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A Literature Review of Studies Evaluating Rotator Cuff Activation during Early Rehabilitation Exercises for Post-Op Rotator Cuff Repair

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ABSTRACT

Wells SN, Schilz JR, Uhl TL, Gurney B. A Literature Review of Studies Evaluating Rotator Cuff Activation during Early Rehabilitation Exercises for Post-Op Rotator Cuff Repair. **JEP**online 2016;19(3):70-99. Despite the modern advancement of surgical repair equipment and techniques, many rotator cuff repairs do not clinically heal. Prescribed rehabilitative exercises must appropriately load the repaired muscle-tendon complex to promote healing and prevent capsular adhesions without damaging the repair. The clinician must possess an understanding of the anatomy and physiology of the healing rotator cuff, and understand the importance of the plane of movement, speed of the movement, position of the extremity, level of assistance, and type of resistance used. Electromyography (EMG) provides a useful means to determine muscle activation levels during specific exercises. Descriptions of specific exercises and EMG activation as they relate to the rotator cuff muscles are described. The specific performance of the exercises, the reliability of such EMG measures, and the descriptive figures are described. Practicing clinicians will benefit from the correct interpretation of the EMG data, and how it can be used in the exercise prescription when formulating a treatment plan.

Key Words: Rotator Cuff, Electromyography (EMG), Supraspinatus, Infraspinatus

INTRODUCTION

Therapeutic exercises for rotator cuff dysfunction are an essential treatment tool used by rehabilitation professionals in a variety of healthcare settings that range from hospitals to outpatient clinics (2,4,7,16,21,38). These exercises can be powerful tools to improve the healing of compromised tissues by increasing blood flow to the tissues while also increasing strength and/or motor control to promote patient function (7,16,38). Exercise prescription and progression requires a systematic approach to enable the therapist to achieve a safe and effective contraction of the muscular tissue relative to the patient's needs and capabilities. The clinician must take into account numerous factors that include the plane of the movement, the speed of the movement, the position of the extremity, the level of assistance, and the type of resistance used (15). Exercises are prescribed along a continuum respecting healing tissues and progressed or regressed based on individual responses (3).

Electromyography (EMG) is a common method of evaluating skeletal muscle activity and function through the capture of electrical activity by either collecting a signal via electrodes placed on the skin overlying the intended muscle (surface EMG) or by fine-wire electrodes placed directly into the muscle (intramuscular EMG) (48). While the EMG provides information on when, how much, and how often a muscle is active throughout a range of motion (ROM), the clinician is careful not to equate the EMG with muscle or joint force (12). Understanding therapeutic EMG amplitudes assists the clinician in prescribing safe and appropriate exercises, and in making modifications without overloading the healing tissues. An appreciation of the anatomy and function of the rotator cuff is essential for therapeutic application of appropriate exercises.

Rotator Cuff Anatomy and Function

The rotator cuff is composed of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles (29). This musculotendinous complex is referred to as a cuff because the inserting tendons of each muscle envelope the head of the humerus to reinforce the stability of the glenohumeral joint. Their role in controlling the direction, degree, and quality of motion of the humeral head during upper extremity movements is required for optimal shoulder function to occur (29,37). The rotator cuff helps to elevate the arm while compressing the humeral head within the glenoid fossa and, therefore, resists translations of the humeral head due to deltoid activity (8,12,49).

The supraspinatus is the most superior located rotator cuff muscle. It originates from in the medial two-thirds of the supraspinous fossa of the scapula. The tendon of the supraspinatus passes under the acromion process, over the glenohumeral joint, and inserts on the superior facet of the greater tubercle (11). Unlike the other three muscles of the rotator cuff that produce an inferior translatory component to counteract the pull of the deltoid, the action line of the supraspinatus produces a superior translatory moment (29).

The supraspinatus is primarily considered an abductor of the humerus that functions in all planes of elevation, although it can also contribute to small amounts of medial and lateral rotation torques depending on the position of the arm (12,29). The supraspinatus peaks in activity at approximately 30 to 60° of glenohumeral abduction due to a pattern of decreasing mechanical advantage of the muscle that accompanies an increase in the abduction angle of

the arm (29). The secondary functions of the supraspinatus include compression of the glenohumeral joint, “steering” of the humeral head, and maintenance of the stability of a dependent arm. However, it is less of a contributor to joint approximation than the other three rotator cuff muscles (29).

The posterior rotator cuff is composed of the infraspinatus and teres minor muscles. The infraspinatus originates from the infraspinous fossa below the spine of the scapula. Its tendon passes posteriorly to the glenohumeral joint to insert on the middle facet of the greater tubercle of the humerus (11). The teres minor is a cord-like muscle that originates from a flattened area of the scapula immediately adjacent to its lateral border below the infraglenoid tubercle. Its tendon inserts on the inferior facet of the greater tubercle of the humerus (11). The action line of the infraspinatus and teres minor in combination with the subscapularis result in an inferior translatory pull on the head of the humerus to counteract the superior translatory pull of the deltoid and supraspinatus (29).

The infraspinatus and teres minor are most commonly known for their roles as the primary external rotators of the GH joint (11,12). Functionally, this action is necessary as it indirectly contributes to abduction of the arm by providing the external rotation that is coupled with elevation of the arm. This coupled movement is necessary for clearance of the greater tubercle from beneath the acromion and lack of external rotation can contribute to subacromial impingement (11,29). The ability of the infraspinatus to provide external rotation to the glenohumeral joint is most effective at 0° abduction and decreases with an increasing angle of abduction due to a reduction of its moment arm (34). In comparison, the teres minor does not seem to be affected by the abduction angle of the glenohumeral joint. The muscle provides a constant external rotation torque throughout arm abduction (34).

Both the infraspinatus and teres minor also function to horizontally abduct the arm due to their location posterior to the glenohumeral joint (12). The secondary role of the posterior rotator cuff is to create glenohumeral joint compression to promote stability and function of the force closed joint (29,41). In addition to compression, the posterior rotator cuff contributes to the creation of the functionally necessary inferior translatory pull of the humeral head on the glenoid fossa during shoulder elevation. This arthrokinematic component must occur to prevent the humeral head from colliding with the acromion which creates subacromial impingement, which is associated various pathologies (29,41). Also, the teres minor has been defined as a weak adductor of the glenohumeral joint but its contradictory action against arm elevation is negligible. This is due to its small moment arm that ranges from 0.2 cm to 0.1 cm depending on the degree of internal and external rotation at the glenohumeral joint (12,34).

The anterior rotator cuff is comprised of the subscapularis muscle, which forms the largest component of the posterior wall of the axilla (11). It originates from the subscapular fossa to insert on the lesser tubercle of the humerus. Thus, the tendon crosses directly anterior to the joint capsule of the glenohumeral joint (11). Due to its large size, it has been divided into two sections that include upper and lower portions. Each part is independently innervated and activated during movement (9,12,34). The action line of the subscapularis promotes its role of inferior translation of the humeral head during elevation of the arm (29). The primary function of the subscapularis is to stabilize and rotate the shoulder joint to allow the arm to inwardly rotate. Internal rotation produced by the subscapularis peaks when the arm is at 0° abduction. The upper subscapularis appears to produce similar activation levels for internal

rotation throughout increasing ranges of glenohumeral abduction, but the literature is still unclear regarding a difference in activation of the lower portion of the subscapularis. The lower portion has been shown to produce both higher and lower activation levels at 0° compared to 90° of abduction (12). When the arm is extended, the subscapularis has been shown to play a significant role in drawing the humerus forward and downward (9).

Rotator Cuff Pathology

Although the prevalence of rotator cuff tears in the general population is not completely clear, it has been established by a combination of magnetic resonance imaging (MRI), cadaveric, and ultrasonographic studies (28,42,54). While one narrative review reported an inconsistent prevalence in the general population to be anywhere from 7 to 40%, a more clear prevalence can be established when the patient's age is taken into account (28). An MRI based study found asymptomatic partial and full-thickness rotator cuff tears to occur in 4% of individuals <40 yrs of age and in more than 50% of individuals >60 yrs of age (42). Though a consistent prevalence is not entirely clear, this appears to be a common condition that increases in frequency with age. Many individuals with a full thickness tear present as asymptomatic and demonstrate no limitations to function. However, it is important to point out that the individuals who are asymptomatic demonstrate a 50% chance of developing pain within 5 yrs (28,53). This is a significant consideration that should be factored into the management of the patient with rotator cuff pathology.

Although the supraspinatus is the most commonly torn rotator cuff muscle, injuries often extend to the infraspinatus and/or subscapularis. When this happens, the injury produces a more extensive deficit (29). Management of a rotator cuff tear can either be conservative or surgical, or it can be both. Conservative treatments that are typically performed include nonsteroidal anti-inflammatory drugs (NSAIDs), glucocorticoid injections, and physical therapy. The surgical route is usually reserved for those who fail to respond to the conservative approach (16). Surgical procedures for the rotator cuff are often a combination of acromioplasty for subacromial decompression, excision of the subacromial bursa, removal of bony spurs at the acromioclavicular level, and cuff debridement, cuff repair, or both (18). Surgeons will choose to take either an open or closed (arthroscopic) approach to perform the repair depending on the training and surgical expertise of the surgeon as well as the wishes of the patient (6).

Despite the modern advancement of surgical repair equipment and techniques, many rotator cuff repairs do not clinically heal (5,13,22,24-26,39,40,44,52). Recent literature has produced rates of retear ranging from 10% in small tears (<2 mm) to 57% in large tears (>6 cm) (5). Many factors play a role in the success or failure of repairs that include patient related factors, surgery related variables, and rehabilitation variables (15). Controversy presently exists regarding the type, volume, and intensity of rehabilitative exercises that should be used in the first 6 wks following surgery to facilitate optimal healing of the repair and prevention of adhesions (15). Prescribed rehabilitative exercises must appropriately load the repaired muscle-tendon complex to promote healing without damaging the repair (15). This study examines the available literature that addresses electromyographic measurements of the rotator cuff muscles during commonly prescribed rehabilitation exercises.

The purpose of this study is to synthesize the current EMG research in order to rank the therapeutic exercises from least to most demanding on the rotator cuff muscle-tendon complex, and to prioritize the exercises that are considered most appropriate during the first 6 wks following rotator cuff repair. It is anticipated that this information will help physical therapists, occupational therapists, athletic trainers, and other orthopedic specialists to have a better idea of what exercises are most suitable for use in the early phase of rehabilitation to protect the repair and promote optimal healing of the muscle-tendon complex. To our knowledge, no study has looked at rotator cuff EMG activation levels in this way. Hence, this study is believed to be a unique review that will contribute to the scientific body of evidence pertaining to post operation rotator cuff rehabilitation.

METHODS

A literature search was completed for available experimental studies, randomized controlled trials, systematic reviews, narrative reviews, and meta-analyses on the topic of this study. The databases utilized were PubMed (1990 to 08/2015), CINAHL (1990 to 08/2015), Pedro (1990 to 08/2015), Cochrane (1990 to 08/2015), and Sports Discus (1990 to 08/2015). The search terms included shoulder, shoulder muscle, rotator cuff, rotator cuff muscles, supraspinatus, infraspinatus, teres minor, subscapularis, electromyography (EMG), EMG activity, exercises, maximum voluntary isometric contraction (MVIC), and all combinations. Reference lists from relevant articles were also used to scan for additional articles.

Articles returned from the search were compared to identify the relevance of information and potential for inclusion. Primary inclusion criteria were studies that investigated EMG activity for the supraspinatus, infraspinatus, teres minor, or subscapularis. If EMG analyses were not performed for any of these muscles, the articles were excluded. To maximize homogeneity of studies, additional exclusion criteria were established including: (a) studies and exercises that did not normalize EMG activity to a MVIC; (b) studies that reported peak %MVIC and not mean %MVIC; (c) studies that used patients with current shoulder pathology; (d) exercises that are not practical to use as rehabilitation exercises; (e) exercises that used exercise machines with variable resistance; (f) studies that examined EMG activity without exercises; (g) exercises that created >20% MVIC on EMG recordings; and (h) studies and exercises that lacked detailed information to discern proper inclusion/exclusion criteria.

RESULTS

The search found that 13 studies met the inclusion criteria for the infraspinatus (1,8,10,14,17, 19,20,23,30,45,46,49,51), 12 for the supraspinatus (8,10,14,17,20,23,30,33,45,46,49,51), 5 for the subscapularis (17,20, 23,49,50), and 2 for the teres minor (17,31). The EMG levels have been previously described and categorized in the literature as follows: (a) low-level muscle activation at 0 to 20% MVIC; (b) moderate-level activation at 21 to 40% MVIC; (c) high-level activation at 41 to 60% MVIC; and (d) very-high level activation at greater than 60% (12). These categories were used to make meaningful comparisons between exercises. While exercise that fit into all of these categories were present, this study examined only the exercises in the low-level muscle activation category (given that they would be the most appropriate exercises to be performed during the first 6 wks of shoulder rehabilitation post rotator cuff repair) (15).

The EMG activity of the 4 rotator cuff muscles was summarized and ranked from lowest to highest activation to allow for a meaningful comparison of activities. The results are depicted in Figures 1 to 6. For exercises that were only examined in a single study the individual mean and standard deviation (when available) were reported. For exercises that were examined in more than one study, the pooled mean and its 95% confidence interval (CI) were reported.

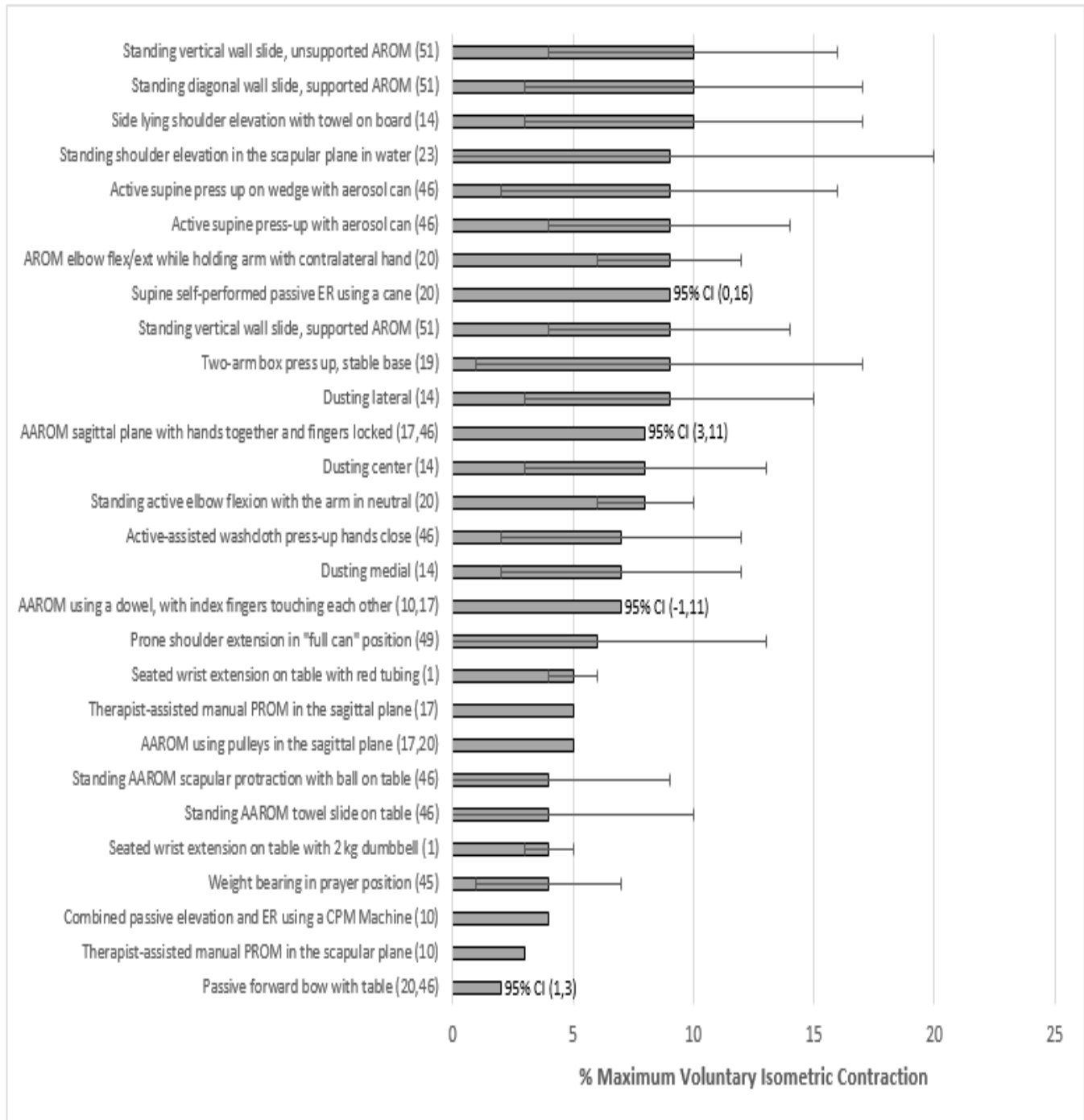


Figure 1. Infraspinatus Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (0 to 10%)

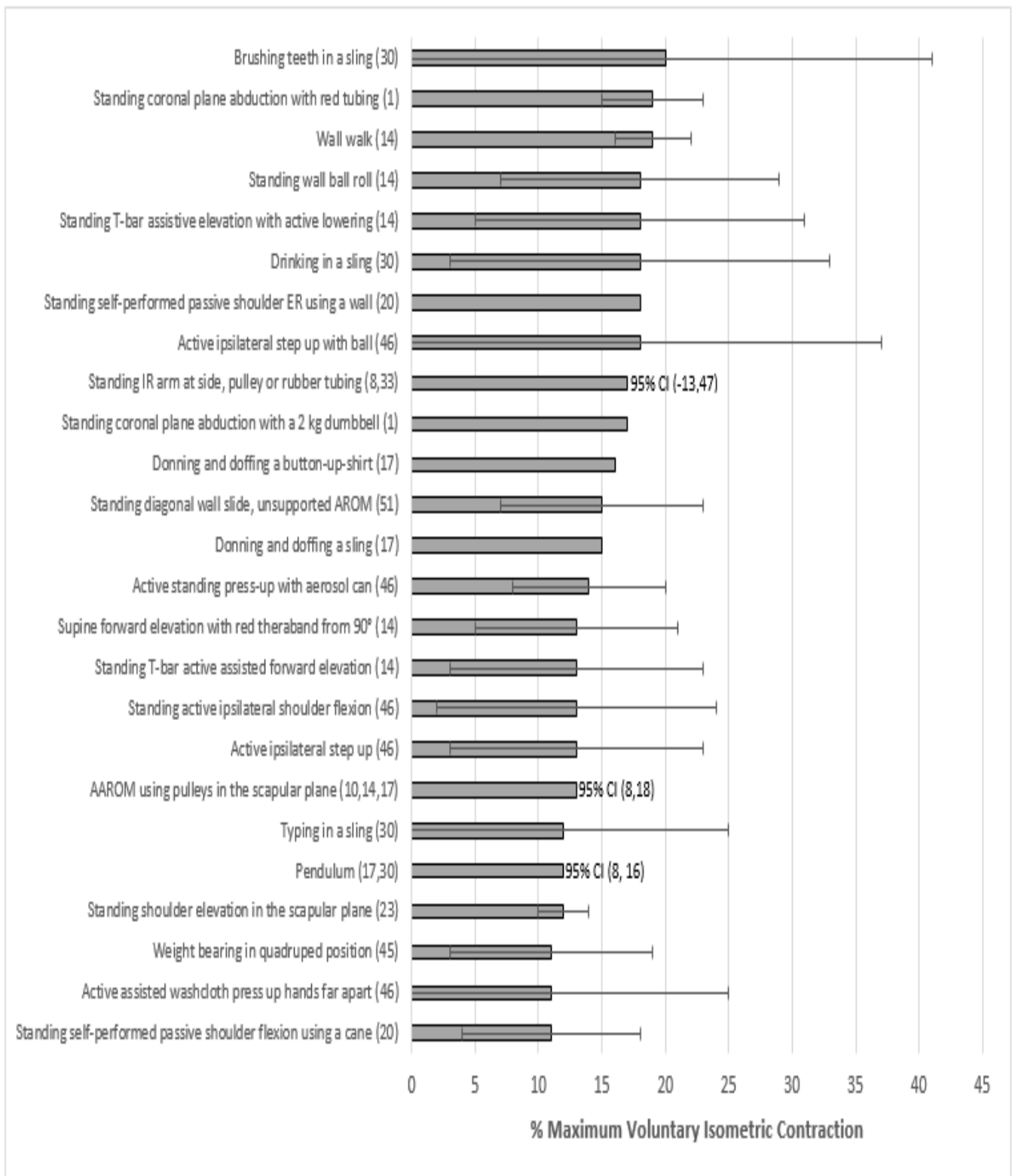


Figure 2. Infraspinatus Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (11 to 20%)

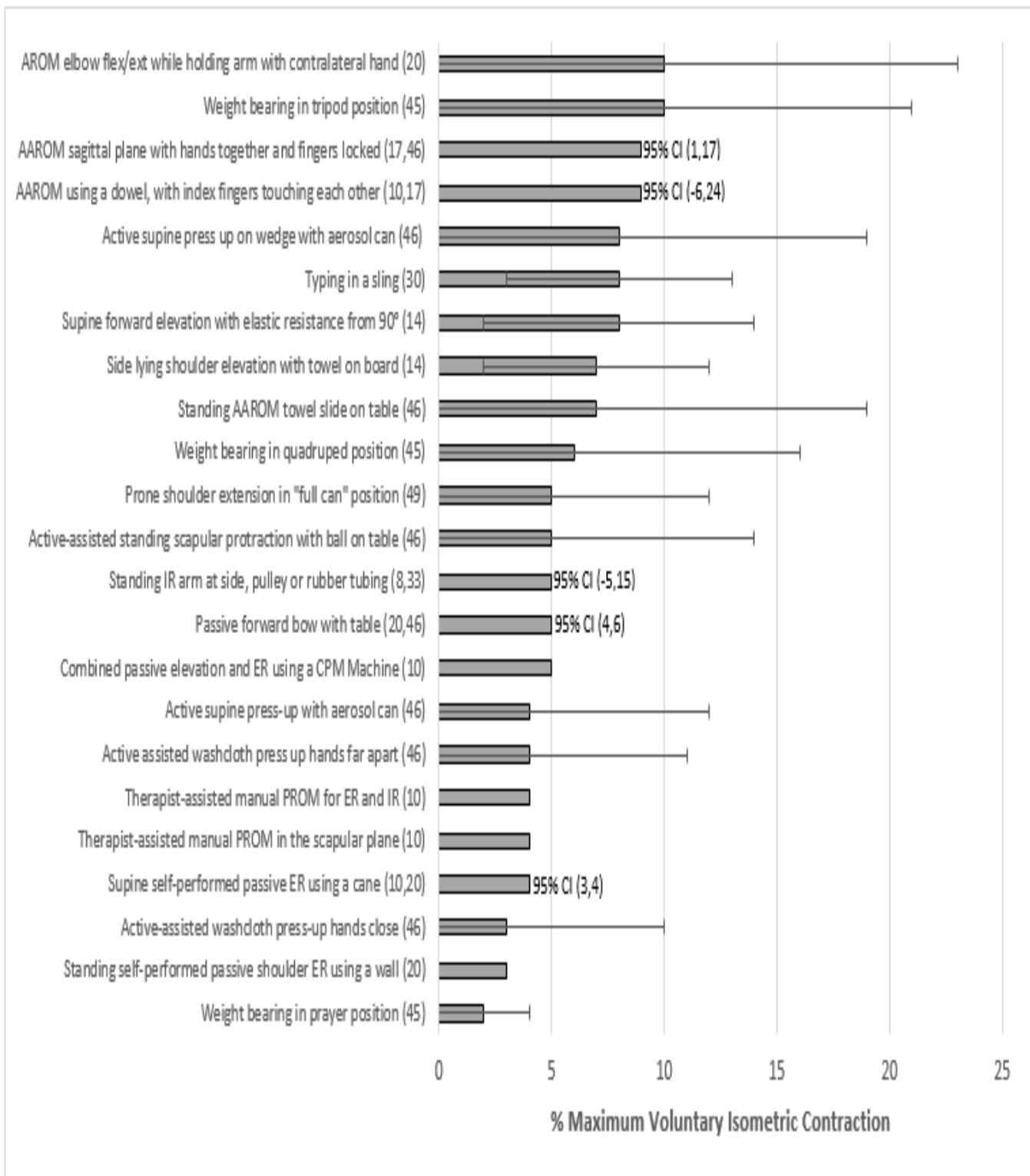


Figure 3. Supraspinatus Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (0 to 10%)

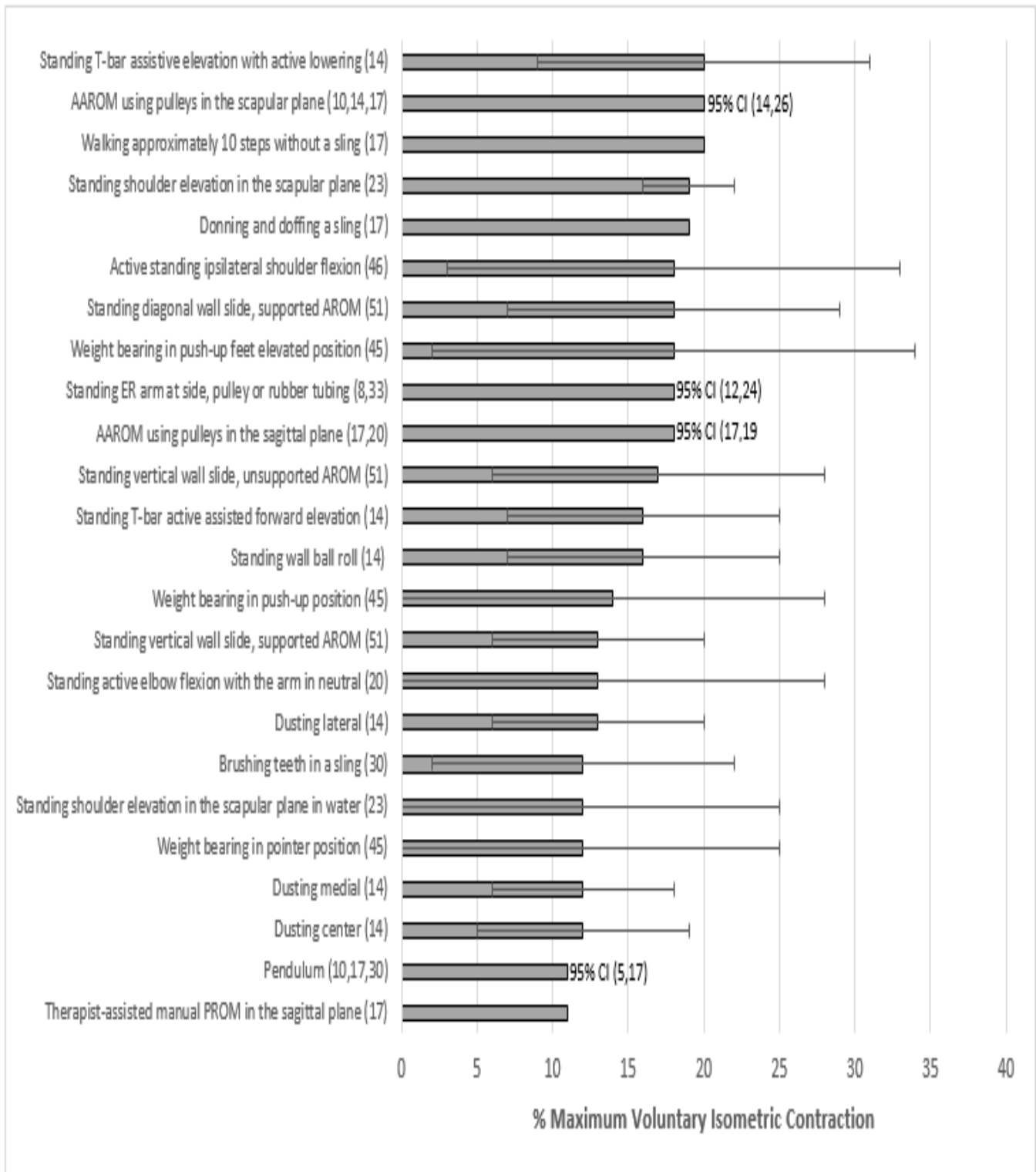


Figure 4. Supraspinatus Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (11 to 20%)

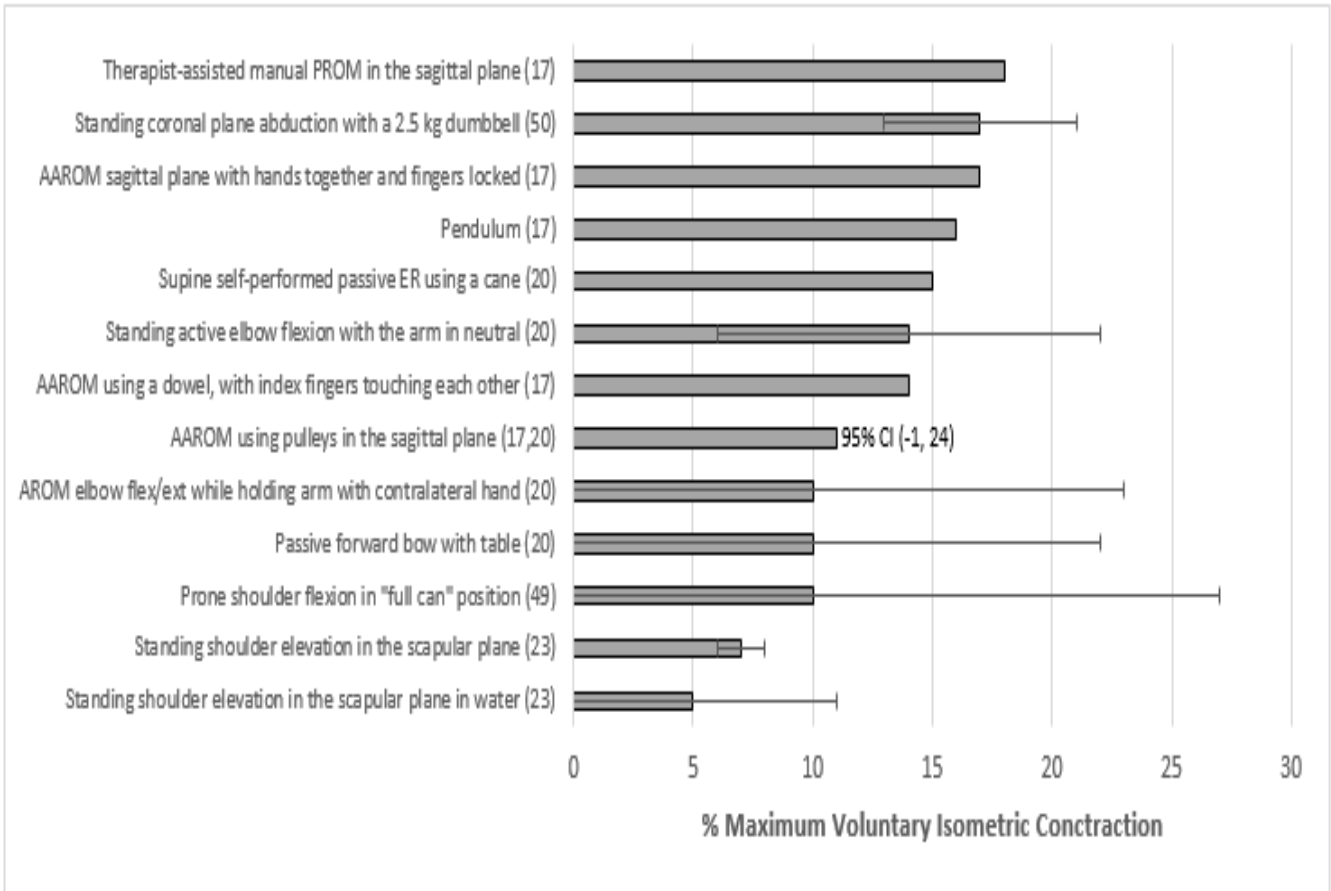


Figure 5. Subscapularis Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (0 to 10%)

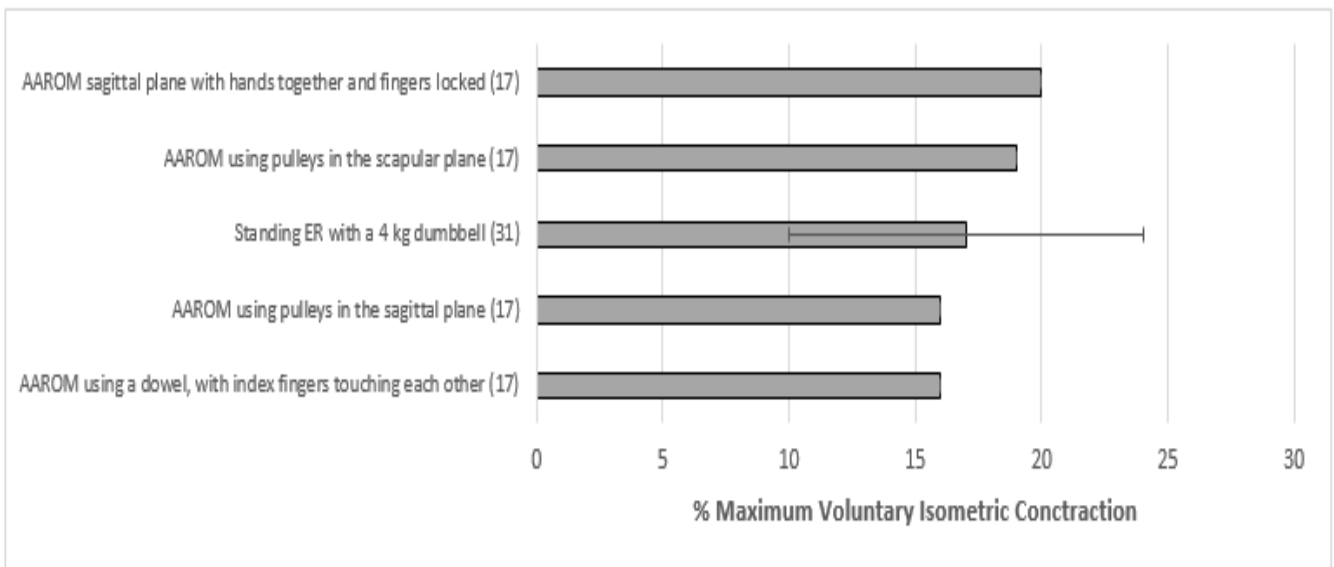









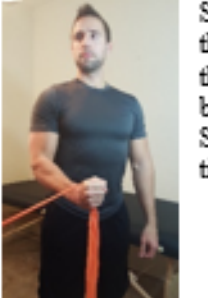















Figure 6. Teres Minor Percentage Maximum Voluntary Isometric Contraction Ranking of Exercises (0 to 10%)








Details of all the exercises that were included in this study are illustrated in Figure 7. The EMG activity and measurement reliability are included when available.







| Exercise | Description | EMG (%MVIC) (SD) | Reliability (ICC) | Reference |
|--|---|---|-------------------|--|
| Weight bearing in prayer position |  Subject kneels with weight shifted primarily over ankles, leans forward places hands on each analog scale, similar to standing weight shift. | SP 2(2) IN 4(3) | | Uhl TL et al. ⁴⁵ |
| Standing self-performed passive shoulder ER using a wall |  Subject Places affected hand on the wall with the elbow bent and gently turns body to the opposite direction until a stretch is felt. | SP 3 IN 18 | | Jung M-C et al. ²⁰ |
| Active-assisted washcloth press-up hands close |  The subject lies supine and mimics a chest press-up holding onto a WC with hands placed close together. | SP 3(7) IN 7(5) | | Uhl TL et al. ⁴⁶ |
| Supine self-performed passive ER using a cane |  While lying down on the back with a towel roll or pillow under the injured shoulder's elbow and the other hand at pocket level, the patient will push the cane/stick of the injured hand backwards over their shoulder. | SP 4(1) IN 9 SB 15 | | Dockery ML et al. ¹⁰ Jung M-C et al. ²⁰ |
| Therapist-assisted manual PROM in the scapular plane |  Therapist manually moves the patient's affected shoulder through available ROM in the scapular plane in a manner that is as pain free for the patient as possible. | SP 4 IN 3 | | Dockery ML et al. ¹⁰ |
| Therapist-assisted manual PROM for ER and IR |  Therapist manually moves the patient's affected shoulder through available ROM for IR and ER in a manner that is as pain free for the patient as possible. | SP 4 | | Dockery ML et al. ¹⁰ |






| | | | | | |
|--|---|---|--|--|--|
| Active assisted washcloth press up hands far apart |  | The subject lies supine and mimics a chest press-up holding onto a WC with hands placed farther apart. | SP 4(7) IN 11(14) | | Uhl TL et al. ⁴⁶ |
| Active supine press-up with aerosol can |  | The subject lies supine, using the affected upper extremity, an aerosol can is pushed from the subject's side up towards the ceiling with the scapular being protracted at the end of the exercise. | SP 4(8) IN 9(5) | | Uhl TL et al. ⁴⁶ |
| Combined passive elevation and ER using a CPM Machine | No Picture Available | Patient's arm is manually moved through passive shoulder elevation and ER ROM with the use of a CPM machine. | SP 5 IN 4 | | Dockery ML et al. ¹⁰ |
| Passive forward bow with table |  | Subject places hand of affected upper extremity on a table. The subject then steps backward away from the stationary hand while simultaneously bending at his or her waist, which places the subject into a forward bow position. | SP 5(1) IN 2(1) SB 10(12) | | Jung M-C et al. ²⁰ Uhl TL et al. ⁴⁶ |
| Standing IR arm at side, pulley or rubber tubing |  | Subject holds an elastic band or pulley at their side with elbow bent. Starting with the hand away from the stomach, the band is pulled towards the stomach. Subject keeps elbow near side the entire time. | SP 5(7) IN 17(22) | | Dark A et al. ³ Myers JB et al. ³³ |
| Active-assisted standing scapular protraction with ball on table |  | The subject stands astride next to a table at waist level with his or her hand on a ball at chest level. The subject slides his or her hand over the ball allowing the ball to roll away from their body at a 45° from the frontal plane. | SP 5(9) IN >20% | | Uhl TL et al. ⁴⁶ |
| Prone shoulder extension in "full can" position |  | Patient lies in the prone position with the arm hanging off the side. The entire arm is then raised backwards in the sagittal plane and then slowly lowered back to the starting position. | SP 5(7) IN 6(7) | | Wattanapra kornkul D et al. ⁴⁹ |






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| Weight bearing in quadruped position |  | Subject is positioned with hands and knees on the ground with shoulder flexed to 90°. | SP 6(10) IN 11(8) | | Uhl TL et al. ⁴⁵ |
| Standing AAROM towel slide on table |  | The subject stands astride next to a table at waist level with his or her hand on a towel. The subject slides the towel on the table top away from his or her body at a 45° from the frontal plane. | SP 7(12) IN 4(6) | | Uhl TL et al. ⁴⁶ |
| Side lying shoulder elevation with towel on board |  | Participant instructed to slide towel on board with weight of hand resting on board, effectively elevating arm overhead to approximately 140° and then lowering hand to starting position. | SP 7(5) IN 10(7) | SP .89 IN .92 | Gaunt BW et al. ¹⁴ |
| Supine forward elevation with elastic resistance from 90° |  | Exercise started with dominant shoulder flexed 90° and elbow extended. Participant actively moved arm into forward elevation of approximately 160°, thereby lengthening band. Dominant arm then lowered slowly back to starting position. | SP 8(6) IN >20% | SP .63 | Gaunt BW et al. ¹⁴ |
| Typing in a sling |  | Patient instructed to type continuously for three 4 second sets. | SP 8(5) IN 12(13) | | Long JL et al. ¹⁰ |
| Active supine press up on wedge with aerosol can |  | The subject lies supine, elevated on a 45° wedge, using the affected upper extremity, an aerosol can is pushed from the subject's side up towards the ceiling with the scapular being protracted at the end of the exercise. | SP 8(11) IN 9(7) | | Uhl TL et al. ⁴⁶ |




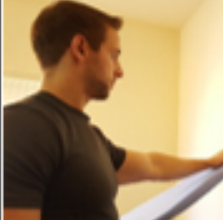
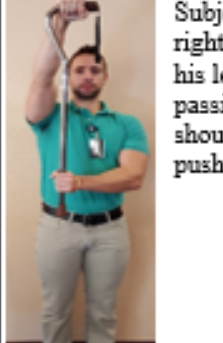

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| <p>AAROM using a dowel, with index fingers touching each other</p> |  | <p>In the standing position, patient holds a wand/cane, index fingers touching, palm down on both sides. The wand is raised up allowing the unaffected arm to perform most of the effort. The affected arm should be partially relaxed.</p> | <p>SP 9(6) IN 7(3) SB 14 TM 16</p> | <p>Dockery ML et al.¹⁰ Gurney B et al.¹⁷</p> |
| <p>AAROM sagittal plane with hands together and fingers locked</p> |  | <p>While sitting or standing patient grasps affected hand with fingers locked and slowly raises it up and forward towards overhead. The affected arm should be relaxed and the other arm performing the work.</p> | <p>SP 9(11) IN 8(6) SB 17 TM 20</p> | <p>Gurney B et al.¹⁷ Uhl TL et al.⁴⁶</p> |
| <p>Weight bearing in tripod position</p> |  | <p>Subject remains in the quadrupedal position, then flexes nondominant shoulder to 180°</p> | <p>SP 10(11) IN >20%</p> | <p>Uhl TL et al.⁴⁵</p> |
| <p>AROM elbow flex/ext while holding arm with contralateral hand</p> |  | <p>While supporting the upper arm of the affected side with the contralateral hand, the elbow is slowly flexed and extended through available ROM.</p> | <p>SP 10(13) IN 9(3) SB 10(13)</p> | <p>Jung M-C et al.²⁰</p> |
| <p>Therapist-assisted manual PROM in the sagittal plane</p> |  | <p>Therapist manually moves the patient's affected shoulder through available ROM in the scapular plane in a manner that is as pain free for the patient as possible.</p> | <p>SP 11 IN 5 SB 18 TM >20</p> | <p>Gurney B et al.¹⁷</p> |

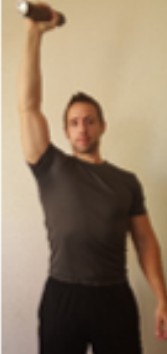
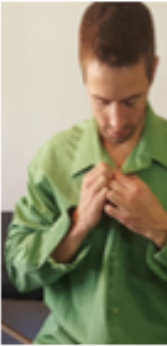
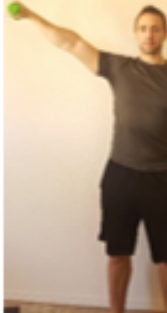

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|--|---|---|---|----------------------------|--|
| Pendulum |  | Patient shifts body weight in circles to allow injured arm to swing in circles freely. Injured arm should be fully relaxed. | SP 11(5) IN 12(3) SB 16 TM >20 | | Dockery ML et al. ¹⁰ Gurney B et al. ¹⁷ Long JL et al. ¹⁰ |
| Dusting center |  | Participant positioned sitting in front of an adjustable table with table at elbow height and elbow at midline of body. Participant placed hand on a towel and then slid towel directly forward and backward in sagittal plane until elbow was fully extended while keeping body still. | SP 12(7) IN 8(5) | SP .83 IN .91 | Gaunt BW et al. ¹⁴ |
| Dusting medial |  | Dusting exercise repeated 45° medial to first exercise. Glenohumeral joint moved through an arc of approximately 0° to 45° for each of first 3 exercises. | SP 12(6) IN 7(5) | SP .90 IN .96 | Gaunt BW et al. ¹⁴ |
| Weight bearing in pointer position |  | Subject maintains same position as tripod position and extends contralateral hip to 0°. | SP 12(13) IN >20% | | Uhl TL et al. ⁴⁵ |
| Standing shoulder elevation in the scapular plane in water |  | While in water and standing with your thumb facing up, raise your arms up towards the ceiling with your arms slightly pulled forward at about a 30 degree angle. | SP 12(13) IN 9(11) SB 5(6) | | Kelly BT et al. ²³ |
| Brushing teeth in a sling |  | Subject instructed to brush continuously for three 4 second sets. | SP 12(10) IN 20(21) | | Long JL et al. ¹⁰ |
| Dusting lateral |  | Dusting exercise repeated 45° lateral to first exercise along plane of the scapula. | SP 13(7) IN 9(6) | SP .94 IN .92 | Gaunt BW et al. ¹⁴ |

| | | | | | |
|---|---|---|---|----------------------------|-------------------------------|
| Standing active elbow flexion with the arm in neutral |  | Subject instructed to bend elbow upwards as shown and then to lower arm to a straighten position. | SP 13(15) IN 8(2) SB 14(8) | | Jung M-C et al. ²⁰ |
| Standing vertical wall slide, supported AROM |  | Subject stands near wall with one foot in front of the other. The affected hand is placed on a sphygmomanometer and then slid up the wall as weight is shifted forward onto the front foot. | SP 13(7) IN 9(5) | | Wise MB et al. ⁵¹ |
| Weight bearing in push-up position |  | Subject maintains push-up position with elbows in full extension and shoulder flexed to approximately 90°. | SP 14(14) IN >20% | | Uhl TL et al. ⁴⁵ |
| Standing wall ball roll |  | Participant stood 1 arm length from wall with a small ball against wall at shoulder height. Participant asked to roll ball up and down wall 1-hand length (approximately a 20° arc) while keeping elbow extended. | SP 16(9) IN 18(11) | SP .96 IN .96 | Gaunt BW et al. ¹⁴ |
| Standing T-bar active assisted forward elevation |  | In standing, participant instructed to primarily use nondominant arm to raise and lower dominant arm into elevation. Dominant arm grasped 1-in. PVC bar with thumb pointing up and moved through an approximately 160° arc. | SP 16(9) IN 13(10) | SP .69 IN .72 | Gaunt BW et al. ¹⁴ |
| Standing vertical wall slide unsupported AROM |  | Subject stands near wall with one foot in front of the other. The affected hand is placed 1 inch away from the wall and then slid up the wall as weight is shifted forward onto the front foot. | SP 17(11) IN 10 (6) | | Wise MB et al. ⁵¹ |

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| AAROM using pulleys in the sagittal plane |  | Using door pulleys and facing away from the door, patient slowly pulls down with the unaffected arm so that the affected arm raises forward and up without effort. The affected arm should be relaxed. The unaffected arm does the work. | SP 18(1) IN 5(4) SB 11(9) TM 16 | | Gurney B et al. ¹⁷ Jung M-C et al. ²⁰ |
| Standing ER arm at side, pulley or rubber tubing |  | Subject holds an elastic band at their side with elbow bent. Starting with the hand near the stomach the band is pulled away. The elbow is kept at the side the entire time. | SP 18(4) IN >20% | | Dark A et al. ⁸ Myers JB et al. ³³ |
| Weight bearing in push-up feet elevated position |  | Subject maintains push-up position with feet elevated 45 cm, elbows in full extension and the shoulder flexed to 90° | SP 18(16) IN >20% | | Uhl TL et al. ⁴⁵ |
| Standing diagonal wall slide, supported AROM |  | Subject stands in front of a slide board angled at 45° with one foot in front of the other. The affected hand is placed on a sphygmomanometer and then slid up the slide board as the weight is shifted forward onto the front foot. | SP 18(11) IN 10(7) | | Wise MB et al. ⁵¹ |
| Active standing ipsilateral shoulder flexion |  | The subject stands astride with the ips foot of the affected arm in front. The subject shifts his or her weight forward and elevates both arms overhead. The motion should be rhythmic with the lower extremity preceding the upper extremity. | SP 18(15) IN >20% | | Uhl TL et al. ⁴⁶ |

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| Donning and doffing a sling |  | Patient independently puts sling on and indecently takes sling off after education by therapist. | SP 19 IN 15 SB >20 TM >20 | | Gurney B et al. ¹⁷ |
| Standing shoulder elevation in the scapular plane |  | Subject stands with the thumb facing up and raises the arm up towards the ceiling with the arm slightly pulled forward at about a 30 degree angle. | SP 19(3) IN 12(2) SB 7(1) | | Kelly BT et al. ²³ |
| Walking approximately 10 steps without a sling |  | Patient is instructed to walk normally for 10 seconds without any additional support for the affected shoulder. | SP 20 IN >20% SB >20 TM >20 | | Gurney B et al. ¹⁷ |
| AAROM using pulleys in the scapular plane |  | Using door pulleys and facing away from the door, patient slowly pulls down with the unaffected arm so that the affected arm raises forward and up at a 30° angle without effort. The affected arm should be relaxed. The unaffected arm does the work | SP 20(5) IN 13(4) SB >20 TM 19 | SP .89 IN .98 | Dockery ML et al. ¹⁰ Gaunt BW et al. ¹⁴ Gurney B et al. ¹⁷ |
| Standing T-bar assistive elevation with active lowering |  | Exercise performed exactly as standing T-bar active-assistive forward elevation except upon lowering dominant arm, participant released bar and under volitional control, actively eccentrically lowered dominant arm to starting position keeping elbow extended. | SP 20(11) IN 18(13) | SP .96 IN .98 | Gaunt BW et al. ¹⁴ |

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|---|---|--|------------------------------------|--|-----------------------------------|
| Seated wrist extension on table with 2 kg dumbbell |  | Participants rested their forearm on a table while holding the in the same hand using a pronated grip. The starting position was from a flexed wrist. The participants then performed a wrist extension through a full range of motion. | IN 4(1) SP Not tested | | Andersen LL et al. ¹ |
| Seated wrist extension on table with red tubing |  | Participants rested their forearm on a table while holding the tubing handle in the same hand using a pronated grip. The elastic tubing was prestretched to twice its resting length. The starting position was from a flexed wrist. The participants then performed a wrist extension through a full range of motion. | IN 5(1) SP Not tested | | Andersen LL et al. ¹ |
| Two-arm box press up, stable base |  | Participants positioned with knee, hip and shoulder flexion at 90°, spine neutral, knees hip width apart and head position maintained. Hands positioned directly beneath and position is held | IN 9(8) SP Not tested | | Herrington L et al. ¹⁰ |
| Standing vertical wall slide, unsupported AROM |  | Subject stands in front of a slide board angled at 45° with one foot in front of the other. The affected hand is placed on board and then slid up the slide board as the weight is shifted forward onto the front foot. | IN 15(8) SP >20 | | Wise MB et al. ⁵¹ |
| Standing self-performed passive shoulder flexion using a cane |  | Subject gripped the head of a cane with his right hand and the bottom of the cane with his left hand in a standing position and then passively elevated the right arm until the shoulder angle reached at least 170° by pushing the cane upward with the left arm. | IN 11(7) SP >20 | | Jung M-C et al. ²⁰ |
| Active ipsilateral step up |  | The subject stands astride with the ips foot of the affected arm on a standard inch step and the other on the floor. The subject shifts his or her weight forward and rises up onto step as both arms are elevated overhead. | IN 13(10) SP >20 | | Uhl TL et al. ⁴⁶ |

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| Active standing press-up with aerosol can |  | The subject is standing, using the affected upper extremity, an aerosol can is pushed overhead toward the ceiling from a bent elbow resting position, with the scapular being protracted at the end of the exercise. | IN 14(6) SP >20 | | Uhl TL et al. ⁴⁶ |
| Donning and doffing a button-up-shirt |  | Patient puts on and takes off a button up shirt using both upper extremities. | IN 16 SP >20 SB >20 TM >20 | | Gurney B et al. ¹⁷ |
| Standing coronal plane abduction with a 2 kg dumbbell |  | Participants stood erect holding the dumbbells to the side and abducted the shoulder joints until the upper arms were slightly above horizontal then lowered back down slowly. | IN 17(0) SP Not tested | | Andersen LL et al. ¹ |
| Active ipsilateral step up with ball |  | The subject stands astride with the ips foot of the affected arm on a standard inch step and the other on the floor, while a light plastic ball is held in both hands. The subject shifts his or her weight forward and rises up onto step as both arms are elevated overhead. The unaffected upper extremity assists the affected upper extremity through the use of the ball during this exercise. | IN 18(9) SP >20 | | Uhl TL et al. ⁴⁶ |






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| Drinking in a sling |  | While in a sling, subject was given a 0.5 l bottle of water and asked to take 2 sips of water and place the bottle back on the table between sips. | IN 18(15) SP >20 | | Long JL et al. ²⁰ |
| Wall walk |  | Participant stood 20 cm to 40 cm from wall with dominant hand resting at shoulder level on wall. Participant instructed to walk hand up and down wall using index and middle fingers into forward elevation within an arc of approximately 30° to 160°. Performed taking 4 beats to walk up and down at a rate of 40 beats per minute | IN 19(3) SP >20 | IN .98 | Gaunt BW et al. ¹⁴ |
| Standing coronal plane abduction with red tubing |  | Participants stood erect holding the tubing to the side and abducted the shoulder joints until the upper arms were slightly above horizontal. During this exercise, the elastic tubing was stretched to slightly more than twice its resting length | IN 19(4) SP Not tested | | Andersen LL et al. ¹ |
| Standing ER with a 4 kg dumbbell |  | With the shoulder abducted and elbow flexed to 90°, the exercise began with the subject's shoulder in full internal rotation. The exercise consisted of moving the shoulder into full external rotation with a 4 kg dumbbell and then returning to the starting position while maintaining the shoulder-abduction and elbow-flexion positions. | TM 17(7) IN >20 | | Marta S et al. ⁴⁵ |
| Prone shoulder flexion in "full can" position |  | Patient lies in the prone position with the arm hanging off the side. The entire arm is then raised forwards in the sagittal plane and then slowly lowered back to the starting position. | SB 10(17) SP >20 IN >20 | | Wattanapornkul D et al. ⁴² |

Figure 7. Detail Pictures and Descriptions of all of the Exercises that were Included in this Study. The EMG Activity and Measurement Reliability were Included When Available.

DISCUSSION

The primary goal of post-surgical rehabilitation for rotator cuff tears is to allow for healing of the repaired rotator cuff tendon while minimizing stiffness and muscle atrophy (15,47). The standard of care for the rehabilitation protocols is divided into a series of progressive phases that begins with maximum protection and progresses to minimum protection. Each phase dictates a specific level of rotator cuff loading that attempts to match the patient's stage of healing. Electromyographic studies that examine the rotator cuff during specific activities have been an integral part of establishing these protocols (15,47). The earlier phases used therapeutic activities that resulted in minimal EMG activity to avoid stress to the repair, which helped to ensure tendon integrity and reduced the risk for gapping. Strengthening exercises, classified as exercises that produce >40% EMG activity, are withheld until later phases when repair integrity is ensured (12). The following sections provide an explanation for muscle activation levels $\leq 20\%$, as delineated in Figures 1 to 6 for the supraspinatus, infraspinatus, teres minor, and subscapularis.

Our review identified 47 low-level exercises for supraspinatus activation, 53 low-level exercises for the infraspinatus, 13 low-level exercises for the subscapularis, and 5 low-level exercises for the teres minor. These findings far exceed the typical exercise quantity generally described in rotator cuff repair protocols for the maximum phase of protection, which is usually <10 (27,32,43). With adequate clinical reasoning and consideration, these exercises may have clinical implications in the maximum protection phase of rotator cuff rehabilitation.

Many of the passive range of motion (PROM) exercises were determined to be low-level activation. This finding is consistent with the maximum protection phase for rehabilitation protocols (27,32,43,47). The data from the present review does not simply identify but rather delineates the degree to which these passive exercises activate the rotator cuff muscles. Data returned for the pendulum (a very commonly prescribed post-operative rotator cuff repair exercise) was ranked 25th (11% MVIC) out of 47 for supraspinatus activation. This finding makes it the highest activation level relative to all other passive interventions for this muscle group. Activity levels for the infraspinatus and subscapularis were also >10% when performing the pendulum. The reason for this finding may stem from the difficulty of the patient attaining true passive movement through "arm swinging" during the pendulum. It is common for patients attempting the pendulum to actively move the shoulder (that results in unwanted rotator cuff activity) instead of allowing for the shoulder to be moved via the trunk (30). Considering how frequently and early this exercise is prescribed in rehabilitation programs, it is imperative that the patient is properly educated when prescribing the exercise for a rotator cuff repair. Otherwise, the patient may not achieve a proper therapeutic effect.

Passive shoulder external rotation using a wall was determined to activate the supraspinatus the least compared to supine passive external rotation with a cane and passive external rotation performed by a physical therapist. However, the difference between activity levels was small and all three produced activity levels lower than the pendulum. Although supraspinatus activity was low for the three passive supine external rotation exercises, they generated higher activity levels in the infraspinatus and, particularly, in the subscapularis. This finding suggests that careful consideration must be taken into account if either of these

muscles is involved in the repair. It is also important for the clinician to understand that passive external rotation of the glenohumeral joint produces a passive tension in the supraspinatus tendon that does not contribute to the recorded EMG activity. Cadaver studies examining the rotator cuff determined external rotation increased supraspinatus tension in the anterior tendon region and relaxed the posterior region, thus contributing to increased gap formation anteriorly (35,36). Tension peaked at 30° of passive external rotation so it may be sensible for clinicians to keep the amount of passive external rotation they perform below this threshold during the maximum protection phase to avoid threatening the integrity of the supraspinatus tendon repair (35,36).

Regarding therapist assisted manual PROM in the scapular and sagittal planes, supraspinatus and infraspinatus activation was found to be lower when the therapist moved the shoulder in the scapular plane. Movement in the scapular plane may feel more comfortable for the patient and result in reduced muscle guarding, which can commonly occur when the shoulder is moved through the sagittal plane. This activity also produced subscapularis activity levels close to 20%. Continuous passive motion (CPM) was examined in one study and found to generate very little activity in the supraspinatus and infraspinatus when it was used for combined elevation with external rotation (9). Passive forward bowing resulted in activity levels $\leq 10\%$ for the supraspinatus, infraspinatus, and subscapularis. To achieve the lowest activation possible with this movement, it was crucial for the resultant movement produced at the shoulder to be created by using the trunk and not by actively moving the UE. Similar exercises that involved the patient actively performing a towel slide on a table resulted in increased supraspinatus and infraspinatus activity.

Weight bearing through the repaired upper extremity (UE) is generally contraindicated in the maximum protection phase of commonly prescribed rotator cuff repair rehabilitation protocols (27,32,43). Our study reviewed 6 weight bearing positions for the UE; all of which produced EMG activity of $\leq 20\%$ for the supraspinatus and 3 of the 6 produced EMG activity of $\leq 10\%$. This indicates that these may be safe for early implementation due to the potential benefit of performing structured weight bearing activities in the maximum protection phase. The weight bearing in prayer position produced the lowest (i.e., 2% MVIC) supraspinatus activity all exercises. However, these positions tended to result in elevated activity of the infraspinatus and reached levels $>20\%$ in the pointer and tripod position. The weight bearing exercises made use of scales in a manner similar to that used for weight bearing activities of the lower extremity (LE) for those with post-surgical weight bearing precautions. This use of scales can allow the clinician to better control the amount of force going through the patient's affected UE.

While active-assisted range of motion (AAROM) exercises are generally withheld until the moderate phase of protection after week 6, EMG activities for a variety of different AAROM shoulder exercises were analyzed in this study and produced rotator cuff activity levels $\leq 20\%$. The AAROM exercises attempt to aid the affected UE through its available ROM. Our review analyzed exercises that were performed with the aid of cane or dowel, a t-bar, pulleys, a towel, a slide board, an exercise ball, or the non-affected UE. All of these exercises promoted assistive elevation of the UE, but the range of rotator cuff activity observed across modalities was varied. When the patient performed AAROM in sidelying with a board or performed sagittal flexion with a dowel or non-affected hand, the supraspinatus and infraspinatus activity was closer to 10%, which is similar to the pendulum activation levels. Activation levels in the

subscapularis and teres minor were $\leq 20\%$ but higher than both the supraspinatus and infraspinatus. When pulleys or a t-bar was used to assist in elevation of the upper extremity, the activity of the supraspinatus, subscapularis, and teres minor was closer to 20% while the infraspinatus activity remained closer to 10%. The pulleys and t-bar assisted exercises might make it more difficult for the patient to achieve true relaxation of the assisted upper extremity, thus resulting in the higher activation levels. Due to this finding of increased activity, the exercises closer to 20% MVIC may not be appropriate for use in the maximum protection phase for patients with repairs involving rotator cuff musculature other than the infraspinatus.

Active range of motion and resistive exercises are contraindicated in the maximum protection phase. Our review returned few exercises that measured at $\leq 20\%$ MVIC, but there were some exceptions worth noting. One study examined variations on chest press ups in the supine position using a wash cloth or an aerosol can with various hand and body positions (46). These exercises produced activities in the supraspinatus that ranged from 3 to 8% MVIC and 7 to 11% MVIC for the infraspinatus. The washcloth exercises produced lower activity levels than the aerosol can for the supraspinatus and vice versa for the infraspinatus. The activity produced in the supraspinatus and infraspinatus for these activities was similar to the activity of the passive interventions described earlier and may occur due to the supine position of the patient. In this position, the effect of gravity on the glenohumeral joint is reduced and the shoulder range of motion is reduced. Although the data for the low intensity press ups was limited to one study, these exercises may prove useful in the maximum protection phase as an adjunct to the more passive interventions and help patients feel more involved with their treatment. Other active range of motion (AROM) activities such as standing flexion in the scapular or sagittal plane with or without the support of a wall or slide board produced activity in the supraspinatus closer to 20%, although they produced values in the infraspinatus closer to 10%. Multiple overhead movements, one with an aerosol can and one with no weight produced infraspinatus activation levels $< 20\%$ while the supraspinatus levels were $> 20\%$. If the supraspinatus is involved in the repair, these movements should be avoided in the maximum protection phase.

Exercises that targeted joints other than the glenohumeral joint were limited in this study, particularly in regards to the supraspinatus muscle activity. Standing elbow flexion produced a low level of activation of the supraspinatus, infraspinatus, and subscapularis even though the activity was higher than all passive interventions mentioned previously. However, one study (20) demonstrated that it was possible to decrease supraspinatus and subscapularis activity during elbow flexion if the upper portion of the arm was supported by the contralateral hand. Wrist extension produced low levels of activation for the infraspinatus that were $\leq 5\%$ with both a dumbbell and elastic band, but the supraspinatus activity was not measured during these activities. No scapular exercises were found that met the criteria for inclusion in this study, though they are commonly used in the maximum protection phase of rotator cuff repair rehabilitation protocols (27,32,43).

The EMG activity levels during common activities of daily living were also examined in this study. Although these activities would not be prescribed to the patient following surgery, it is likely that the activities will occur during a patient's episode of care. Hence, it would benefit the clinician to understand the degree to which these activities influence the rotator cuff. Some ADLs were examined with the patient wearing a sling while others were performed without a sling. Most activities carried out with a sling resulted in relatively low activity of the

rotator cuff compared to activities performed without a sling. One exception to this was drinking a bottle of water while wearing a sling, which resulted in 19% activity for the infraspinatus and >20% activity for the supraspinatus. Walking without a sling and donning and doffing a button up shirt without a sling produced similarly elevated activity at $\geq 20\%$ for the supraspinatus. Typing and teeth brushing activity while wearing a sling were also examined for the supraspinatus and infraspinatus. While supraspinatus activity remained close to 10% for both activities, infraspinatus activity ranged from 12% to 20% (20). Although rehabilitation exercises are performed at a low frequency, ADLs such as walking can occur at high frequency and pose a significant threat to rotator cuff repair integrity. Sling compliance and education should become a critical component of patient care. If patients are adequately informed of the proper use of the sling to reduce unnecessary stress to the repair, optimal tendon repair healing during the maximum protection phase can be ensured.

CONCLUSIONS

The purpose of this review was, first, to analyze the current EMG research on the rotator cuff muscles and, second, to rank the therapeutic exercises from least to most demanding on muscle-tendon complex so clinicians may better determine the most appropriate therapeutic interventions for their patients during the first 6 wks following a rotator cuff repair. Our findings indicate that there are many therapeutic interventions not commonly prescribed in rehabilitation protocols that may prove beneficial during the maximum protection phase after repair. The EMG activity of the involved muscles ranged from 2 to 20%, which placed them all in the low-level activation category as has been described to be clinically meaningful in the literature.

Our findings clarified the pendulum, which is a commonly prescribed maximum protection exercise, by indicating that it produced a highly variable rotator cuff activity that exceeds many other passive interventions. Also, our findings examined the dangers posed by sling non-compliance and activities of daily living (ADLs) on repair integrity. Most importantly, by following a gradual progression based on EMG activity, therapeutic exercises can be advanced in a systematic fashion that takes into account the plane of the movement, speed of the movement, the position of the extremity, the level of assistance, and the type of resistance used. If the clinician can correctly use a gradual progression of therapeutic activities based on clinical expertise combined with the knowledge of rotator cuff EMG activity, rotator cuff repairs will be better protected during the inflammation and proliferative phase when repaired tissue remains immature and vulnerable to re-tear.

This study included only individuals without rotator cuff pathology that may decrease the generalizability to a patient population that has rotator cuff pathology. Future studies may also benefit from investigating the pathological population as well as examining therapeutic exercises and activities that elicit >20% EMG activity to help aid clinicians in the successful rehabilitation of their post-operative rotator cuff repair patients.

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