the actual rehabilitation program used for each patient is highly individualized based on the unique situation and his or her tolerance of the rehabilitation program. Extensive and regular patient education is also vital during the entire course of rehabilitation. Often, the patient needs help understanding that the repair must be significantly protected for an extended period and needs instruction in how to protect the upper extremity during rehabilitation and daily functional activities.

Specific Rehabilitation Guideline

The Appendix specifies our complete Routine Rotator Cuff Repair Rehabilitation Guideline. In this section, I explain the rationale for selected components of the guideline. The guideline is divided into 3 phases based on general timeframes of healing and staged ROM targets. To advance from one rehabilitation phase to the next, the patient must gain physician approval to advance, successfully complete the core components of the previous rehabilitation activities, and meet the time criteria.

Phase 1

The primary focus of phase 1 rehabilitation, which constitutes the first 6 postoperative weeks, is to maximally protect the surgical repair, and the secondary focus is to achieve, but not significantly exceed, the staged ROM goals that the referring physician helps establish. As mentioned, for a rehabilitation activity to be safe after a rotator cuff repair, the strength of the surgical repair always should be much more than the stress that is placed on the repaired tendon during each rehabilitation exercise. During rehabilitation after rotator cuff repair, this stress is determined for all rehabilitation activities (home exercises, clinic exercises, and manual therapy) by (1) the amount of muscle activation of the repaired musculotendon unit, (2) the plane of motion used, (3) the specific glenohumeral joint ROM, and (4) the number of times the tissue is loaded (the number of repetitions). Appropriate exercise selection cannot occur without understanding these factors.

Zuckerman et al[13] and Hatakeyama et al[14] evaluated the mechanical stress that specific glenohumeral PROM placed on the supraspinatus (SSP) in cadavers. Hatakeyama et al[14] found that passive external rotation (PER) with the extremity in slight abduction (20º-30º) resulted in very low stress (<5 N) to the SSP from 60º of internal rotation to 60º of external rotation. Zuckerman et al[13] found very low stress in the SSP (<5 N) with PROM from 0º to 120º of elevation performed in the plane of the scapula (passive forward elevation [PFE]). Therefore, these motions appear safe to use during the immediate postoperative period. These investigators did not test motion at more than 120º, but they theorized that tension on the rotator cuff likely increases with end-range PFE.

Orthopaedic surgeons and rehabilitation providers are almost in universal consensus that elevation in the plane of the scapula with the thumb oriented up (humeral external rotation) is **the** preferred plane of movement to use during early overhead motion of the shoulder. It provides minimal capsular stress; optimal length-tension relationship to the rotator cuff, deltoid, and scapula muscles to enable efficient function; and optimal subacromial clearance to minimize impingement. Therefore, for PROM during phase 1 rehabilitation after rotator cuff repair, the only planes of motion that the patient performs at home are PER with the upper extremity in slight abduction and PFE.

However, for early PROM after rotator cuff repair to be safe, the rehabilitation provider not only must choose planes of motion that provide low stress to the repair, but also must use specific exercises that have documented low EMG activity in the repaired rotator cuff. The Table lists the documented EMG activity level of the SSP and anterior deltoid (AD) for common passive elevation exercises performed in the plane of the scapula. In studies, researchers have demonstrated that PFE performed in the supine or upright position with the assistance of the rehabilitation provider or PFE performed in the supine position with the patient assisting himself or herself has much less EMG activity in the SSP and AD than the rope-and-pulley PFE has.[15,16] The pendulum, the table step-back, continuous passive motion (CPM) machine, and aquatic exercises also have demonstrated very low EMG activity. We have found that the pendulum, table step-back, Kinex KS2 (Kinex Medical Company, LLC, Waukesha, WI) shoulder CPM machine, and rehabilitation provider-assisted or family-assisted sitting exercises are the most effective and well-tolerated exercises to achieve PFE during the first few weeks after surgery (Figures 1-3). We also have found that although self-assisted PROM

Table. Common passive elevation exercises in the plane of the scapula and the associated electromyographic activity level of the supraspinatus and anterior deltoid.

Exercise	Electromyographic Activity
Therapist-assisted forward elevation	Average supraspinatus 4%, anterior deltoid 8%[15] Average supraspinatus 5%, anterior deltoid 7% supine[16] Average supraspinatus 12%, anterior deltoid 4% upright[16]
Self-assisted forward elevation supine	Average supraspinatus 3%, anterior deltoid 11%[16]
Pulley forward elevation	Average supraspinatus 17%, anterior deltoid 25%[15] Average supraspinatus 13%, anterior deltoid 21%[16] Maximal supraspinatus 17%, anterior deltoid 31%[17]
Pendulum	Average supraspinatus 9%, anterior deltoid 3%[16] Average supraspinatus 6%[15] Maximal supraspinatus (small 10-cm diameter circle) 8-8.7%[18] Maximal supraspinatus (large 51-cm diameter circle) 13.7-18.8%[18]
Specific aquatic exercises	Average supraspinatus 1-5%, anterior deltoid 1-8%[19]
Closed chain (table step-back)	Average supraspinatus 5%, anterior deltoid 2%[20]
Continuous passive motion machine	Average supraspinatus 5%, average anterior deltoid 3%[15]

in the supine position (Figure 4) is safe to start immediately after surgery, it typically is not well-tolerated until the patient achieves about 110º of PFE. More detailed information about the benefits and safety of shoulder CPM use and how we specifically use the Kinex KS2 with our patients after rotator cuff repair can be found in chapter II-3. As the Table demonstrates, the rope-and-pulley exercise has a noticeably higher EMG activity level in the SSP than the other exercises listed, so we do not recommend starting this exercise until postoperative week 6 for the typical

Figure 1. Pendulum exercise initially is performed with small circles.

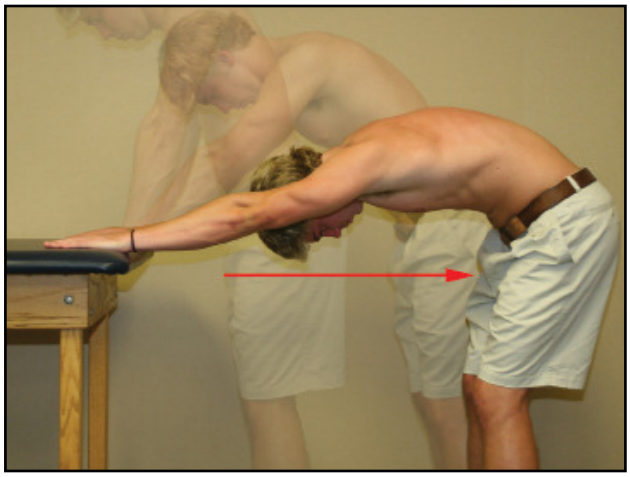

Figure 2.Table step-back exercise for passive forward elevation.

Figure 3. Assisted passive forward elevation. The assistant typically stands diagonally in front of patient.

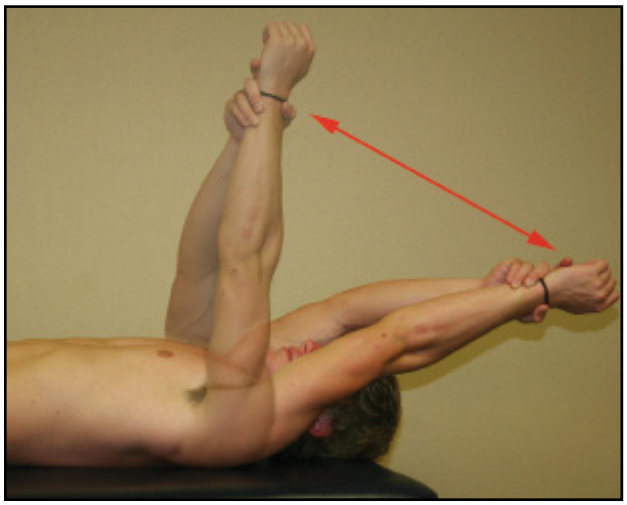

Figure 4. Self-assisted supine active-assisted forward elevation. The hand-assisted exercise is preferred.

patient after arthroscopic rotator cuff repair. Because of the theorized increased mechanical stress to the SSP with end-range PFE, we also restrict the end ranges of this motion during the first 6 weeks of recovery.

For PER, McCann et al[16] and Dockery et al[15] demonstrated very low EMG activity levels in the SSP, AD, and infraspinatus with all exercises tested. However, neither group of investigators evaluated the EMG activity in the subscapularis, which is likely the muscle most at risk of injury with these exercises, so extreme caution must be used when prescribing PER exercises for patients with subscapularis repairs. Clinically, we have found that PER performed while sitting and with the assistance of a family member or rehabilitation provider and the PER walk-around are the most gentle, the most effective, and most well-tolerated exercises in the early postoperative period (Figures 5 and 6).

The number of times a rotator cuff repair is stressed or loaded, even in a submaximal manner, is an important, but often overlooked, rehabilitation variable that has important implications regarding the length of immobilization and the number of repetitions performed during early exercise. Much in the same way micromotion prevents bony union during fracture healing, submaximal tissue loading or cyclic loading can potentially disrupt the tenuous tissue-healing bonds between the rotator cuff tendon and its bony insertion. In human cadavers, cyclic loading has been shown to increase the gap between the repaired tendon and the bone to which it is repaired.[21,22] This increased gap, at some point, is believed detrimental to healing of the repair.[21] Although the exact effect of submaximal loading during various rehabilitation interventions is unknown, the rehabilitation provider should keep in mind that repeated and excessive submaximal tensioning of the repair during the early phases of tissue healing might be detrimental to the clinical healing of the repaired rotator cuff to its humeral insertion. Therefore, repetitive submaximal stresses should be carefully controlled during phase 1 rehabilitation.

Clinically, this has implications for both exercise volume and immobilization. This research suggests that, during phase 1 rehabilitation, as able both AROM

Figure 5. Assisted sitting passive external rotation.

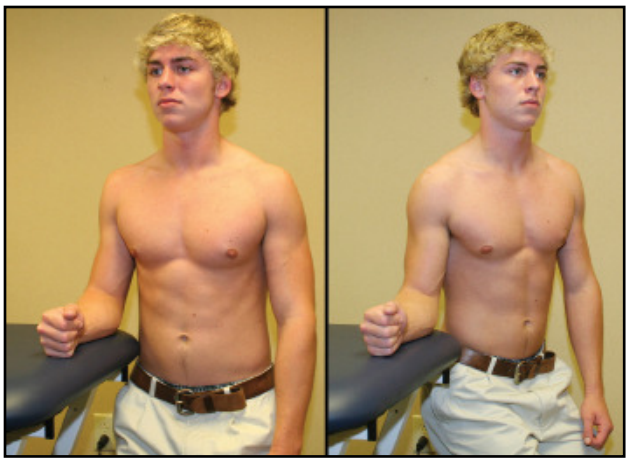

Figure 6. Passive external rotation walk-around exercise.

and PROM should be minimized during exercise and functional activities. Therefore, although enough PROM needs to be prescribed to achieve staged ROM goals and prevent excessive joint stiffness, we recommend keeping both the number of exercises performed and total repetitions fairly low during this timeframe. We also emphasize educating patients about the importance of minimizing active use of the upper extremity during the first 6 postoperative weeks.

Based on the cyclic loading studies discussed, the results of basic science research on tendon healing in animal models,[23-26] and recent ultrasound evidence suggesting that a moderate percentage of arthroscopic rotator cuff repairs might not heal completely to bone,[27,28] surgeons are re-evaluating the concept of immediate PROM after rotator cuff repair. Rehabilitation providers at a few facilities delay the initiation of traditional glenohumeral PROM up to 6 weeks even after routine-sized rotator cuff repairs in an attempt to maximize early healing. Parsons et al[29] retrospectively reviewed 43 patients who had undergone arthroscopic rotator cuff repair and were immobilized 6 weeks before glenohumeral ROM was initiated. They grouped these patients into a stiff group and a nonstiff group at the time ROM was initiated. Patients were considered *stiff* if their PFE was less than 100° and their PER was less than 30° at the time ROM was initiated. Ten (23%) patients were considered *stiff* at postoperative week 6. At 1 year, they found no difference in ROM, the American Shoulder and Elbow Surgeons score, or the Constant score. However, they reported a trend toward a lower retear rate in the stiff group (70% versus 36%).

In nonpublished work, Leggin et al [30] evaluated the effect of delayed rehabilitation on PROM, AROM, and function by evaluating starting PROM at an average of 4.5 weeks after surgery compared with starting at an average of 1 week after surgery in a group of patients after arthroscopic rotator cuff repair. At 12 weeks, they found only a 4° difference in PFE and an 8° difference in PER between groups. They found the delayed rehabilitation group had 32° less AFE and scored 9 points lower on the Penn Shoulder Scale compared with the early PROM group. They found overall that delayed rehabilitation seemed to shift the recovery back a few weeks but did not impede recovery. In the next few years, I believe the concept of delaying the initiation of rehabilitation after rotator cuff repair will be evaluated more extensively to determine its effectiveness for improving healing rates while minimizing recurrent stiffness. If successful in both of these areas, then this practice likely will become more widespread.

Even given this possibility, we believe that early PROM (initiated in the first 1 to 5 postoperative days) is beneficial, and if only exercises demonstrating very low EMG activity are used and performed correctly, it is not detrimental to healing after the routine rotator cuff repair. Early glenohumeral PROM traditionally has been a well-accepted technique for rehabilitation after shoulder surgery because it helps minimize the negative effects of immobilization, such as formation of adhesions and joint contracture, muscle atrophy and serial sarcomere loss, and articular cartilage degradation.

Merely choosing the appropriate exercises is not sufficient to successfully achieve early rehabilitation goals. Helping the patient to maximally relax the extremity, paying attention to detail with exercise technique, stopping the PROM at a point of mild stretch and slight discomfort, and extensively educating the patient play enormous roles in the success of rehabilitation during the early stage of rehabilitation. These issues are outlined in the Appendix and are addressed extensively in chapter II-2. Supplementary PROM that is performed very gently by the rehabilitation provider is helpful, especially if the patient is behind in achieving staged ROM goals. Directions of motion used during phase 1, which are performed as comfortable, include abduction with neutral rotation to

less than 90°, external and internal rotation in middle ranges of abduction, PFE, and external rotation at 80° to 90° of forward elevation to stretch the coracohumeral ligament. Detailed descriptions of these motions are presented in chapter II-3.

Although every attempt is made to help the patient achieve his or her staged PROM goals in FE and ER as outlined in the Appendix through early PROM, careful exercise selection, and flawless exercise technique, some patients will fall behind our staged ROM targets. In these situations, we typically increase the frequency of the home exercise program to 4 to 6 times each day and increase the frequency of clinic visits. We do not increase the intensity of clinic or home exercise stretching, so we do not impede healing of the repair. Therefore, if necessary, it is better for the patient to be behind targeted PROM goals than to meet these goals but undermine healing of the repair.

Phase 2

The focus of phase 2, which typically constitutes postoperative weeks 6 through 12, is to continue to protect the surgical repair that while getting stronger, is still weak; to gently normalize PROM; to begin a well-structured AROM and strengthening progression that gradually increases demand to the musculature of the shoulder girdle while protecting the repair; and to minimize inflammation and pain. The rehabilitation provider still must ensure that the stress of the activities in the rehabilitation program is less than the strength of the surgical repair.

Obtaining adequate flexibility while keeping the pain and inflammation level low should be the first priority of phase 2 rehabilitation. A variable amount of stretching is needed to achieve this goal. If the ROM of the patient is much less than staged goals, then the initiation of AROM and strengthening should be delayed until PROM is improved. To effectively improve PROM, the rehabilitation provider must recognize the influence that multiple structures have on a single glenohumeral motion. For example, a limitation in forward elevation of the upper extremity might be associated with limited mobility of any portion of the glenohumeral capsule, especially the posterior capsule, surrounding soft tissues, acromioclavicular joint, sternoclavicular joint, scapulothoracic joint, cervical spine, thoracic spine, or lumbar spine. These factors are addressed in chapters II-3, IV-2, and IV-3. Therefore, a thorough assessment of the entire upper extremity is warranted.

For PROM at the beginning of phase 2, the patient gradually starts gentle stretching in planes of motion other than PFE and PER in slight abduction. This stretching might include external rotation in increasing degrees of abduction, posterior shoulder stretching, and functional internal rotation (Figures 7-10). The last 2 directions place direct stress on an SSP repair, so the clinician needs to take extra care in prescribing and properly educating the patient in performing these exercises. For example, initiation of these 2 directions typically is delayed in repairs of larger cuff tears and in patients with poor-quality tissue.

The failure strength of the repaired rotator cuff during phase 2 rehabilitation is much less than that of a normal shoulder and varies widely based on many factors. Therefore, when starting the AROM and strengthening phase of rehabilitation, the rehabilitation provider must use great care to select exercises that start with very low stress to the healing tissue and progress in a gradual and measured way. When beginning AROM and strengthening, selecting exercises that have a very low documented EMG activity and ordering them so that the activity level in the rotator cuff slowly increases should be the primary criteria for advancement of exercises along with selecting planes of movement that do not place excessive tension on the repair. An evidence-based AROM-to-strengthening progression is incorporated and outlined in our rehabilitation guideline and detailed in chapter II-4.

The rehabilitation provider also should remember several clinical hints that help in the appropriate selection of AROM and strengthening exercises. First, during appropriate advancement of these exercises, the patient's level of pain should not increase, and substitution patterns should not occur. A reliable way to achieve this is to choose rehabilitation exercises that are at or below the patient's comfortable use of the extremity. For example, a patient who cannot reach the top of his or her head without pain should perform an assistive exercise in the overhead position rather than an active exercise. Second, because of the physics of the shoulder girdle, a little resistance to the shoulder