Narrative Review
Rotator cuff repair: considerations of surgical characteristics and evidence based interventions for improving muscle performance

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Background: Rotator cuff tears may lead to significant limitations in function, pain and disability. The extent of recovery from surgical intervention and subsequent rehabilitation can vary depending on the complexities of the tear, repair procedure, and post-operative patient management. Evidence suggests that tear and surgical characteristics will influence patient presentation in terms of strength and function, and thus need to be considered when healthcare professionals design rehabilitation programs.

Objectives: The objective of this manuscript is to present evidence-based rehabilitation guidelines for management of patients following repair of full-thickness rotator cuff tears, while taking into consideration the method of repair and the characteristics of the rotator cuff defect.

Major findings: Many studies have examined different characteristics of rotator cuff tears, various surgical procedures to correct the deficits, and physical interventions that target the specific range of motion and strength deficits post rotator cuff repair. A significant number of investigations have reported muscle activation levels with exercises and daily activities, which may offer a prescriptive utility to the clinician providing post-operative management. However, there are insufficient evidence-based rehabilitation programs that consider the characteristics of the rotator cuff tear defect or method of repair when addressing the post-operative clinical presentation, related impairments, functional limitations and interventions.

Conclusion: Rotator cuff tears and repairs have various characteristics that can impact patient recovery. Optimal recovery is dependent on appropriate communication among healthcare professionals and a rehabilitation professional’s understanding of how the tear classifications and surgical management can influence the standard treatment plan for rotator cuff repair.

Keywords: Rotator cuff tear, Rotator cuff repair, Rotator cuff facilitation, Rotator cuff strength

Introduction
Rotator cuff tears may result in significant shoulder dysfunction and functional impairments. Patients with tears can have various clinical presentations, which are attributed to numerous factors, including the characteristics of the rotator cuff defect. Surgical repair of the rotator cuff aims to restore the damaged tendon, reduce pain, and ultimately improve function. Physical therapists and other rehabilitation professionals have examined the post-operative management of patients post rotator cuff repair and developed interventions to improve function in this population. Variables that have been shown to highly correlate with improved function are integrity of the repaired rotator cuff¹ and strength.² The objectives of this manuscript are to review the outcomes of the various methods of rotator cuff repair, identify tear characteristics or repair procedures that could impact rotator cuff healing and patient recovery, and to present evidence-based rehabilitation strategies and guidelines for management of rotator cuff strengthening in patients after surgical repair.

Rotator Cuff Tear Characteristics
Rotator cuff tears individually are assessed using several parameters. These parameters include tear size, tear shape, and tissue quality. The combination of these elements of a rotator cuff tear makes up the personality of that given tear. The unique personality of a rotator cuff tear and subsequent repair are worthy of individualized consideration in the rehabilitation phase. Rotator cuff tears are classified as
full-thickness, or partial thickness, depending upon depth of the defect in the tendon. This manuscript will focus on full-thickness tears. In addition, patient factors such as patient smoking status and medical comorbidities should also be considered in the evaluation of rotator cuff repair and rehabilitation. Although outside the scope of this manuscript, it is important to recognize that diabetes mellitus, smoking, and worker’s compensation all have been correlated with poorer outcomes post rotator cuff repair when compared to subjects without these factors.

Rotator cuff tear size is often measured by the maximum diameter and cross-sectional area of the involved region of the tendon. Different diameters have been utilized to create classifications such as small, medium, large, and massive rotator cuff tears. The most commonly utilized classification system involving tear size was originated by DeOrio and Cofield, who defined measures as small (<1 cm), medium (1–3 cm), large (3–5 cm), and massive (>5 cm) rotator cuff tears. Classifications such as this provide descriptive size data but lack important attributes such as tear location or degree of retraction. In this regard, a classification that examines the degree of frontal plane retraction is the Patte classification. A study examining the interrater reliability among 12 fellowship-trained orthopedic surgeons utilizing these classifications found a fair agreement ($\kappa=0.32$) in the DeOrio and Cofield classification and a moderate agreement ($\kappa=0.54$) in the Patte classification. The findings of this study suggest acceptable practical use of these classification systems. The benefit of doing so may outweigh the risks. Larger-sized rotator cuff tears, tears involving multiple tendons, and increased degree of retraction have been correlated with increased failure rates.

An additional consideration related to size is the involvement of additional tendons (or location) of the tear. Tears involving the infraspinatus or teres minor have been found to have a greater incidence of re-tears and due to these tendon involvements, require more protection and slower progression in internal rotation range of motion and external rotation strengthening exercises. Due to these findings and potential changes in operative and postsurgical management, various classification systems involving topographic features have been proposed.

The utilization of these topographic classifications in describing rotator cuff tears could provide significant benefit to rehabilitation professionals. Larger rotator cuff tears carry increased risks of failure, re-tear, and reduced functional outcome. Therefore, modification of standard rehabilitation programs to account for these topographic characteristics has been the focus of recent literature.

Rotator cuff tears have been classified further based on their shape. Lo and Burkhart described and reviewed surgical management of tears based on these shapes. Two general categories have been identified. First, the crescent shaped tears involve rotator cuff tendons torn away from their humeral head insertions (Figs. 1A, 2, and 3). Repair of these tears involves reattachment of the tendons to their humeral head attachments (Fig. 1B). The second category of tears involves tearing between tendons in addition to tendon tearing from bone. These tears can be U-shaped (Figs. 4A and 5) or L-shaped tears.
U- and L-shaped tears require suturing of the tendon split, often termed 'margin convergence', followed by reattachment to the bone.\textsuperscript{23,24} The biomechanics of repairing U-shaped and L-shaped tears involves decreasing the marginal tear strains with side-to-side suturing. This converts the tear into a crescent shaped tear that is repaired to bone (Figs. 4B, 4C, 6B, 6C, and 7). Although post-operative rehabilitation implications have not been specifically studied for repair of these different rotator cuff tear shapes, surgical outcome studies\textsuperscript{24–27} have been used to provide a link of these geometric classifications to prognosis.\textsuperscript{18}

Standard repair of the rotator cuff involves either one or both of the following: tendon to bone repair or tendon to tendon repair. Suture anchor fixation (tendon to bone) has shown to have strong biomechanical properties.\textsuperscript{28,29} Side to side repairs (tendon to tendon) have been shown to be effective in reducing the cuff deficit and provide good patient outcomes,\textsuperscript{30,31} but the tendon-suture interface has often been found to be a common point of failure in unsuccessful repairs.\textsuperscript{32} Thus, it may be prudent to progress more cautiously in the early rehabilitation phases with U-shaped and L-shaped tears that necessitate tendon-to-tendon suturing.

An additional consideration of a rotator cuff tear that impacts the complexity of the tear and subsequent repair and recovery is tissue quality. Tissue quality of tendon, muscle, and bone all need to be

![Figure 4](image-url) U-shaped rotator cuff tear. (A) Superior view of a U-shaped rotator cuff tear involving the supraspinatus (SS) and infraspinatus (IS) tendons; (B) U-shaped tears demonstrate excellent mobility from an anterior-to-posterior direction and are initially repaired with side-to-side sutures using the principle of margin convergence; (C) the repaired margin is then repaired to bone in a tension-free manner.\textsuperscript{22} Adapted from: Lo, IK and Burkhart, SS, American Journal of Sports Medicine (volume 31, issue 2, pp. 308–324), Copyright \textcopyright 2003 by SAGE Publications. Reprinted by Permission of SAGE Publications.

![Figure 5](image-url) Arthroscopic picture of U-shaped tear.

![Figure 6](image-url) Acute L-shaped rotator cuff tear. (A) superior view of an acute L-shaped rotator cuff tear involving the supraspinatus tendon (SS) and rotator interval (RI); (B) the tears should be initially repaired along the longitudinal split; (C) the converged margin is then repaired to bone. IS, infraspinatus; Sub, subscapularis tendon; CHL, coracohumeral ligament.\textsuperscript{22} Adapted from: Lo, IK and Burkhart, SS, American Journal of Sports Medicine (volume 31, issue 2, pp. 308–324), Copyright \textcopyright 2003 by SAGE Publications.
Rotator Cuff Repair Considerations

From a surgical repair procedure standpoint, rotator cuff repairs can be evaluated based on the surgical approach (arthroscopic vs mini-open vs open) and on the fixation method (single vs double row fixation). Each of these variables contributes to the makeup of a given rotator cuff repair.

Initially rotator cuff repairs were performed in an open fashion. This approach involved the detachment of the deltoid origin from the anterior acromion, resection of a portion of the anterior acromion, rotator cuff repair and reattachment of the anterior deltoid to the remaining anterior acromion through drill holes. Post-operative protection for the deltoid reattachment is critical with this open approach.  

Mini-open repair was initiated to address the needed precautions and potential failure of the deltoid repair. During the mini-open repair procedure, the deltoid muscle is split vertically along the orientation of the muscle fibers to allow for visualization and repair of the torn rotator cuff tendon. Acromioplasties performed with the mini-open approach are typically performed arthroscopically. Numerous studies have supported this procedure with good to excellent results in approximately 90% of patients.

Arthroscopic rotator cuff repair is the least invasive surgical repair method. It involves no formal incision, no deltoid detachment and no open deltoid split. Arthroscopic rotator cuff repair provides the best visualization of the rotator cuff of the three repair methods. Studies comparing repair methods often focus on arthroscopic versus mini-open repair. These studies compare repair integrity through follow up MRI, computed tomography and clinical outcomes scores. A retrospective study by Sauerbrey et al. compared 54 patients post-arthroscopic repair versus mini-open repair at a minimum of 13 months post-op. The groups in this study were homogenous in relation to age (57/56 years), and tear size (2.0/2.7 cm²). This study found no differences in pain, patient satisfaction, or function between the mini-open and arthroscopic procedures.

Anatomic healing of the rotator cuff is an obvious goal of rotator cuff repair. Interestingly, some studies have shown high clinical outcome scores despite radiologically documented rotator cuff repair failures. Despite this, it is generally accepted that healed rotator cuff repairs offer a greater chance at better clinical outcomes in terms of pain, function, and strength.  

Arthroscopic rotator cuff repair healing rates have been assessed and compared to open techniques. In a comparison study and meta-analysis, it has been shown that arthroscopic rotator cuff repair healing rates have been equal to healing rates with the mini-open techniques. Repair approaches do not correlate with failure rate. Factors that consistently correlate with higher rotator cuff repair failure rates include increasing age and greater tear sizes.

The personalities of rotator cuff repairs engender further complexity as surgical fixation techniques are discussed. The variety of surgical techniques involves tendon fixation options to the humeral head insertions. A landmark improvement in fixation to bone was the development of the suture anchor. Suture anchors are placed into bone. They have sutures in them that pass through eyelets. The sutures are passed through the tendon and tied to fix the tendon to the bone. Suture anchors typify modern rotator cuff fixation to bone.

Suture anchor fixation methods can be divided into single and double row repairs. Single row repairs involve one row of anchors in an anterior to posterior direction along the tear insertion site. Double row repairs are defined by one row of anchors placed along the medial margin of the tear insertion site and another row of anchors placed along the lateral margin of the tear insertion site (Figs 8 and 9). Double row repairs were developed due to the belief that single row suture anchor techniques did not adequately restore the supraspinatus to its footprint insertion, leading to inadequate healing. Double row constructs not only have been proven to reproduce the insertion anatomy better, but also have been shown to be biomechanically superior to single row repairs. In addition, a systematic review examining 1252 repairs found that double row repairs of tears greater than 1 cm have been found to have significantly lower anatomical failure rates based on MRI and ultrasound evaluations. Despite these advantages of
double row rotator cuff repair constructs, some studies have found that they have not been demonstrated to result in better clinical outcomes scores than their single row repair counterparts.51–54 Regarding post-operative rehabilitation progressions for single versus double row rotator cuff repairs, the progressions should be predicated on characteristics other than the repair technique. The differences in anatomical healing rates have not been explored with use of different rehabilitation protocols for single versus double row repairs. As previously noted, clinical presentation may be affected by any of the tear characteristics, surgical repair procedures, or patient factors. Rehabilitation professionals will need to recognize the factors making up the rotator cuff tear personality and design the rehabilitation program in accordance with individualized attention.

Post-operative Rehabilitation
The rehabilitation program following rotator cuff repair may be broken down into three main phases: (1) maximum protection/passive, (2) moderate protection/active, and (3) minimum protection/resistive. The rate at which a patient progresses through these phases is dependent upon numerous factors related to the patient and surgical characteristics as previously discussed. These include the following: size, shape, and location of the tear, surgical procedure, tissue quality, and additional patient factors (age, co-morbidities, smoking, etc.). Therefore, variance exists between the rates at which patients can progress through the rehabilitation programs. The authors recognize that various rehabilitation protocols have been published and may conflict with one another.

The goal of the first phase or rehabilitation programs for rotator cuff repair is to prevent post-operative stiffness and scar tissue adherence while allowing for tendon to bone healing.21 This phase typically begins with shoulder immobilization and lasts 0–6 weeks. Phase two progresses over weeks 7–12 and consists of passive to active exercises for the rotator cuff musculature and scapular stabilizers.21 The third phase begins after week 12 and includes the addition of strengthening exercises and progression to functional activities. Various exercises have been identified as appropriate during each of these phases post rotator cuff repair. Naturally, with the association of poorer outcomes with muscle atrophy of the infraspinatus and supraspinatus,2 it is often the focus of rehabilitation professionals to utilize tactics that will best facilitate and eventually strengthen these rotator cuff muscles. Activation and facilitation of the rotator cuff and scapular musculature is best demonstrated through muscle activity analysis using electromyography (EMG). Therefore, it is our intention to provide a comprehensive rotator cuff repair rehabilitation protocol consisting of exercises based upon EMG activity while encouraging readers to keep in mind the considerations of tear and surgical characteristics as previously discussed. Rehabilitation guideline timeframes are provided with the assumption of a medium sized tear; smaller or larger tears will warrant appropriate alteration of these timeframes.

The analysis of muscular activity through the use of EMG involves the muscle’s response in relation to its maximal voluntary isometric contraction (MVIC). Therefore, prior to determining the effectiveness of a particular exercise in facilitating a muscular response, the muscle is tested for its MVIC. The normalized mean value for a particular exercise can be expressed as a percentage of the MVIC; the higher the percentage, the higher muscle activity recorded. General categories have been developed to assist in classifying the amount of muscle activity. McCann et al.55 suggest the following interpretation of the percentage of MVIC: minimal activity <20% MVIC, moderate activity 20–50% MVIC, and marked activity >50% MVIC. Uhl et al.56 suggest a different scale: low activity <20% MVIC, moderate activity 20–40% MVIC; high activity 41–60% MVIC; and very high >60% MVIC. These scales can be useful in determining appropriateness of various exercises and activities in each of the phases of a rotator cuff rehabilitation program. Based on these
findings, the authors of this manuscript recommend the following: (1) exercises in phase one should demonstrate minimal activity (less than 20% MVIC) in the rotator cuff musculature; (2) exercises in phase two should demonstrate moderate activity (20–40% MVIC) in the rotator cuff and scapular musculature; and (3) exercises in phase three should demonstrate high activity (41–60% MVIC) in the rotator cuff and scapular musculature in order to maximize gains in returned strength.

**Maximum protection phase/passive exercise (weeks 0–6)**

**Immobilization**

Shoulder immobilization is recommended in the maximum protection phase following rotator cuff repair regardless of the tear characteristics or method of surgical fixation. Hatakeyama et al. identified tensile forces on the repaired rotator cuff tendon were less at 45 and 30° compared to 15 and 0° of shoulder abduction. Additionally, strain was lowest in the scapular plane versus the sagittal plane for all four abducted positions. Therefore, an abductor pillow brace with the shoulder supported between 30 and 45° of abduction in the scapular plane is recommended for patients following rotator cuff repair. Immobilization has been recommended for 3 weeks and then only discontinued as determined by the surgeon or physical therapist. Suggested rehabilitation exercises are included in Table 1, with evidence for maximum protection phase interventions included in Table 2.

**Pendulum (Codman’s)**

In addition to active movement of the hand, wrist and elbow, the maximum protection phase usually consists of passive movement and light activity of daily living (ADLs) for the operative extremity. The pendulum exercise, also known as Codman’s, is a typical exercise performed in this phase. Caution, however, should be taken when performing this exercise. Long et al. found that smaller pendulums (less than 20 cm in diameter) are safer post rotator cuff repair than larger pendulums (greater than 51 cm in diameter) due to >20% MVIC produced in the infraspinatus and supraspinatus muscles with the larger motion. In addition, researchers have indicated that even the support by the contralateral limb on the table may cause greater than minimal supraspinatus activity. Due to the potential for increased strain as described, it is recommended that the pendulum exercise be appropriately instructed and performed to effectively protect the integrity of the healing rotator cuff tendon regardless of tear type, tear size, or method of fixation.

**Table 1 Suggested rehabilitation exercises**

<table>
<thead>
<tr>
<th>Maximum protection phase/passive exercise</th>
<th>Immobilization in abductor pillow brace with shoulder in 30–45° in scapular plane</th>
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</thead>
<tbody>
<tr>
<td>(0–6 weeks)</td>
<td>CPM machine in combined elevation and ER</td>
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<tr>
<td></td>
<td>Supine self-assisted elevation with stick or contralateral arm</td>
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<td></td>
<td>Supine ER/IR with stick</td>
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<td></td>
<td>PROM by PT: elevation (in scapular plane), ER, IR</td>
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<tr>
<td></td>
<td>Upright pulley</td>
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<tr>
<td></td>
<td>Upright pendulum in small diameter &lt;20 cm</td>
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<td></td>
<td>ADLs with involved arm: typing</td>
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<tr>
<td></td>
<td>ADLs with uninvolved arm: cross-body reaching, slow forward reaching and downward reaching</td>
</tr>
<tr>
<td></td>
<td>Closed chain: Prayer and Quadrupled positions</td>
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<tr>
<td></td>
<td>Gentle scapular exercises: depression, protraction ONLY</td>
</tr>
<tr>
<td></td>
<td>Serratus: cross-body rotations with uninvolved arm at lower heights with/without stepping</td>
</tr>
<tr>
<td></td>
<td>Aquatic exercises: elevation in the scapular plane at slow speeds (30–45°/second); buoyancy assisted FF, ER; scapular stabilization; pendulums</td>
</tr>
<tr>
<td></td>
<td>AVOID AROM of the involved arm</td>
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<tr>
<td></td>
<td>AVOID isometrics during maximum protection phase</td>
</tr>
<tr>
<td>Moderate protection phase/active exercise</td>
<td>Progressive scapular exercises: inferior glide, low row, ‘Lawnmower’, ‘Robbery’; (1) SL ER, (2) SL FF, (3) prone HABD, and (4) prone EXT</td>
</tr>
<tr>
<td>(7–12 weeks)</td>
<td>Isometric exercises (5 directions) with/without NMES</td>
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<tr>
<td></td>
<td>Active rotator cuff exercises: supine active elevation, upright elevation with elbow bent and straight, upright abduction</td>
</tr>
<tr>
<td>Minimum protective phase/resistive exercise</td>
<td>Resistive exercises with DB: (1) elevation, elbow bent and straight; (2) abduction; (3) prone ER; (4) SL ER; and (5) standing ER in scapular plane, 90°, and/or 0° (with/without towel roll)</td>
</tr>
<tr>
<td>(12 weeks and beyond)</td>
<td>Resistive exercises with elastic bands: (1) ER elbow moving fixed; (2) IR; (3) forward elevation; and (4) EXT</td>
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<td></td>
<td>Advanced scapular stabilizer exercises: push-up plus, dynamic hug, prone arm raise overhead, shoulder ABD in the plane of the scapula above 120°</td>
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</tbody>
</table>

**Note:** CPM, continuous passive motion; ER, external rotation; IR, internal rotation; PROM, passive range of motion; ADL, activity of daily living; FF, forward flexion; AROM, active range of motion; SL, sidelying; HABD, horizontal abduction; EXT, extension; NMES, neuromuscular electrical stimulation; DB, dumbbell.
### Table 2 Evidence for maximum protection phase

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Study</th>
<th>Comments</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine self-assisted elevation</td>
<td>McCann et al.55</td>
<td>Phase 1 exercises as described by Neer (1987): min mm activity (&lt;20% MVIC) in infraspinatus, supraspinatus, anterior/middle/posterior deltoid, serratus anterior, middle trapezius, and biceps; supine exercises preferred over upright due to intersubject variability in this study</td>
<td>Considered safe in maximum protection phase</td>
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<tr>
<td>Supine helper-assisted elevation</td>
<td>Dockery et al.50</td>
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<td></td>
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<tr>
<td>Supine ER with stick</td>
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<tr>
<td>Upright pendulum</td>
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<tr>
<td>Upright pulley</td>
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<tr>
<td>CPM machine</td>
<td>Dockery et al.50</td>
<td>All exercises produced low MVIC in rotator cuff muscles (&lt;20%) except moderate MVIC (25.2%) in deltoid with pulley exercise</td>
<td>CPM and PT PROM safer for passive motion and repair protection; all considered safe in this phase</td>
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<tr>
<td>Pulls</td>
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<tr>
<td>Pendulum</td>
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<td>Self-assisted elevation with other arm</td>
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<td>Self-assisted IR and ER with bar</td>
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<tr>
<td>PT-assisted elevation in scapular plane and ER/IR</td>
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<tr>
<td>Pendulums</td>
<td>Long et al.58</td>
<td>Larger pendulums performed incorrectly generate more supraspinatus activity than smaller, correctly performed pendulums; smaller pendulums (20 cm diameter) safer post rotator cuff repair</td>
<td>Considered safe in maximum protection phase, however, recommend supervised exercise; caution: Contralateral limb support on a table may cause supraspinatus activation58 Typing ok with involved UE, however, caution with drinking and brushing teeth with post-operative arm</td>
</tr>
<tr>
<td>Light ADLs with involved UE</td>
<td>Long et al.58</td>
<td>Typing ok</td>
<td>Typing ok with involved UE, however, caution with drinking and brushing teeth with post-operative arm</td>
</tr>
<tr>
<td>ADLs with uninvolved UE:</td>
<td>Smith et al.59</td>
<td>1. Fast straightforward reaching with non-involved limb can cause potential infraspinatus stress (&gt;20% MVIC);</td>
<td>Avoid fast straightforward reaching and pulling motions with non-involved arm; cross-body reaching, slow straightforward reaching and downward reaching by uninvolved arm safe and activate lower trapezius as a scapular stabilizer</td>
</tr>
<tr>
<td>1. Straightforward reaching</td>
<td></td>
<td>2. Resisted pulling motions with non-involved arm (i.e. opening doors, starting lawnmowers, and pulling carts and objects) can cause potential stress to supraspinatus (&gt;20% MVIC);</td>
<td></td>
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<tr>
<td>2. Pulling motions</td>
<td></td>
<td>3. Cross-body reaching by uninvolved arm OK as MVC in anterior deltoid, supraspinatus, and biceps &lt;10% MVI;</td>
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<tr>
<td>3. Cross-body reaching</td>
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<td>4. Downward reaching similar EMG activity as cross-body reaching,</td>
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<tr>
<td>4. Downward reaching</td>
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<tr>
<td>Closed chain prayer and quadruped positions</td>
<td>Uhl et al.56</td>
<td>Low (&lt;20% MVIC) of deltoid and infraspinatus</td>
<td>Will facilitate co-contraction early in post-op rehab</td>
</tr>
<tr>
<td>Gentle scapular exercises</td>
<td>Smith et al.62,64</td>
<td>Isolated scapular depression and protraction standing in immobilizer sufficient to strengthen serratus anterior and trapezius while maintaining &lt;20% MVIC in infra/supraspinatus, anterior deltoid and biceps; avoid scapular clock, elevation, and retraction as &gt;.20% MVIC</td>
<td></td>
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<tr>
<td>Kinetic chain exercises</td>
<td>Smith et al.64</td>
<td>Cross-body rotations at low or medium heights will generate clinically significant EMG activity in serratus anterior while producing safe levels of activation in supra/infraspinatus, biceps and anterior deltoid (&lt;20% MVIC)</td>
<td>Better serratus anterior activator than scapular depression and protraction</td>
</tr>
<tr>
<td>Aquatic exercises</td>
<td>Kelly et al.66</td>
<td>Elevation in the scapular plane at slow speeds (30–45/second) safe as MVIC in the rotator cuff and deltoid &lt;20%</td>
<td>Elevation in the scapular plane at slow speeds (30–45/second) safe</td>
</tr>
<tr>
<td>Aquatic exercises</td>
<td>Brady et al.65</td>
<td>Accelerated restoration of PROM in FF and quality of life in land program with aquatic therapy</td>
<td>Buoyancy assisted FF, ER; scapular stabilization; pendulums are all safe and appropriate exercises</td>
</tr>
</tbody>
</table>

**Note:** CPM, continuous passive motion; ER, external rotation; IR, internal rotation; PROM, passive range of motion; ADL, activity of daily living; FF, forward flexion; SL, sidelying.

**Light ADLs**

The EMG activity of the rotator cuff musculature has been studied during various ADLs deemed appropriate in maximum protection phase. Long et al.58 determined that typing with the surgically-repaired extremity required minimal activity of the supraspinatus, infraspinatus, and deltoid muscles. However, drinking from a cup and brushing teeth require moderate supraspinatus activity. Therefore, it is recommended that the uninvolved extremity complete these activities instead. Generally, contralateral limb movements for ADLs at self-selected speeds are unlikely to harm healing tissue.59 However, Smith et al.59 found that fast straightforward reaching with the uninvolved limb...
could cause potential infraspinatus stress as shown by >20% MVIC in EMG. This occurs as the surgically-repaired extremity retracts and externally rotates to counterbalance the reach. Resisted pulling motions with the uninvolved arm (i.e., opening doors, starting lawn mowers, and pulling carts and objects) should also be avoided as potential stress to the supraspinatus has been observed by EMG (>20% MVIC).\textsuperscript{59} Cross-body reaching and downward reaching by the uninvolved arm may be safe as minimal activity is seen in the anterior deltoid, supraspinatus, and biceps brachii.\textsuperscript{59} These activities should be safe for all tear sizes, shapes and methods of surgical fixation as EMG activity is minimal in the muscles involved.

### Passive and active-assisted exercises

Passive range of motion (PROM) and active-assisted exercises are also typically prescribed during the maximum protection phase. McCann \textit{et al.}\textsuperscript{55} investigated deltoid and rotator cuff muscle activity during four supine elevation exercises: self-assisted elevation, helper-assisted elevation, shoulder external rotation with a stick, and helper-assisted external rotation. All four of these exercises offer protection of the repaired rotator cuff tendons and deltoid as evidenced by minimal activity in the supraspinatus, infraspinatus, anterior deltoid, and middle deltoid via EMG. In addition, McCann \textit{et al.}\textsuperscript{55} examined six upright exercises commonly seen in this phase of rehabilitation: forward elevation with a pulley, pendulums, elevation with stick, wall slide (patient faces wall and slides hand up the wall in the sagittal plane), assisted extension, and assisted internal rotation (upright position). When compared to the supine exercises, the upright exercises demonstrated higher activity in the rotator cuff musculature but still within the minimal range and, thus, are safe in this phase of rehabilitation.

Dockery \textit{et al.}\textsuperscript{60} studied similar passive exercises in addition to the effects of a continuous passive motion machine (CPM). Electromyography analysis of the supraspinatus, infraspinatus, anterior deltoid and trapezius was performed during CPM use, self-assisted exercises (pulley, pendulum, elevation with other arm, self-assisted internal and external rotation) and therapist-assisted exercises (elevation in scapular plane, internal and external rotation). It was determined that CPM use and therapist-assisted PROM are safer for passive motion and repair protection; however, all exercises resulted in low MVIC in the rotator cuff muscles and deltoid (<20%) and are considered safe in the maximum protection phase of rehabilitation.\textsuperscript{60} Although patient usage of a CPM is recommended to complement the passive ROM by a therapist during this rehabilitation phase, caution should be taken to avoid aggressive PROM into internal rotation with repairs of the infraspinatus and into external rotation with repairs of the subscapularis tendons.

### Gentle scapular exercises (serratus anterior, trapezius muscle group)

Exercises for the scapular stabilizers, including the trapezius complex (upper and lower trapezius) and the serratus anterior, may be initiated in this phase of rehabilitation as they have a synergistic relationship with the glenohumeral rotators.\textsuperscript{61} Early activation of the scapular stabilizers may promote improved scapulothoracic rhythm and functional use of the post-surgical shoulder.\textsuperscript{61}

Scapular exercises commonly performed include retraction, protraction, elevation, depression, and the scapular clock. Smith \textit{et al.}\textsuperscript{62} studied the effects of these scapular movements on the rotator cuff musculature through EMG analysis. Data analysis revealed that only isolated scapular depression and protraction in standing while wearing an immobilizer are safe for the repaired infraspinatus or supraspinatus while sufficiently activating the serratus anterior. The scapular depression exercise activated the serratus anterior more than the other motions. Should the surgery also include the repair of the subscapularis tendon, no scapular exercise is appropriate in this phase as high activity (40–63% MVIC) was observed in this muscle.\textsuperscript{62}

Arm supported scapular retraction in the scapular plane at 90 and 120° was studied by Bressel \textit{et al.}\textsuperscript{63} Electromyography activity of the lower trapezius, supraspinatus and infraspinatus were recorded. Results suggest that potential neuromuscular re-education of the lower trapezius with the arms supported at 90° are possible early following supraspinatus repairs, but not infraspinatus repairs as too much tension is placed on the infraspinatus.

An alternative method of activating the scapular stabilizers while minimizing the activity of the rotator cuff muscles may involve utilizing the contralateral limb. Reaching across the body with the right arm can activate the left lower trapezius. Smith \textit{et al.}\textsuperscript{62} found significant lower trapezius activity with cross-body forward reaching, slow straightforward reaching, and downward reaching with the contralateral upper extremity.\textsuperscript{59} In addition, kinetic chain exercises such as cross-body rotations, which involves reaching across the body while rotating the trunk simultaneously, at low or medium heights will generate clinically significant EMG activity in the serratus anterior while producing safe levels of activation in the supraspinatus, infraspinatus, biceps brachii, and anterior deltoid; adding a step to the motion will activate the serratus anterior even more selectively. Greater serratus anterior activity was seen in the...
kinetic chain motions when compared to isolated scapular elevation and depression. Cross-body reaches at shoulder height with the non-involved arm effectively activate the lower trapezius, the second most important scapular stabilizer, while minimizing activity in the rotator cuff musculature. However, none of these kinetic chain exercises are appropriate when the repair includes the subscapularis tendon. These activities may potentially allow reactivation of scapular stabilizers in a protected environment while minimizing activity of the healing rotator cuff, anterior deltoid and biceps brachii.

Aquatic therapy
Aquatic therapy is an appropriate option in the maximum protection phase following rotator cuff repair. Brady et al. found accelerated restoration of PROM in forward flexion and improved quality of life in subjects who underwent a land program with the addition of aquatic therapy. Exercises performed during the maximum protection phase included buoyancy assisted forward flexion and external rotation, scapular stabilization and pendulum exercises. Buoyancy assisted elevation in the scapular plane at slow speeds (30–45°/second) is safe for post-operative rotator cuff repairs as the MVIC in the rotator cuff and deltoid is minimal (<20%).

Exercises that traditionally, on land, show higher EMG activity of the rotator cuff musculature may be appropriate during the maximum protection phase when performed in the water. Water buoyancy and shorter lever arms could help diminish tensile strain and protect the repaired tendons. For example, active shoulder range of motion, which may not begin until the moderate protection phase, could be performed earlier in the water due to the lower load environment. Aquatic therapy for repaired rotator cuff tendons should begin as soon as the arthroscopic portals or surgical incisions are completely healed or otherwise covered with a waterproof bandage to allow for accelerated restoration of motion.

Closed-chain activity
Uhl et al. examined muscle activity of the pectoralis major, anterior deltoid, posterior deltoid, and infraspinatus during closed chain activities. Closed-chain activities can be utilized to enhance proprioception of the glenohumeral joint. Closed-chain activities in the prayer and quadruped positions are appropriate during the passive phase of rehabilitation as minimal activity (<20% MVIC) of the rotator cuff and deltoid musculature is exhibited.

Moderate protection phase/active exercise (weeks 7–12)
Progression to the moderate protection/active phase involves several factors: quality of tissue repair, stability of fixation, and forces generated at the surgical reconstruction. Typically the patient is ready for active exercise between the sixth and seventh post-operative weeks. Moderate activity of the rotator cuff musculature is appropriate at this time as the healing of the tissue repair is sufficient and less at risk for rupture. Common exercises in this phase of rehabilitation include progression of scapular stabilization, isometric exercise for the rotator cuff musculature, and active range of motion of the glenohumeral joint. Evidence for these suggested interventions is included in Table 3.

Progressive scapular exercises (serratus anterior, trapezius muscle group)
Scapular stabilization is a coupled motion with glenohumeral rotation. Therefore, at this point the healing process should be directed at force couples rather than isolated muscle-focused exercise. Schachter et al. determined that during isolated glenohumeral internal and external rotation, the scapular muscles (serratus anterior and middle trapezius) are at least as active as the glenohumeral rotators. Hence, inclusion of scapular retraining exercises in rotator cuff rehabilitation programs is supported.

Kibler et al. examined the EMG activity of the lower trapezius and serratus anterior during four scapular stabilization exercises. These exercises consisted of: (1) inferior glide (isometric with humeral head depression and scapular retraction); (2) low row (isometric with scapular external rotation and posterior tilt); (3) ‘lawnmower’ (trunk rotation with scapular retraction); and (4) ‘robbery’ (trunk extension with scapular retraction). The ‘robbery’ exercise begins with the subject standing with the trunk flexed approximately 40–50° with arms forward flexed and palms facing the thighs. With the elbows kept close to the body, the subject moves into trunk and arm extension and flexes elbows so palms are facing up and away from the body while simultaneously retracting the scapulae towards the back pockets. Each of these exercises requires no more than 90° of shoulder elevation and, therefore, is appropriate at this point in the rehabilitation program. Moderate activity (20–40% MVIC) of the lower trapezius and serratus anterior was found indicating appropriateness for retraining neuromuscular control in the active phases of rehabilitation.

Cools et al. analyzed the ratio of upper trapezius to lower trapezius, middle trapezius, and serratus anterior during 12 common exercises performed early in the moderate protection/active phase of rehabilitation. Minimizing upper trapezius activity is an important component in restoring appropriate scapulohumeral rhythm following rotator cuff repair. Sideling external rotation, sideling forward flexion, and prone horizontal abduction were found to have
low upper to lower trapezius ratios while prone shoulder extension was found to have a low upper to middle trapezius ratio. These findings support the use of these four exercises in the active phase of rehabilitation as upper trapezius activity is minimized and scapulohumeral rhythm is improved. It was also recommended that standing flexion movements should be avoided if excessive shoulder girdle elevation due to activity of the upper trapezius is observed with this motion. However, if the patient can flex the shoulder with normal scapulohumeral rhythm and avoid excessive hiking, then this motion should be employed during this phase. If excessive hiking is present, then the motion can still be used, but in a recumbent position at an angle where the motion is demonstrated without the shoulder girdle elevation. Mirror feedback may also be helpful in retraining the patients’ proprioception with this exercise.

**Isometrics and neuromuscular re-education**

Isometrics of the shoulder musculature are commonly performed during the active phase of rotator cuff rehabilitation. McCann et al. performed EMG analysis of the rotator cuff and deltoid muscles during a 5-second isometric contraction in five directions: external rotation, internal rotation, forward elevation, abduction, and extension. Minimal activity of the supraspinatus, infraspinatus and deltoids was found with internal rotation while moderate to marked activity was found in the other four directions. Similar findings were found by Decker et al. supporting the use of shoulder internal rotation isometric exercise to strengthen the subscapularis while eliciting minimal activity in the supraspinatus. Shoulder isometrics are appropriate during the moderate protection phase/active phase, however, should be avoided during the maximum protection/passive phase as rotator cuff muscle activity is too high. Submaximal isometric contractions should be supervised in repairs of the infraspinatus and subscapularis in external rotation and internal rotation, respectively.

Neuromuscular electrical stimulation (NMES) may be used as an adjunct treatment to enhance force production, muscle recruitment, and improve muscle function. Isometric contraction of the infraspinatus assisted with NMES of the infraspinatus was studied in patients following repair of the supraspinatus tendon. Results showed a 22% increase in force production by the infraspinatus regardless of age, gender, size of tear, number of days post-op, or intensity of NMES. This suggests that NMES may be an appropriate and safe modality to enhance the facilitation of the rotator cuff musculature during the active phase of rehabilitation. Caution should be taken to apply NMES to surrounding rotator cuff

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**Table 3 Evidence for moderate protection phase**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Study</th>
<th>Comments</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressive scapular exercises</td>
<td>Kibler et al.67</td>
<td>Four exercises examined by EMG found to have moderate (20–40% MVIC) and are appropriate for retraining neuromuscular control</td>
<td>Inferior glide: isometric with humeral head depression and scapular retraction (SA and LT) Low row: isometric with scapula ER and post tilt (SA and LT) Lawnmower: included trunk rotation and scapular retraction (SA and LT) Robbery: trunk extension with scapular retraction</td>
</tr>
<tr>
<td>Progressive scapular exercises</td>
<td>Cools et al.68</td>
<td>12 trap exercises looking at low UT/LT, UT/MT, UT/SA ratios; early active rehab exercises to include (1) SL ER, (2) SL FF, (3) prone HABD, and (4) prone EXT; nos. 1–3 have low UT/LT ratios and no. 4 has low UT/MT ratio</td>
<td>NMES considered safe in improving ER force production post rotator cuff repair</td>
</tr>
<tr>
<td>Isometrics with/without NMES</td>
<td>Reinold et al.70</td>
<td>22% increase in isometric force production of the infraspinatus with NMES in patients post RCR</td>
<td></td>
</tr>
<tr>
<td>Active rotator cuff exercises</td>
<td>McCann et al.15</td>
<td>Phase II exercises as described by Neer (1987): supine active elevation; upright elevation with elbow bent and straight, upright abduction consistently showed moderate activity (20–50%); begin upright elevation with elbow bent then progress to elbow straight</td>
<td>Supine active elevation; upright elevation with elbow bent and straight, upright abduction all appropriate in this phase</td>
</tr>
<tr>
<td>Closed-chain tripod and pointer</td>
<td>Uhl et al.66</td>
<td>Moderate (20–40% MVIC) in posterior deltoid and infraspinatus</td>
<td>Intermediate level of facilitation and co-contraction with trunk stabilization</td>
</tr>
</tbody>
</table>

**Note:** ER, external rotation; FF, forward flexion; SL, sidelying; HABD, horizontal abduction; EXT, extension; NMES, neuromuscular electrical stimulation.
muscle tendons and not directly to the repaired tendon.

**Active rotator cuff exercises**
Active range of motion exercises of the glenohumeral joint are typically performed during the moderate protection/active phase of rehabilitation. McCann et al.\(^5\) analyzed the EMG activity of the rotator cuff musculature during supine active elevation, upright elevation with elbow bent and with elbow straight, and upright abduction. Elevation in this study consisted of motion of the entire shoulder complex. Moderate activity (20–50% MVIC) of the rotator cuff musculature was found consistently in these exercises and are, therefore, appropriate in the active phase of rehabilitation. It is suggested that upright elevation begin with elbow bent then progressed to the elbow straight as increased activity of the rotator cuff musculature is seen with the elbow extended.\(^5\)

**Aquatic therapy**
Aquatic exercises can also be performed during the moderate protection/active phase of rehabilitation. Appropriate exercises studied by Brady et al.\(^6\) include standing breaststroke, reaching the hand behind the back, and kicking with a kickboard. Exercises may progress in the minimal protection/resistive phase to include resisted forward flexion and external rotation with paddles, ball proprioception exercises and resistance, and wall push-ups.\(^6\)

**Closed-chain exercise**
Uhl et al.\(^6\) determined that closed chain activities in the tripod and pointer positions are appropriate in the active phase of rehabilitation since moderate muscle activity (20–40% MVIC) is seen in the pectoralis major, anterior deltoid, posterior deltoid, and infraspinatus muscles. For the tripod exercise, the subject begins in the quadruped position and then flexes one shoulder to 180°. The pointer exercise is performed in the same position as the tripod with the addition of contralateral hip extension to 0°. Push-ups should be reserved for the resistive phase as muscular activity is high in these muscles tested (41–60% MVC).\(^6\)

**Minimum protection phase/resistive exercise (weeks 12 +)**
Transition to the minimal protection phase/resistive phase of rehabilitation typically occurs 12 weeks post-operatively. During this phase, strengthening

### Table 4 Evidence for minimum protection phase

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Study</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Resistive exercises with dumbbells or elastic bands</td>
<td>McCann et al.(^5)</td>
<td>Phase III exercises as described by Neer (1987): (1) elevation with 2.25 kg, elbow bent; (2) straight; (3) abduction with 2.25 kg; (4) T band ER elbow moving; and (5) fixed, IR, T band forward elevation, T band extension consistently showed moderate levels of activity in rotator cuff and deltoid</td>
</tr>
<tr>
<td>Resistive exercises with dumbbells or elastic bands</td>
<td>Boettcher et al.(^7)</td>
<td>Preferred exercises in this study: (1) pendant ER and (2) prone ER vs ‘can’ exercises due to lower deltoid activity</td>
</tr>
<tr>
<td>ER with dumbbell</td>
<td>Reinold et al.(^7)</td>
<td>Prone HABD – high activity of middle and post deltoid, making less preferred if trying to target cuff muscles; exercise in scapular plane or at 0° ABD – less mid and post deltoid than in 90° ABER at 90° ABD in standing in supine – mimic sporting activity but place extra stress to the inf. GH ligament complex; SL ER at 0° ABD – higher mm activity of all cuff mms than in standing at 0° ABD; ER in scapular plane – functional while minimizing INF GH ligament stress and improving dynamic stabilization; towel roll may aid in improved form and decreased substitution by deltoid</td>
</tr>
<tr>
<td>Push-up (normal, feet elevated, one-arm)</td>
<td>Uhl et al.(^6)</td>
<td>HIGH to very HIGH (41–60% MVC) in infraspinatus and deltoids</td>
</tr>
<tr>
<td>Advanced scapular stabilizer exercise</td>
<td>Decker et al.(^7)</td>
<td>Push-up plus and dynamic hug exercises elicited greatest EMG activity in serratus anterior; prone arm raise overhead and shoulder abduction in scapular plane above 120° elicited greatest simultaneous activity of the serratus anterior and trapezius muscle group</td>
</tr>
<tr>
<td>Advanced scapular stabilizer exercise</td>
<td>Eckstrom et al.(^7)</td>
<td>Advanced co-contraction with trunk stabilization</td>
</tr>
</tbody>
</table>

**Note:** ER, external rotation; IR, internal rotation; SL, sidelying; HABD, horizontal abduction.
of the rotator cuff begins and progression to functional lifting and sport activities are allowed (Table 4). Sufficient healing of the rotator cuff has completed so that moderate to high muscular activity of the rotator cuff musculature during exercise does not pose a great risk to rupture of the repaired tendon. Strengthening exercises may utilize elastic resistive bands or dumbbells with the glenohumeral joint in various positions to strengthen the rotator cuff muscles.

**Resistive exercises**
McCann et al.\(^{55}\) investigated seven commonly prescribed exercises in this phase: shoulder elevation with 2.25 kg with the elbow bent and straight, shoulder abduction with 2.25 kg, external rotation, internal rotation, forward elevation and extension with elastic resistive bands. Each exercise consistently showed moderate levels of activity in the rotator cuff and deltoid muscles and are, therefore, appropriate for the resistive phase of rehabilitation.\(^{55}\)

Boettcher et al.\(^{71}\) studied five exercises typically recommended to strengthen the rotator cuff, specifically the activity of the supraspinatus. Muscular activity of the rotator cuff and deltoid were examined during the following exercises: elevation in the scapular plane with glenohumeral external rotation (‘full can’), elevation in the scapular plane with glenohumeral internal rotation (‘empty can’), prone elevation (horizontal abduction), pendant external rotation (at 0° abduction), and prone external rotation. Exercises incorporating external rotation were best for strengthening the supraspinatus while minimizing surrounding muscular activity, especially the deltoid. Pendant external rotation and prone external rotation exercises are preferred over the elevation in the scapular plane exercises due to lower deltoid activity. These two exercises also highly activate the infraspinatus, which may be advantageous in facilitating centralization of the humeral head in the glenoid fossa.

Reinold et al.\(^{72}\) examined the activity of the supraspinatus and deltoid muscles during three exercises: elevation in the scapular plane with external rotation (‘full can’), elevation in the scapular plane with glenohumeral internal rotation (‘empty can’), and prone elevation in the scapular plane with external rotation. All exercises provided similar amounts of supraspinatus activity (62–67% MVIC). However, elevation in the scapular plane with glenohumeral external rotation demonstrated the lowest middle and posterior deltoid activity. This exercise may be best in maximizing the amount of supraspinatus activity while minimizing activity in the deltoid muscle.\(^{72}\)

Seven exercises commonly used for external rotation strengthening were analyzed by Reinold et al.\(^{73}\) These exercises utilized a dumbbell for resistance in the following positions: prone horizontal abduction at 100° with full external rotation, prone external rotation at 90° abduction, standing external rotation at 90° abduction, standing external rotation with arm elevated 45° in the scapular plane, standing external rotation at 0° abduction, standing external rotation at 0° abduction with towel roll, and sidelying external rotation at 0° abduction. Prone horizontal abduction showed high activity of the middle and posterior deltoid, making it less preferred when trying to target strengthening of the rotator cuff muscles. Exercises in the scapular plane or at 0° abduction demonstrated less middle and posterior deltoid than in 90° abduction, but at 90° abduction, the posterior deltoid activity may provide a compressive force and assist in external rotation. External rotation at 90° abduction in standing and in supine is useful in mimicking sporting activity but places extra stress to the inferior glenohumeral ligament complex. Sidelying external rotation at 0° abduction results in higher muscle activity of all rotator cuff muscles than the same activity in standing. External rotation in the scapular plane offers functional benefits of external rotation at 90° while minimizing inferior glenohumeral ligament stress and maximizing the length-tension relationship of the rotator cuff muscles for dynamic stabilization. A towel roll may aid in improved form and decreased substitution by the deltoid, although this study found no significant differences.\(^{73}\) A limitation of this study, however, is that the researchers performed standing external rotation with a dumbbell in hand. Therapists do not routinely prescribe this as the resistance force line is not in line with the rotator cuff. Additional studies found that the placement of a towel roll in the axilla during sidelying external rotation increased activity of the infraspinatus by 10%,\(^{74}\) prevented reduced blood flow to the supraspinatus,\(^{75}\) and increased the subacromial space.\(^{76}\)

Advanced training of the scapular stabilizers is common in this phase. Decker et al.\(^{77}\) found that the push-up plus and the dynamic hug exercises elicited the greatest EMG activity in the serratus anterior muscle. Eckstrom et al.\(^{78}\) identified two exercises that produced marked (>50% MVIC) activity simultaneously in the serratus anterior and trapezius muscle group: the prone arm raise overhead and shoulder abduction in the plane of the scapula above 120°. These exercises may be effective in restoring the scapulohumeral rhythm in the post-surgical shoulder to return the patient to prior level of function.

**Conclusion**
Rotator cuff tear characteristics, surgical repair procedures and tactics, and patient factors can all affect the clinical presentation as well as the overall patient...
outcome of rotator cuff repair. Both communication between orthopedic surgeon and rehabilitation professional, as well as a rehab professional’s understanding of the influences that these factors can have on patient outcome are essential in optimizing care. Post-surgical rehabilitation after rotator cuff repair focuses on patient function, restoration of mobility, and return of strength. It is important for rehabilitation professionals to recognize evidence based tactics to restore the impairments after rotator cuff repair, and utilize them appropriately with consideration of the numerous variables that can impact patient recovery. More research is warranted to further bridge the gap between rotator cuff tear characteristics, repair procedures, and rehabilitation implications.

References


