Activation of the Shoulder Musculature During Pendulum Exercises and Light Activities

There are a variety of rehabilitation protocols following rotator cuff repair. Many surgeons allow patients to begin gentle passive motion within a day of surgery, but active motion is generally restricted to prevent retear of the rotator cuff. Nevertheless, Galatz et al. reported retearing of the rotator cuff after surgical repair in over 75% of patients with large tears. While not all patients with failure of their repair experience functional deficits equivalent to their preoperative status, it is imperative to optimize postoperative care, including rehabilitation, to limit recurrence.

There are numerous rehabilitation protocols following rotator cuff repair. One of the most commonly used exercises after rotator cuff repair is the pendulum, which is also referred to as Codman’s exercise. To perform this exercise, a patient leans forward at the waist and allows the arm to swing like a pendulum, moving in circles generated by trunk motion. Burkhart et al. observed, however, that patients sometimes mistakenly make this an active exercise, performing it incorrectly by using their shoulder muscles to swing the arm rather than simply allowing it to hang in a relaxed state. This type of muscle activity would not be recommended immediately after rotator cuff repair.

Patients are usually interested in returning to activities of daily living (ADLs) as soon as possible after surgery. Although patients are asked to limit active use of the operative extremity immediately after surgery, they may still perform light activities, believing that their shoulder muscles are protected in the sling. Light ADLs that are thought to be harmless by the patient and that may not be addressed in the postoperative instructions by the surgeon may activate the shoulder muscles and increase the tension on the repair. Little is known about muscle activation in the rotator cuff muscles when simple ADLs, such as typing, brushing teeth, and drinking water from a bottle, are performed.

The purpose of this study was to measure the EMG signal amplitude of

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**Study Design:** Prospective, single-group, repeated-measures design.

**Objectives:** To evaluate electromyographic (EMG) signal amplitude in the supraspinatus, infraspinatus, and deltoid muscles during pendulum exercises and light activities in a group of healthy subjects.

**Background:** There are numerous rehabilitation protocols used after rotator cuff repair. One of the most commonly used exercises in these protocols is the pendulum. Patients can easily perform these exercises incorrectly, and may also perform light activities of daily living without knowing that they may be putting excessive stress on the repair. The effect of improperly performed pendulum exercises and light activities after rotator cuff repair is unknown.

**Methods:** Muscle activity was recorded in 13 subjects performing pendulum exercises incorrectly and correctly in both large (51-cm) and small (20-cm) diameters, and while typing, drinking, and brushing their teeth.

**Results:** Incorrect and correct large pendulums and drinking elicited more than 15% maximum voluntary isometric contraction in the supraspinatus and infraspinatus. The supraspinatus EMG signal amplitude was greater during large, incorrectly performed pendulums than during those performed correctly. Both correct and incorrect large pendulums resulted in statistically higher muscle activity in the supraspinatus than the small pendulums.


**Keywords:** EMG, infraspinatus, rotator cuff, supraspinatus

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the supraspinatus, infraspinatus, and deltoid muscles in a group of healthy subjects who performed pendulums correctly (using trunk motion to cause the arm to move) versus incorrectly (using shoulder musculature to cause the arm to move), and 3 ADLs that included typing, brushing teeth, and drinking from a water bottle. We hypothesized that performing pendulum exercises incorrectly would elicit more muscle activity than performing pendulum exercises correctly, and that pendulum exercises and select light activities would not elicit more than 15% of the maximum voluntary isometric contraction (MVIC) in the shoulder muscles.

**METHODS**

Approval was obtained from the University of Michigan Institutional Review Board prior to beginning the study, and all subjects signed an informed consent document and were compensated. The subjects’ rights were protected during the course of the study. We recruited healthy, right-hand–dominant individuals aged 18 years or older. Exclusion criteria included any history of shoulder pain, injury, or surgery, use of an assistive device for ambulation, and inability to tolerate the study protocol. The right shoulder was tested in all trials. Seventeen subjects were recruited to participate in this study. Two subjects were unable to complete the study due to vasovagal episodes, and 2 others were excluded due to technical problems obtaining EMG data. Of the 13 subjects in our final analysis, 7 were males and 6 females, with an average age of 29 years (range, 20–57 years).

A physician sterilized and inserted 1 set of 50-mm, disposable, paired-wire electrodes (VIASYS Healthcare Inc, Madison, WI) through a 25-gauge needle, for EMG monitoring of the supraspinatus and infraspinatus muscles. Each paired-wire electrode consisted of 2 strands of insulated nickel alloy wire. The wires were arranged so that 2 mm and 5 mm of the first and second wire exited the needle, respectively. The last 2 mm of insulation was stripped from each wire. The wires for the supraspinatus were placed approximately 2 cm superior to the midpoint of the scapular spine, and the wires for the infraspinatus were placed approximately 2 cm inferior to the midpoint of the scapular spine. Bipolar, pediatric-sized Ambu Blue Sensor Ag-AgCl electrodes (Ambu Inc, Glen Burnie, MD) were used for the surface recordings of the middle deltoid muscle. These oval-shaped electrodes were placed approximately 3 cm distal to the lateral aspect of the acromion, with an interelectrode distance of 2.2 cm. The technique for placement of the wire and surface electrodes was consistent with that described by Basmajian and De Luca. The locations of the electrodes are shown in Figures 1 and 2. Proper placement of the electrodes was verified by noting an appropriate electromechanical delay and resisted action of the muscle. One of the surface electrodes was also placed on the right olecranon as a ground.

Data were recorded at 1000 Hz on a Noraxon Myosystem 2000 EMG system (Noraxon, Inc, Scottsdale, AZ), collected on a computer using MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL), and stored for offline data analysis. The system uses differential amplifiers with a gain of 1000. There was an input impedance of 10 MΩ, a signal-to-noise ratio of less than 1 mV root-mean-square (RMS), and a common-mode rejection ratio of 135 dB. The data-processing approach was designed to represent the contraction dynamics of muscle, based on published EMG-driven muscle force prediction models. Signal processing began with full-wave rectification, followed by a 2-pass, fourth-order, low-pass Butterworth filter with a cutoff frequency of 3 Hz to obtain a signal for the ith muscle, $e_i(t)$. Then a recursive filter was applied: $u_i(t) = \alpha u_i(t-d) - \beta_u u_i(t-d) - \beta_2 u_i(t-2)$, where $u_i(t)$ was the processed signal at time $t$, $\alpha$ was a gain for the muscle ($\alpha = .02$), $d$ was electromechanical delay ($d = 40$ ms), and $\beta_u$ and $\beta_2$ were coefficients for the recursive filter ($\beta_2 = -.146$ and $\beta_2 = .48$). Muscle activation was then estimated from $u_i(t)$, assuming a linear relationship. The end product of this processing was an estimate of muscle activation.

One dependent measurement was computed for each muscle for each trial: maximum normalized muscle activation. Normalization was done by dividing the activation of a muscle by its maximum muscle activation, computed from EMG data recorded during MVIC trials. The subject was asked to perform maximal isometric external rotation and abduction movement to elicit MVIC for each muscle.

**FIGURE 1.** Location of wire electrodes for electromyographic data collection of the supraspinatus and the infraspinatus muscles.

**FIGURE 2.** Location of surface electrodes for electromyographic data collection of the deltoid muscle.
muscle. The isometric actions were performed by having the patient pull on a secured rope while standing. For abduction, the elbow was in extension, for external rotation, the elbow was in 90° of flexion and held against the torso (by the patient, not by a restrictive device). No sling was used. A rest EMG measurement was also obtained, with the patient sitting quietly at rest for at least 4 seconds. The average baseline muscle activation level at rest was determined and subtracted from all other values. The peak muscle activation was determined for each trial so that the peak percent MVIC could be calculated for each activity. The peak percent MVIC over the entire trial for each muscle during each activity was recorded for the individual subjects. The mean for all of the subjects was then obtained from these peak values, and the standard deviations were calculated. These methods are consistent with prior studies.  

The subject was then placed in a standard sling and asked to complete the 3 ADLs in a previously determined randomized order. Typing was performed using a standard keyboard, and the height of the chair was adjusted for individual comfort. Subjects were asked to type continuously, while three 4-second data sets were recorded. Similarly, each subject was given a toothbrush and asked to brush their teeth continuously while three 4-second data sets were recorded. For the drinking task, each subject was given an identical 0.5-L bottle of water. The subject was asked to take 2 sips of water, placing the bottle back on the table between sips. EMG activity was recorded for 3 trials of 2 sips each. No time limit was used. The subjects were not timed for this activity, as the intention was to allow the subjects to perform the task as they would normally.

Subjects were then instructed, using a combination of verbal explanation and demonstration by a physician, in how to perform pendulum exercises. In this study, correct pendulum exercises were the swinging or stooping exercises that originally described for the early postoperative period, which were meant to be a passive exercise for the shoulder. Alternatively, incorrect pendulum exercises were similar swinging exercises performed using active motion of the shoulder muscles. The subjects were given as much time as they felt necessary to practice the pendulum exercise before the actual trials commenced. The subject performed the 4 types of pendulum exercises (large incorrect, large correct, small incorrect, and small correct) in a previously determined, randomized order. The pendulum exercises were standardized by using a diagram of 10-cm-wide concentric circles, the largest of which was 51 cm and the smallest 20 cm in diameter, placed on the floor (Figure 3). The subject performed the pendulum exercise in either the incorrect or correct method for each size. Three revolutions of each pendulum were completed without any time limit. The diameter of the circle of the pendulum was assured by taping a laser pointer to the dorsal surface of the subject’s wrist and asking the subject to keep the laser essentially within a 10-cm-wide concentric circle. It was emphasized to the subject during the correct exercises that it was more important for the exercise to be passive than for the laser pointer to remain perfectly within the concentric circle diagram. The subject was also instructed to stop any correct pendulum trial if the subject perceived that the motion was active rather than passive.

**Statistical Analysis**

A power analysis was performed based on data collected in a pilot study of 3 subjects. It was based on detecting a difference of 10% MVIC in the supraspinatus muscle, as the pilot data showed a standard deviation of the difference between large active and passive pendulum exercises of 10.9% MVIC. It was determined that 12 subjects would be sufficient to provide 80% power, when controlling for type I error at 0.05 using a 2-sided test.

Statistical analyses were performed for both pendulum and ADL data. Normal probability plots were prepared for each dependent variable, and it was determined that they were not sufficiently normal to justify using parametric statistical methods. Therefore, a Friedman test was used to implement a nonparametric repeated-measurements analysis of the pendulum data. This was a 2-by-2 model, with 1 factor being the experimental factor of interest and the other factor being a subject. Significance was set at 0.05 for assessing main effects. When a main effect was found, post hoc analyses were performed to assess pairwise differences using the method described by Pett. The method compares differences in average ranks, and it limits the overall type I error to 0.05.

**RESULTS**

Three activities (large correct pendulums, large incorrect pendulums, and drinking from a water bottle) showed a mean peak percent MVIC greater than 15% in the supraspinatus and infraspinatus muscles. Mean peak percent MVIC and standard deviations for all activities are reported in the Table. A graphic representation is included in Figures 4 and 5.

Supraspinatus percent MVIC was affected by pendulum exercise (P<.001). Post hoc analyses showed that the difference in percent MVIC in the supraspinatus between incorrect and correct pendulum exercises reached statistical significance for large-diameter pendul
lums, but not for small-diameter pendulums. Because the statistical power analysis was based on large pendulum data, no strong conclusions can be made about the lack of differences found between correct and incorrect performance of small pendulum exercises. The difference in percent MVIC in the supraspinatus for large versus small pendulums was significant for those performed both correctly and incorrectly.

The statistical analysis also showed that drinking from a bottle of water had significantly higher muscle activation than typing for both the supraspinatus and the infraspinatus muscles.

**DISCUSSION**

CODMAN was one of the first to emphasize the complex nature of the shoulder joint, which allows for equally complex motion. In 1944, Inman et al performed a study of shoulder morphology and function, as well as EMG analysis of shoulder musculature. They emphasized that shoulder muscle groups act synchronously during certain movements. This has important implications in rehabilitation after rotator cuff repair, because the desired effect is to maintain passive range of motion without stressing the repair. The effect of improperly performed postoperative pendulum exercises and light ADLs after rotator cuff repair is largely unknown. Measuring the amount of muscle activation during tasks may provide information about the effect of activity on the rotator cuff. Our results indicate that the EMG activity of the supraspinatus is higher when healthy subjects perform pendulum exercises incorrectly in larger (51-cm diameter) circles, and a significant difference in activation of all 3 muscles was found between the large and small diameters for both the correctly and incorrectly performed pendulums.

Many previous researchers have examined activation of the shoulder musculature during active and isometric exercises for rehabilitation. Few, however, have looked at EMG data for activities that are meant to be passive. Dockery et al found approximately 5% MVIC in the rotator cuff by examining...
surface EMG data for pendulum exercises, but he did not include fine-wire EMG nor did he study any ADLs. McCann et al.29 studied multiple passive exercises, including the pendulum, using wire electrode EMG techniques. They found minimal activity in the supraspinatus, deltoid, and infraspinatus with pendulum exercises presumably performed correctly. No mention is made of the specific instructions to the patient on how the exercises were to be performed.29 Smith et al.36–38 have published EMG data for the immobilized shoulder to determine the safety of various exercises and activities after shoulder surgery. They recommended that certain motions, such as a backwards pulling motion, even if performed with the contralateral arm, should be avoided after rotator cuff repair, because the muscles in the operative extremity are not quiescent.28 In several published papers, this group has studied various types of exercises, including scapulothoracic and contralateral limb movements; however, pendulum exercises and specific ADLs were not included, although some of the resisted motions were meant to simulate ADLs, such as opening a door or lifting a bag.26–38

Although standardizing ADLs is more difficult than standardizing specific rehabilitation exercises, we felt that it was important to have subjects perform actual tasks rather than less-complicated motions associated with different activities. While there have been some ergonomic studies involving keyboards that measure the EMG signal amplitude in some of the shoulder musculature during typing and similar activities, none of these studies look at the EMG data for the supraspinatus, which is the muscle most commonly involved in rotator cuff tears.7,11,12,40,46 Kelly et al.23 investigated EMG data for more intense ADLs, such as lifting 1- to 10-pound (0.5- to 4.5-kg) objects and washing the back, in subjects with symptomatic versus asymptomatic rotator cuff tears compared to healthy controls. The results of that study showed that the symptomatic patients had more EMG signal amplitude for the muscles of the torn rotator cuff tendon than the asymptomatic patients, which could explain the disability of the symptomatic patients who were not compensating by using the surrounding shoulder musculature.23 Interestingly, Kelly et al.23 showed that the percent MVIC of the supraspinatus was higher for all studied activities in patients with rotator cuff tears than in normal controls. For example, the activity of lifting a 1-pound (0.5-kg) weight to the level of the shoulder required less than 20% MVIC for controls but over 50% MVIC for patients with symptomatic rotator cuff tears.23 Although our tasks were not identical, the findings of Kelly et al.23 do bring into the forefront the differences in EMG findings between healthy subjects and patients with rotator cuff tears. It is unclear whether patients who have had a rotator cuff repair would be more similar to a control subject or a patient with a rotator cuff tear.

While there is no definitive consensus opinion, previous reports of EMG data for the shoulder have considered activity levels of less than 20% to 25% MVIC to be low or minimal.20,29,36–38 Based on these reports, our study shows that there is at least moderate activity produced in the supraspinatus muscle by large incorrect pendulums and drinking in healthy subjects. However, the published EMG activity designsations are not standardized for percentage levels or for the definition of MVIC. For example, McCann et al.29 used a different method to obtain MVIC than we used. Rather than a maximum isometric contraction, subjects in their study lifted a 2.25-kg weight, and the EMG output for this action was used as MVIC.29
Thus, their results may represent a lower overall muscle activity than studies that use a maximal isometric contraction, as we did. In an effort to be conservative, we designated muscle activation greater than 15% MVIC to be potentially indicative of higher loads than desirable in a newly repaired rotator cuff. Although our study involves healthy subjects, the goal is to help identify activities that may potentially be safely performed by a patient who has recently undergone rotator cuff repair. Fifteen percent MVIC correlates to 30 N of force, based on our estimates. This is lower than the lowest force (50 N) that we found in the literature for failure after cyclic loading of the rotator cuff.\textsuperscript{5,22,23,24,25,30,35,37,42,45,46}

We chose a threshold of 15% of maximum activation for our data interpretation, based on biomechanical calculations. One study using in vitro biomechanical testing of sutured supraspinatus defects indicated a 50% loss of repair at (mean \pm SD) 206 \pm 88 cycles of loading at 44 \pm 15 N.\textsuperscript{3} A conservative value of 30 N was chosen as an upper limit of safe loading for the limited-repetition activities used in this study. Thirty-one N was estimated to be a percent of maximal contraction for our data interpretation, based on biomechanical calculations. While our EMG processing method was designed to include important elements of models to estimate muscle force from EMG, the method lacks a nonlinear transformation from muscle activation to muscle force. However, our nonparametric statistical analysis is based only on the weak assumption of an ordinal scale of measurement.\textsuperscript{22} Because EMG-to-force mappings are monotonically increasing, our statistical results are independent of the exact functional relationship between computed muscle activation and muscle force.\textsuperscript{23} Third, the activity of the shoulder muscles in healthy subjects may not be representative of the activity of individuals with a repaired rotator cuff muscle. Fourth, the average age of the volunteers is younger than the average age of patients undergoing rotator cuff surgery.

In analyzing our results, there are several reasons that large pendulum exercises could produce more muscle activity than small pendulum exercises. Performing the larger-diameter exercises may be more difficult than the smaller exercises, making it harder for the subject to perform the pendulum passively. Alternatively, pendulum exercises may not be truly passive at all. If so, then a larger exercise would require more muscle activity. Furthermore, although we focused on the supraspinatus, as this tendon is most frequently involved in rotator cuff tears, we did note that the data for the infraspinatus was less consistent overall. It is unclear whether even passive pendulum exercises may elicit relatively high muscle activation in the infraspinatus, at least in some individuals.

This study has several limitations. First, our instrumentation was limited to a 1000-Hz bandwidth. It has been reported that 5% of the power of the supraspinatus signal is greater than 510 Hz, when measured using fine-wire electrodes\textsuperscript{41}; therefore, a small amount of signal may be aliased, given the sampling rate we used. Second, EMG is not a direct measurement of muscle force. However, our nonparametric statistical analysis is based only on the weak assumption of an ordinal scale of measurement.\textsuperscript{22} Because EMG-to-force mappings are monotonically increasing, our statistical results are independent of the exact functional relationship between computed muscle activation and muscle force.\textsuperscript{23} Third, the activity of the shoulder muscles in healthy subjects may not be representative of the activity of individuals with a repaired rotator cuff muscle. Fourth, the average age of the volunteers is younger than the average age of patients undergoing rotator cuff surgery.

If we anticipate that the findings in healthy individuals may approximate the findings in patients who have undergone rotator cuff repair, then some concern is raised about the rehabilitation of these patients postoperatively. If patients are going to perform pendulums without supervision, then it is important that they understand and remember to do the exercises passively in small circles (approximately 20 cm in diameter). Those involved in the postoperative care of patients who have undergone rotator cuff repair may wish to consider these recommendations when prescribing home exercise programs for individual patients. Currently, some clinicians and therapists instruct patients to perform pendulum exercises with the opposite arm supported by a table. It is possible that support of the contralateral limb may affect muscle activity in the affected shoulder during pendulum exercises. In our study, subjects were permitted to use a table for support of the contralateral limb, if preferred, though most did not. Codman’s original description of the exercise did not mention contralateral arm support.

There are some patients who will lack the ability to perform pendulum exercises as prescribed, so supervised or assisted range-of-motion exercises may be safer for these individuals. Just as individual patients may perform pendulums incorrectly or differently, our subjects, although they underwent specific instruction and were observed during the exercises, had some level of variability in the amount of muscle activity recorded with the different exercises. With regard to ADLs, those patients who wish to return to typing in the early phase after rotator cuff repair may be able to do so without placing excess strain on the repair. However, even though the patient is able to perform a task, such as drinking from a bottle of water or brushing teeth, with the operative arm in a sling, the activity may not be entirely safe. Thus, patients may need specific instructions (restrictions) postoperatively for ADLs.

**CONCLUSION**

**LARGE PENDULUMS AND PENDULUMS PERFORMED INCORRECTLY GENERATE MORE SUPRASPINATUS MUSCLE ACTIVITY IN THE SHOULDER THAN SMALLER, CORRECTLY PERFORMED PENDULUM EXERCISES.** Based on this finding, we believe that it is possible that larger pendulum exercises may not be desirable early in rehabilitation after rotator cuff repair. In healthy individuals, drinking water from a bottle produces...
more supraspinatus muscle activity than typing. Drinking water from a bottle may also not be desirable immediately after rotator cuff repair.

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**KEY POINTS**

**FINDINGS:** Large pendulums and pendulums performed incorrectly generate more supraspinatus muscle activity than smaller, correctly performed pendulum exercises.

**IMPLICATIONS:** Smaller pendulums (20 cm in diameter) may be safer for patients who have had rotator cuff repair.

**CAUTION:** EMG is not a direct measurement of muscle force, so translation of EMG results to imply muscle force should be done with caution. Further, findings in healthy subjects may not replicate the findings in patients with rotator cuff repair.

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