. Gerber C, Schneeberger AG, Hoppeler H, Meyer DC. Correlation of atrophy and fatty infiltration on strength and integrity of rotator cuff repairs: a study in thirteen patients. J Shoulder Elbow Surg 2007;16:691-6. http://dx.doi.org/10.1016/j.jse.2007.02.122
39. Gerber C, Schneeberger AG, Perren SM, Nyffeler RW. Experimental rotator cuff repair. A preliminary study. J Bone Joint Surg Am 1999;81:1281-90.
40. Gladstone JN, Bishop JY, Lo IK, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. Am J Sports Med 2007;35:719-28. http://dx.doi.org/10.1177/0363546506297539
41. Grigereit A, Ziesing A, Vogt L, Banzer W. EMG analysis of shoulder muscles during preventive and therapeutic exercise in the overhead athlete. Sportverletz Sportschaden 2003;17:21-5 [in German]. http://dx.doi.org/10.1055/s-2003-38588
42. Gulotta LV, Nho SJ, Dodson CC, Adler RS, Altchek DW, MacGillivray JD. Prospective evaluation of arthroscopic rotator cuff repairs at 5 years:

part I—functional outcomes and radiographic healing rates. J Shoulder Elbow Surg 2011;20:934-40. http://dx.doi.org/10.1016/j.jse.2011.03.029
43. Harris JD, Pedroza A, Jones GL. Predictors of pain and function in patients with symptomatic, atraumatic full-thickness rotator cuff tears: a time-zero analysis of a prospective patient cohort enrolled in a structured physical therapy program. Am J Sports Med 2012;40:359-66. http://dx.doi.org/10.1177/0363546511426003
44. Harryman DT II, Mack LA, Wang KY, Jackins SE, Richardson ML, Matsen FA III. Repairs of the rotator cuff. Correlation of functional results with integrity of the cuff. J Bone Joint Surg Am 1991;73:982-9.
45. Hartsell HD. Postsurgical shoulder strength in the older patient. J Orthop Sports Phys Ther 1993;18:667-72.
46. Hawkins RJ, Misamore GW, Hobeika PE. Surgery for full-thickness rotator-cuff tears. J Bone Joint Surg Am 1985;67:1349-55.
47. Hintermeister RA, Lange GW, Schultheis JM, Bey MJ, Hawkins RJ. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. Am J Sports Med 1998;26:210-20.
48. Holtby R, Razmjou H. Measurement properties of the Western Ontario rotator cuff outcome measure: a preliminary report. J Shoulder Elbow Surg 2005;14:506-10. http://dx.doi.org/10.1016/j.jse.2005.02.017
49. Huberty DP, Schoolfield JD, Brady PC, Vadala AP, Arrigoni P, Burkhart SS. Incidence and treatment of postoperative stiffness following arthroscopic rotator cuff repair. Arthroscopy 2009;25:880-90. http://dx.doi.org/10.1016/j.arthro.2009.01.018
50. Iannotti JP, Deutsch A, Green A, Rudicel S, Christensen J, Marraffino S, et al. Time to failure after rotator cuff repair: a prospective imaging study. J Bone Joint Surg Am 2013;95:965-71. http://dx.doi.org/10.2106/jbjs.l.00708
51. Illyes A, Kiss RM. Electromyographic analysis in patients with multidirectional shoulder instability during pull, forward punch, elevation and overhead throw. Knee Surg Sports Traumatol Arthrosc 2007;15:624-31. http://dx.doi.org/10.1007/s00167-006-0163-1
52. Jost B, Zumstein M, Pfirrmann CW, Gerber C. Long-term outcome after structural failure of rotator cuff repairs. J Bone Joint Surg Am 2006;88:472-9. http://dx.doi.org/10.2106/JBJS.E.00003
53. Keener JD, Galatz LM, Stobbs-Cucchi G, Patton R, Yamaguchi K. Rehabilitation following arthroscopic rotator cuff repair: a prospective randomized trial of immobilization compared with early motion. J Bone Joint Surg Am 2014;96:11-9. http://dx.doi.org/10.2106/jbjs.m.00034
54. Keener JD, Wei AS, Kim HM, Paxton ES, Teefey SA, Galatz LM, et al. Revision arthroscopic rotator cuff repair: repair integrity and clinical outcome. J Bone Joint Surg Am 2010;92:590-8. http://dx.doi.org/10.2106/jbjs.i.00267
55. Kelly BT, Roskin LA, Kirkendall DT, Speer KP. Shoulder muscle activation during aquatic and dry land exercises in nonimpaired subjects. J Orthop Sports Phys Ther 2000;30:204-10.
56. Kibler WB, Sciascia AD, Uhl TL, Tambay N, Cunningham T. Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. Am J Sports Med 2008;36:1789-98. http://dx.doi.org/10.1177/0363546508316281
57. Killian ML, Cavinatto L, Galatz LM, Thomopoulos S. The role of mechanobiology in tendon healing. J Shoulder Elbow Surg 2012;21:228-37. http://dx.doi.org/10.1016/j.jse.2011.11.002
58. Kim YS, Chung SW, Kim JY, Ok JH, Park I, Oh JH. Is early passive motion exercise necessary after arthroscopic rotator cuff repair? Am J Sports Med 2012;40:815-21. http://dx.doi.org/10.1177/0363546511434287
59. Klintberg IH, Gunnarsson AC, Svantesson U, Styf J, Karlsson J. Early loading in physiotherapy treatment after full-thickness rotator cuff repair: a prospective randomized pilot-study with a two-year follow-up. Clin Rehabil 2009;23:622-38. http://dx.doi.org/10.1177/0269215509102952
60. Kocher MS, Horan MP, Briggs KK, Richardson TR, O'Holleran J, Hawkins RJ. Reliability, validity, and responsiveness of the American Shoulder and Elbow Surgeons subjective shoulder scale in patients with shoulder instability, rotator cuff disease, and glenohumeral arthritis. J Bone Joint Surg Am 2005;87:2006-11. http://dx.doi.org/10.2106/JBJS.C.01624
61. Koh KH, Lim TK, Shon MS, Park YE, Lee SW, Yoo JC. Effect of immobilization without passive exercise after rotator cuff repair: randomized clinical trial comparing four and eight weeks of immobilization. J Bone Joint Surg Am 2014;96:e44. http://dx.doi.org/10.2106/jbjs.l.01741
62. Koo SS, Parsley BK, Burkhart SS, Schoolfield JD. Reduction of postoperative stiffness after arthroscopic rotator cuff repair: results of a customized physical therapy regimen based on risk factors for stiffness. Arthroscopy 2011;27:155-60. http://dx.doi.org/10.1016/j.arthro.2010.07.007
63. Kuhn JE, Dunn WR, Sanders R, An Q, Baumgarten KM, Bishop JY, et al. Effectiveness of physical therapy in treating atraumatic full-thickness rotator cuff tears: a multicenter prospective cohort study. J Shoulder Elbow Surg 2013;22:1371-9. http://dx.doi.org/10.1016/j.jse.2013.01.026
64. Lambers Heerspink FO, Hoogeslag RA, Diercks RL, van Eerden PJ, van den Akker-Scheek I, van Raay JJ. Clinical and radiological outcome of conservative vs. surgical treatment of atraumatic degenerative rotator cuff rupture: design of a randomized controlled trial. BMC Musculoskelet Disord 2011;12:25. http://dx.doi.org/10.1186/1471-2474-12-25
65. Lee BG, Cho NS, Rhee YG. Effect of two rehabilitation protocols on range of motion and healing rates after arthroscopic rotator cuff repair: aggressive versus limited early passive exercises. Arthroscopy 2012;28:34-42. http://dx.doi.org/10.1016/j.arthro.2011.07.012
66. Leggin BG, Michener LA, Shaffer MA, Brenneman SK. The Penn shoulder score: reliability and validity. J Orthop Sports Phys Ther 2006;36:138-51. http://dx.doi.org/10.2519/jospt.2006.36.3.138
67. Levy O, Mullett H, Roberts S, Copeland S. The role of anterior deltoid reeducation in patients with massive irreparable degenerative rotator cuff tears. J Shoulder Elbow Surg 2008;17:863-70. http://dx.doi.org/10.1016/j.jse.2008.04.005
68. Likar R, Molnar M, Pipam W, Koppert W, Quantschnigg B, Disselhoff B, et al. Postoperative transcutaneous electrical nerve stimulation (TENS) in shoulder surgery (randomized, double blind, placebo controlled pilot trial). Schmerz 2001;15:158-63.
69. Long JL, Ruberte Thiele RA, Skendzel JG, Jeon J, Hughes RE, Miller BS, et al. Activation of the shoulder musculature during pendulum exercises and light activities. J Orthop Sports Phys Ther 2010;40:230-7. http://dx.doi.org/10.2519/jospt.2010.3095
70. Mall NA, Kim HM, Keener JD, Steger-May K, Teefey SA, Middleton WD, et al. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. J Bone Joint Surg Am 2010;92:2623-33. http://dx.doi.org/10.2106/jbjs.i.00506
71. Mall NA, Tanaka MJ, Choi LS, Paletta GA Jr. Factors affecting rotator cuff healing. J Bone Joint Surg Am 2014;96:778-88. http://dx.doi.org/10.2106/jbjs.m.00583
72. Mallon WJ, Misamore G, Snead DS, Denton P. The impact of preoperative smoking habits on the results of rotator cuff repair. J Shoulder Elbow Surg 2004;13:129-32. http://dx.doi.org/10.1016/j.jse.2003.11.002
73. Markes M, Brockow T, Resch KL. Exercise for women receiving adjuvant therapy for breast cancer. Cochrane Database Syst Rev 2006:CD005001. http://dx.doi.org/10.1002/14651858.CD005001
74. McCann PD, Wootten ME, Kadaba MP, Bigliani LU. A kinematic and electromyographic study of shoulder rehabilitation exercises. Clin Orthop Relat Res 1993;179-88.
75. McCarron JA, Derwin KA, Bey MJ, Polster JM, Schils JP, Ricchetti ET, et al. Failure with continuity in rotator cuff repair "healing". Am J Sports Med 2013;41:134-41. http://dx.doi.org/10.1177/0363546512459477
76. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. J Athl Train 2009;44:160-4. http://dx.doi.org/10.4085/1062-6050-44.2.160

77. Meyer M, Klouche S, Rousselin B, Boru B, Bauer T, Hardy P. Does arthroscopic rotator cuff repair actually heal? Anatomic evaluation with magnetic resonance arthrography at minimum 2 years follow-up. J Shoulder Elbow Surg 2012;21:531-6. http://dx.doi.org/10.1016/j.jse.2011.02.009
78. Michener LA, Boardman ND, Pidcoe PE, Frith AM. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. Phys Ther 2005;85:1128-38.
79. Michener LA, McClure PW, Sennett BJ. American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, patient self-report section: reliability, validity, and responsiveness. J Shoulder Elbow Surg 2002;11:587-94. http://dx.doi.org/10.1067/mse.2002.127096
80. Michener LA, Snyder AR, Leggin BG. Responsiveness of the numeric pain rating scale in patients with shoulder pain and the effect of surgical status. J Sport Rehabil 2011;20:115-28.
81. Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J Bone Joint Surg Br 1995;77:296-8.
82. Miller BS, Downie BK, Kohen RB, Kijek T, Lesniak B, Jacobson JA, et al. When do rotator cuff repairs fail? Serial ultrasound examination after arthroscopic repair of large and massive rotator cuff tears. Am J Sports Med 2011;39:2064-70. http://dx.doi.org/10.1177/0363546511413372
83. Myers JB, Pasquale MR, Laudner KG, Sell TC, Bradley JP, Lephart SM. On-the-field resistance-tubing exercises for throwers: an electromyographic analysis. J Athl Train 2005;40:15-22.
84. Nho SJ, Brown BS, Lyman S, Adler RS, Altchek DW, MacGillivray JD. Prospective analysis of arthroscopic rotator cuff repair: prognostic factors affecting clinical and ultrasound outcome. J Shoulder Elbow Surg 2009;18:13-20. http://dx.doi.org/10.1016/j.jse.2008.05.045
85. Oh JH, Kim SH, Ji HM, Jo KH, Bin SW, Gong HS. Prognostic factors affecting anatomic outcome of rotator cuff repair and correlation with functional outcome. Arthroscopy 2009;25:30-9. http://dx.doi.org/10.1016/j.arthro.2008.08.010
86. Oh JH, Kim SH, Lee HK, Jo KH, Bin SW, Gong HS. Moderate preoperative shoulder stiffness does not alter the clinical outcome of rotator cuff repair with arthroscopic release and manipulation. Arthroscopy 2008;24:983-91. http://dx.doi.org/10.1016/j.arthro.2008.06.007
87. Osbahr DC, Cawley PW, Speer KP. The effect of continuous cryotherapy on glenohumeral joint and subacromial space temperatures in the postoperative shoulder. Arthroscopy 2002;18:748-54.
88. Parsons BO, Gruson KI, Chen DD, Harrison AK, Gladstone J, Flatow EL. Does slower rehabilitation after arthroscopic rotator cuff repair lead to long-term stiffness? J Shoulder Elbow Surg 2010;19:1034-9. http://dx.doi.org/10.1016/j.jse.2010.04.006
89. Piitulainen K, Hakkinen A, Salo P, Kautiainen H, Ylinen J. Does adding a 12-month exercise programme to usual care after a rotator cuff repair effect disability and quality of life at 12 months? A randomized controlled trial. Clin Rehabil 2014;29:447-56. http://dx.doi.org/10.1177/0269215514547598
90. Reilly P, Macleod I, Macfarlane R, Windley J, Emery RJ. Dead men and radiologists don't lie: a review of cadaveric and radiological studies of rotator cuff tear prevalence. Ann R Coll Surg Engl 2006;88:116-21. http://dx.doi.org/10.1308/003588406x94968
91. Reinold MM, Macrina LC, Wilk KE, Dugas JR, Cain EL, Andrews JR. The effect of neuromuscular electrical stimulation of the infraspinatus on shoulder external rotation force production after rotator cuff repair surgery. Am J Sports Med 2008;36:2317-21. http://dx.doi.org/10.1177/0363546508322479
92. Reinold MM, Macrina LC, Wilk KE, Fleisig GS, Dun S, Barrentine SW, et al. Electromyographic analysis of the supraspinatus and deltoid muscles during 3 common rehabilitation exercises. J Athl Train 2007;42:464-9.
93. Reinold MM, Wilk KE, Fleisig GS, Zheng N, Barrentine SW, Chmielewski T, et al. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J Orthop Sports Phys Ther 2004;34:385-94. http://dx.doi.org/10.2519/jospt.2004.34.7.385
94. Riboh JC, Garrigues GE. Early passive motion versus immobilization after arthroscopic rotator cuff repair. Arthroscopy 2014;30:997-1005. http://dx.doi.org/10.1016/j.arthro.2014.03.012
95. Roddey TS, Olson SL, Gartsman GM, Hanten WP, Cook KF. A randomized controlled trial comparing 2 instructional approaches to home exercise instruction following arthroscopic full-thickness rotator cuff repair surgery. J Orthop Sports Phys Ther 2002;32:548-59. http://dx.doi.org/10.2519/jospt.2002.32.11.548
96. Rokito AS, Zuckerman JD, Gallagher MA, Cuomo F. Strength after surgical repair of the rotator cuff. J Shoulder Elbow Surg 1996;5:12-7.
97. Rulewicz GJ, Beaty S, Hawkins RJ, Kissenberth MJ. Supraspinatus atrophy as a predictor of rotator cuff tear size: an MRI study utilizing the tangent sign. J Shoulder Elbow Surg 2013;22:e6-10. http://dx.doi.org/10.1016/j.jse.2012.10.048
98. Shen C, Tang ZH, Hu JZ, Zou GY, Xiao RC, Yan DX. Does immobilization after arthroscopic rotator cuff repair increase tendon healing? A systematic review and meta-analysis. Arch Orthop Trauma Surg 2014;134:1279-85. http://dx.doi.org/10.1007/s00402-014-2028-2
99. Smith J, Dahm DL, Kotajarvi BR, Boon AJ, Laskowski ER, Jacofsky DJ, et al. Electromyographic activity in the immobilized shoulder girdle musculature during ipsilateral kinetic chain exercises. Arch Phys Med Rehabil 2007;88:1377-83. http://dx.doi.org/10.1016/j.apmr.2007.07.028
100. Sonnabend DH, Watson EM. Structural factors affecting the outcome of rotator cuff repair. J Shoulder Elbow Surg 2002;11:212-8. http://dx.doi.org/10.1067/mse.2002.122272
101. St Pierre P, Olson EJ, Elliott JJ, O'Hair KC, McKinney LA, Ryan J. Tendon-healing to cortical bone compared with healing to a cancellous trough. A biomechanical and histological evaluation in goats. J Bone Joint Surg Am 1995;77:1858-66.
102. Tate AR, McClure P, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. J Athl Train 2009;44:165-73. http://dx.doi.org/10.4085/1062-6050-44.2.165
103. Thigpen CA, Padua DA, Morgan N, Kreps C, Karas SG. Scapular kinematics during supraspinatus rehabilitation exercise: a comparison of full-can versus empty-can techniques. Am J Sports Med 2006;34:644-52. http://dx.doi.org/10.1177/0363546505281797
104. Thomazeau H, Boukobza E, Morcet N, Chaperon J, Langlais F. Prediction of rotator cuff repair results by magnetic resonance imaging. Clin Orthop Relat Res 1997;275-83.
105. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly. Assessment by MRI in 55 patients with rotator cuff pathology. Acta Orthop Scand 1996;67:264-8.
106. Thomopoulos S, Williams GR, Soslowsky LJ. Tendon to bone healing: differences in biomechanical, structural, and compositional properties due to a range of activity levels. J Biomech Eng 2003;125:106-13. http://dx.doi.org/10.1115/1.1536660
107. Townsend H, Jobe F, Pink MM, Perry J. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. Am J Sports Med 1991;19:264-72.
108. Uhl TL, Carver TJ, Mattacola CG, Mair SD, Nitz AJ. Shoulder musculature activation during upper extremity weight-bearing exercise. J Orthop Sports Phys Ther 2003;33:109-17. http://dx.doi.org/10.2519/jospt.2003.33.3.109
109. Uhl TL, Kibler WB, Gecewich B, Tripp BL. Evaluation of clinical assessment methods for scapular dyskinesis. Arthroscopy 2009;25:1240-8. http://dx.doi.org/10.1016/j.arthro.2009.06.007
110. Uhl TL, Muir TA, Lawson L. Electromyographical assessment of passive, active assistive, and active shoulder rehabilitation exercises. Pm R 2010;2:132-41. http://dx.doi.org/10.1016/j.pmrj.2010.01.002

111. U.S. House. 112th Congress. The middle class tax relief and job creation act of 2012. Section 3005(g) (2012).
112. Wessel J, Razmjou H, Mewa Y, Holtby R. The factor validity of the Western Ontario Rotator Cuff Index. BMC Musculoskelet Disord 2005;6:22. http://dx.doi.org/10.1186/1471-2474-6-22
113. Wise MB, Uhl TL, Mattacola CG, Nitz AJ, Kibler WB. The effect of limb support on muscle activation during shoulder exercises. J Shoulder Elbow Surg 2004;13:614-20. http://dx.doi.org/10.1016/j.jse.2004.04.006
114. Wu XL, Briggs L, Murrell GA. Intraoperative determinants of rotator cuff repair integrity: an analysis of 500 consecutive repairs. Am J Sports Med 2012;40:2771-6. http://dx.doi.org/10.1177/0363546512462677
115. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. http://dx.doi.org/10.2106/jbjs.e.00835
116. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg 2010;19:116-20. http://dx.doi.org/10.1016/j.jse.2009.04.006
117. Yoo JH, Cho NS, Rhee YG. Effect of postoperative repair integrity on health-related quality of life after rotator cuff repair: healed versus retear group. Am J Sports Med 2013;41:2637-44. http://dx.doi.org/10.1177/0363546513499152