Electromyographic activity in the shoulder musculature during resistance training exercises of the ipsilateral upper limb while wearing a shoulder orthosis

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Background: Resistance training is usually postponed until 3 months after rotator cuff surgery to prevent the damaging effects of high muscle stress on the repaired tendon. After upper limb immobilization, non-injured muscles as well as the repaired muscles are affected by long-term inactivity. Exercises with minimal cuff activity may be appropriate in the early postoperative period, so we aimed to quantify the effect of resistance exercises on the muscle activity of a semi-immobilized upper limb.

Method: Fifteen shoulder muscles of the dominant limb of 14 healthy subjects were evaluated by electromyography, with 11 surface electrodes and 4 fine-wire electrodes in the rotator cuff muscles. While wearing an orthosis, the subjects completed resistance tests including elbow and wrist flexion/extension with 3 loads, maximal squeezing, and shoulder adduction against 3 different foams. The peak activity of each muscle was normalized to maximal voluntary contraction (% MVC).

Results: Shoulder muscles were activated less than 20% MVC during elbow and wrist flexion/extension with 2-lb (907-g) and 4-lb (1814-g) loads. In the maximal squeezing test, rotator cuff activity exceeded 20% MVC in some cases. During shoulder adduction tests, subscapularis, latissimus dorsi, triceps, and pectoralis major had the highest activation levels; supraspinatus and infraspinatus were minimally activated.

Conclusion: Supported elbow and wrist flexion/extension in the horizontal plane, with weights of up to 4 lb (1814 g), minimally activates the rotator cuff muscles while potentially preventing muscle disuse of other upper limb musculature. Resisted shoulder adduction cannot be considered safe for all rotator cuff injuries.

Level of evidence: Basic Science Study, Electromyography.

Keywords: Electromyography; orthosis; resistance training; rotator cuff; shoulder; rehabilitation
shoulder musculature is required. Alenabi et al1 found that the effect of resistance training exercises on the immobilized range of activities, and therefore further research of the efficacy of kinetic chain exercises may be potentially useful during rehabilitation.41 However, these studies investigated only a limited number of tests using the ipsilateral upper limb. The tests are expected for all of the upper limb muscles after 6 weeks of immobilization. In addition, strength is diminished with disuse23,29; therefore, the further 6 weeks of low muscle activity can be expected at least to maintain the strength loss if not to exacerbate it.

The main reason for postponing strength training after rotator cuff surgery is that high muscle activity can damage the repaired tendon.36 However, if resistance training can be shown to activate the shoulder and upper limb muscles independently or with minimal activation of the rotator cuff, it can be assumed that such training may be implemented in the postoperative period without harming the repaired tendon. For instance, Smith et al30 found that isolated scapular depression and protraction motions could maintain low levels of electromyographic activity in the supraspinatus and infraspinatus muscles while producing levels of electromyographic activity sufficient for strengthening of the serratus anterior and trapezius muscles. It was also suggested that selected kinetic chain exercises could potentially be implemented during periods of shoulder immobilization.31 However, these studies investigated only a limited range of activities, and therefore further research of the effect of resistance training exercises on the immobilized shoulder musculature is required. Alenabi et al3 found that resisted elbow, wrist, and finger movements minimally activated the rotator cuff muscles and therefore could be considered potentially safe during the postoperative period. Thus it is of interest to determine if these same activities could be safely performed with resistance.

The purpose of this study was to identify resistance training exercises of the ipsilateral upper limb that could be safely performed during postoperative immobilization. Furthermore, we intended to quantify the effect of different loads on shoulder muscle activity. We hypothesized that training exercises such as resisted elbow and wrist flexion/extension, maximal gripping, and restricted shoulder abduction would minimally activate the rotator cuff muscles while effectively activating other upper limb musculature.

**Methods**

The dominant shoulders of 14 healthy volunteers (10 men, 4 women; 12 right handed, 2 left handed; mean age, 25 ± 4 years; mean weight, 73.4 ± 9.5 kg; mean height, 1.74 ± 0.08 m) were evaluated by electromyography (EMG). All subjects were free from shoulder and neck pain or disability as determined by the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire22 and exhibited full pain-free shoulder range of motion.

Rectangular silver–silver chloride bipolar surface electrodes (20-mm interelectrode distance; CareFusion, San Diego, CA, USA) and standard placement techniques6,8,12,39 were used to record EMG signals from shoulder muscles of the dominant limb, including the deltoid (anterior, middle, and posterior), trapezius (upper, lower, and middle), biceps, triceps, latissimus dorsi, pectoralis major (sternal), and serratus anterior. Fine-wire intramuscular electrodes (30 mm, 27 gauge; CareFusion, San Diego, CA, USA) were used to record EMG signals from the rotator cuff. Specifically, the electrodes were inserted into the supraspinatus, infraspinatus, and teres minor as described by Perotto and Delagi37 and into the lower subscapularis as described by Kadaba et al23 with standard aseptic techniques. The ground electrode was placed on the nondominant clavicle. To check electrode placement, the subjects were asked to perform submaximal isometric contractions in specific positions that were expected to generate high EMG activity, and the EMG signals were evaluated. Finally, the subjects performed maximal voluntary contraction (MVC) tests following the protocol outlined in our previous study1 to determine the MVC for each of the 15 muscles.

**Immobilization**

The dominant shoulder was immobilized with two orthoses, both of which elevated the arm in the scapular plane.

1. Type 1 (Fig. 1). This custom orthosis (Laboratoire Orthopédique Médicus, Montréal, Canada) was a pre-production prototype and has not yet been tested on a patient population. The orthosis was fixed to the waist with a belt and supported the forearm between the elbow and wrist. The length of the support bar between the elbow and wrist was adjusted to abduct the shoulder while supporting the forearm. The subject could flex and extend the elbow in the horizontal plane, flex and extend and rotate the wrist, and move the fingers while wearing the orthosis.

2. Type 2 (Fig. 2, A). This standard orthosis (Otto Bock HealthCare GmbH, Duderstadt, Germany) was fixed to the waist and the contralateral shoulder by two belts. The ipsilateral shoulder was immobilized in abduction with a removable wedge; the elbow and wrist were also immobilized. During the tests, the rigid wedge was replaced by wedge-shaped foams of 3 different densities, keeping the shoulder in 42° of abduction (Fig. 2, B). Appendix 1 explains how the foam densities were compared and highlights the differences between the foams.

**Tests**

While wearing the shoulder orthosis, the subjects completed a number of tests using the ipsilateral upper limb. The tests are...
explained in detail in Table I. During our testing, we used standard exercise dumbbells (2 lb = 907 g, 4 lb = 1814 g, and 6 lb = 2722 g; for the convenience of readers, we call them 2-lb, 4-lb, and 6-lb weights, respectively). We also used 3 different foams with different densities as described in Appendix 1. There was 1 minute of rest between tests. Where applicable, a metronome was used to control the pace of the movements.

Data processing

A custom data acquisition program (Matlab R2012b; The MathWorks, Natick, MA, USA) was used to collect and to process the EMG data to obtain the % MVC for each muscle during each movement. The electrode signals acquired at 4000 Hz were passed through an amplifier (Model 15A54, Grass Technology, West Warwick, RI, USA) with 10-1000 Hz bandwidth detection for the surface electrodes and 10-3000 Hz bandwidth detection for the fine-wire electrodes (common-mode rejection ratio >90 dB; input impedance >20 MΩ; noise: 10 μV peak to peak). The signals were filtered by use of a second-order Butterworth bandpass filter at 20-400 Hz. A tenth-order notch filter at 60, 120, and 240 Hz was also applied to remove the effect of power hum. The sliding root-mean square amplitude with a 100-ms window was calculated and normalized to generate a % MVC for each muscle. Less than 5% of the raw data was removed and not used in further analysis because of noise contamination.

For the tests with cyclic repetitions, the peak activation during the 6 middle cycles was determined and averaged for each participant. To determine the muscle activity patterns, the means and standard deviations of the normalized EMGs were calculated across the study population and demonstrated in graphs. For the tests completed with 3 different loads (dumbbells or foams), a repeated measure analysis of variance with repeated factors of muscle and load was performed. By considering a significant interaction between muscle and loads, we used analysis of variance with 1 repeated factor (load) for each muscle followed by paired comparisons with Bonferroni adjustment. The value of $P \leq .05$ was used to determine significance. Software SPSS 20 was used for all the statistical procedures.

Many studies have used the classification of the magnitude of normalized EMG as low (<20% MVC), moderate (21%-40% MVC), high (41%-60% MVC), and very high (>60% MVC) to describe the level of muscle activities during rehabilitation exercises or sports. This classification has also been considered in this study. Low muscle activity has been reported during the first phase of the early postoperative rehabilitation protocol, and this level of activity can be considered safe after rotator cuff surgery, whereas >20% MVC activation has been considered the activity level that is effective for moderate muscle strengthening.

Results

Elbow and wrist exercises

The mean peak activations of all tested shoulder muscles were <20% MVC during elbow flexion/extension in the
horizontal plane with 2- and 4-lb loads (Fig. 3, A). The mean peak activation of the biceps exceeded 20% MVC with use of the 6-lb load (24.2% ± 14.9% MVC), whereas the mean peak activations of other shoulder muscles remained below 20% MVC. However, with use of the 6-lb weight, the recorded activation of the teres minor, infraspinatus, and supraspinatus surpassed 20% MVC in 3 of the 14 cases. The effect of load on increasing the muscle activation was significant for middle trapezius, biceps, triceps, pectoralis major, and infraspinatus \((P < .05)\) as illustrated in Table II.

The mean peak activations of the shoulder muscles during wrist flexion/extension with the 3 different loads were <20% MVC (Fig. 3, B). The highest mean activation was recorded for teres minor with use of the 6-lb load (14.0% ± 10.9% MVC). Activation of the supraspinatus and subscapularis remained below 20% MVC for all subjects regardless of the load, whereas for 4 of the 14 subjects, teres minor or infraspinatus activation surpassed 20% MVC with use of the 6-lb load. The effect of load on increasing the muscle activity was significant for lower trapezius, middle deltoid, biceps, pectoralis major, and serratus anterior \((P < .05)\) as illustrated in Table II.

### Maximal squeezing

When the subjects maximally squeezed an anti-stress ball, rotator cuff activity increased significantly and in 6 of the 14 subjects exceeded 20% MVC, but the mean peak activations were below 20% MVC (17.7% ± 12.2% MVC for teres minor, 15.0% ± 13.4% MVC for infraspinatus, 15.8% ± 11.1% MVC for subscapularis, and 12.7% ± 8.8% MVC for supraspinatus) (Fig. 4). Biceps and triceps showed the highest activation levels with 42.2% ± 20.1% MVC and 41.8% ± 31.0% MVC, respectively, whereas the mean peak activation of latissimus dorsi and lower trapezius also surpassed 20% MVC. There was high variation in muscle activation between the study subjects.

### Arm adduction exercises

For this test, the subjects submaximally squeezed the foam wedges of 3 different densities that were positioned under the arm. With all 3 foams, latissimus dorsi, triceps, pectoralis major, and subscapularis had the highest activation levels, which surpassed 20% MVC (Fig. 5). In contrast, supraspinatus and infraspinatus were minimally activated, with mean peak activations below 20% MVC. Statistical analysis showed significant differences in the levels of muscle activity between foams for middle trapezius, biceps, triceps, latissimus dorsi, pectoralis major, serratus anterior, teres minor, and subscapularis \((P < .05); \text{Table III})

### Discussion

The purpose of this study was to identify resistance training exercises that could be performed during postoperative immobilization without inducing high activation of the rotator cuff muscles. Preservation of muscle strength after rotator cuff surgery is important for recovery of normal shoulder function and prevention of recurrent defect.\(^\text{15}\) Furthermore, for certain populations, such as athletes and manual laborers, this is even more important. It can be assumed that after 6 weeks of immobilization, not only the shoulder muscles but also all the upper limb muscles would have experienced significant strength loss.\(^\text{20,31}\) Moreover, it has been shown that 6 weeks of immobilization also resulted in humeral bone density loss, and good bone recovery is thought to be related to recovery of normal shoulder function.\(^\text{32}\) Therefore, it is of interest to identify resistance training exercises that can be performed safely

<table>
<thead>
<tr>
<th>Movement</th>
<th>Start position</th>
<th>Test details</th>
<th>Load</th>
<th>Rhythm</th>
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<tbody>
<tr>
<td>Elbow flexion/extension</td>
<td>Standing, elbow extended</td>
<td>10 cycles of elbow extension/flexion in the horizontal plane with each load</td>
<td>2-, 4-, and 6-lb weights *</td>
<td>40 beats/min Each cycle = 2 beats</td>
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<tr>
<td>Wrist flexion/extension</td>
<td>Standing, elbow extended</td>
<td>10 cycles of wrist extension/flexion with each load</td>
<td>2-, 4-, and 6-lb weights *</td>
<td>40 beats/min Each cycle = 2 beats</td>
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<tr>
<td>Squeezing</td>
<td>Standing, elbow extended</td>
<td>Two sets of squeezing a small anti-stress ball with maximum force for 5 s</td>
<td>Maximal force</td>
<td>30 s rest between 2 sets</td>
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<tr>
<td>Arm adduction</td>
<td>Standing, arm in 42° abduction</td>
<td>10 cycles of submaximally squeezing the foam, which is positioned under the arm</td>
<td>3 foam densities</td>
<td>40 beats/min Each cycle = 2 beats</td>
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* 2 lb = 907 g, 4 lb = 1814 g, and 6 lb = 2722 g. For the convenience of readers, we call them 2-lb, 4-lb, and 6-lb weights.
in the postoperative period to maintain upper limb muscle strength or at least to reduce the amount of strength lost. In this study, the safety margin was set with low EMG activity (<20% MVC) for the repaired muscles. The results of this study indicate that some types of resistance training exercises of upper limb muscles could minimally activate the rotator cuff and may be applicable during the postoperative immobilization period.

During supported elbow flexion/extension in the horizontal plane with 2- and 4-lb weights, activation of the rotator cuff muscles remained below 20% MVC, whereas the biceps was more highly activated. Increasing the load resulted in a significant increase in EMG activity of some shoulder muscles (Table II), a finding that is similar to previous studies; but aside from the infraspinatus, the activation of the rotator cuff muscles did not change considerably with increased load. Elbow flexion/extension with a 6-lb load activated the biceps more than the lighter loads did, but the activity level of rotator cuff muscles also surpassed 20% MVC in some cases. Therefore, resistance training with 2- and 4-lb loads can be considered potentially safe, whereas a 6-lb load may endanger the repaired tendon. Because of the high loading of the biceps, elbow flexion/extension activities are also better avoided when there is concomitant biceps disease or when a biceps tenotomy or tenodesis has been performed at the time of rotator cuff repair.

Laursen et al have shown that shoulder muscle activity increased by increasing the speed of a hand movement task. Our previous study has also shown that resisted elbow flexion with higher speed could result in higher muscle activation, especially in the biceps. In the present study, the elbow movement was slow (40 beats/min), so it should be noted that increasing speed can change the level of muscle activity.

One must consider, however, that the resisted elbow flexion/extension exercises were performed in a nonstandard

Figure 3  Shoulder muscle activity while wearing an orthosis with use of 2-lb (907-g), 4-lb (1814-g), and 6-lb (2722-g) loads during (A) elbow flexion/extension and (B) wrist flexion/extension. UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; AD, anterior deltoid; MD, middle deltoid; PD, posterior deltoid; BC, biceps; TC, triceps; LD, latissimus dorsi; PM, pectoralis major; SA, serratus anterior; TM, teres minor; IS, infraspinatus; SC, subscapularis; SS, supraspinatus.

### Table II  Comparison of muscle activation between loads

<table>
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<tr>
<th>Elbow flexion/extension with 2-, 4-, and 6-lb loads</th>
<th>UT</th>
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<th>Wrist flexion/extension with 2-, 4-, and 6-lb loads</th>
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UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; AD, anterior deltoid; MD, middle deltoid; PD, posterior deltoid; BC, biceps; TC, triceps; LD, latissimus dorsi; PM, pectoralis major; SA, serratus anterior; TM, teres minor; IS, infraspinatus; SC, subscapularis; SS, supraspinatus.

2 lb = 907 g, 4 lb = 1814 g, and 6 lb = 2722 g.

* P < .05; the difference is significant.
orthosis, in which the weight of the arm was fully supported and elbow flexion/extension was allowed in the horizontal plane. Further testing is required to determine if the results could be extrapolated to elbow flexion/extension in other planes and unsupported elbow flexion/extension.

Wrist flexion/extension while wearing an orthosis with 2- and 4-lb weights did not highly activate the rotator cuff muscles. The results showed that the teres minor had the highest activity among the muscles of this study, which can be attributed to its stabilizer role.\(^5\) Wrist flexion/extension with a 6-lb load activated the infraspinatus and teres minor more than 20% MVC in 4 of 14 cases. Our results suggest that wrist resistance training with loads of up to 4 lb can be expected to minimally activate the rotator cuff muscles. However, when a patient has an injury of the teres minor or infraspinatus, wrist resistance exercises with a 6-lb load may need more caution. It seems that rotator cuff muscle activity increased because of a demand for co-contraction to stabilize the shoulder joint and allow better wrist control.

Maximal squeezing highly activated the biceps and triceps (\(>40\%\) MVC) and moderately activated the lower trapezius and latissimus dorsi (\(>20\%\) MVC); the mean peak activations of the rotator cuff muscles remained low (\(<20\%\) MVC). However, there was a large variability of rotator cuff activity between subjects. In this study, we did not evaluate the levels of muscle activity during submaximal squeezing or repetitive squeezing exercises. However, studies\(^{12,43}\) have shown that both static and dynamic hand gripping tasks at 30% and 50% MVC, particularly in elevated arm positions, increased the load on some shoulder muscles, including the rotator cuff muscles. It was also suggested that gripping redistributes muscle activity from the deltoid muscle group to the rotator cuff.\(^3\) So it is wise to say that maximal squeezing, which is similar to a gripping task, may not be a safe activity after rotator cuff repair. Furthermore, muscle

![Graph](image-url)
activity can be influenced by the manner in which a mechanical load is controlled. In our test, maximal squeezing was completed while standing with the elbow extended. Changing the upper extremity posture may affect muscle activity, such as it affects grip strength.

In this study, we did not evaluate the activity of forearm muscles, but it can be expected that 6 weeks of immobilization of the upper limb with a standard orthosis that immobilizes not only the shoulder but also the elbow and wrist would result in strength loss of the forearm muscles as well as of the arm muscles. MacDougall et al. have shown that 6 weeks of immobilization of the elbow resulted in a 41% strength loss and significant decrease in fast-twitch and slow-twitch fiber areas in triceps brachii. Resistance training of the elbow and wrist joints could prevent the strength loss of forearm muscles. Davies et al. showed that 6 weeks of isometric strength training increased the size and strength of elbow flexor muscles. Moss et al. also showed that dynamic training with loads of 15% and 35% of 1 RM (1 repetition maximal) resulted in an increase in 1 RM of elbow flexors. We suggest that resistance training exercises that mobilize the elbow and wrist joints while minimally activating the rotator cuff muscles may be appropriate during the first phase of rehabilitation and may prevent the complications of muscle disuse.

In our previous study, we found that certain elbow, wrist, and finger movements could be considered potentially safe during the postoperative immobilization period and suggested semi-immobilization instead of full immobilization of the upper limb after rotator cuff repair. In the present study, we studied adduction movement of the shoulder against 3 types of resistance to add the idea of shoulder semi-immobilization. Adduction exercises with a low-density foam minimally activated the supraspinatus, infraspinatus, and teres minor while moderately activating the subscapularis, pectoralis major, latissimus dorsi, and triceps muscles. The muscle activation significantly increased with increasing foam density for 8 of the 15 muscles studied (Table III). For some subjects, adduction exercises with a high-density foam resulted in activation of above 20% MVC for all 4 rotator cuff muscles, although the mean peak activation levels were still below 20% MVC for supraspinatus and infraspinatus. In general, we can conclude that low-density foam resulted in the safest activity pattern. For tears in which the subscapularis and biceps are not involved, adduction resistance training with low-density foam maintains minimal activation of the injured muscles. However, considering the preoperative tendon retraction and postoperative tension on the repaired tendons, it is not clear if decreasing the degree of shoulder abduction (which occurs as the subject squeezes the foam) could have any harmful effect on repaired tendon. It has been shown that the optimal position of shoulder immobilization will depend on the injury but generally that abduction of around 60° is required. During the adduction exercise, the shoulder position repeatedly changed from approximately 42° to approximately 20° of shoulder abduction. Whether this range of shoulder abduction is enough to protect the repair requires further investigation. Thus, until further research is done, we do not advise any resisted shoulder adduction exercises in the first 3 months after surgery.

It is known that an increase in the firing rates of motor units increases force and the integrated form of EMG, and there is at least a qualitative relation between the EMG signal and muscle force. However, the authors acknowledge that EMG cannot quantitatively measure the amount of tension on the repaired tendon. It was suggested that a suitably calibrated EMG can be used as a coarse predictor of muscle tension for muscles whose length is not changing rapidly. Our subjects’ shoulders were in an immobilized or semi-immobilized position, and we observed that light resistance exercises of shoulder, elbow, and wrist joints could minimally activate the rotator cuff muscles, which is compatible with the first phase of rehabilitation protocols, so we could speculate that these types of training may not impose a high force on the repaired tendon and can be “potentially” safe.

We appreciate that there may be differences between healthy volunteers and individuals with known shoulder disease. However, we chose to complete this study with healthy volunteers as a first step toward optimizing postoperative immobilization protocols. Second, much of the scientific information about shoulder rehabilitation has been yielded from the evaluation of young healthy subjects. Third, EMG data are commonly normalized on the basis of MVC levels, and such types of contraction not only are unsafe to assess on individuals with known shoulder disease but also are generally not accurate as muscle pain can reduce MVC level and change EMG

<table>
<thead>
<tr>
<th>Table III</th>
<th>Comparison of muscle activation between foams</th>
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<tr>
<td>Foams</td>
<td>UT</td>
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* P < .05; the difference is significant.
activity. The authors appreciate that further testing on a patient population is required.

Conclusions
Supported elbow flexion/extension in the horizontal plane and wrist flexion/extension with weights of up to 4 lb do not require high activity of the rotator cuff muscles and therefore can be considered potentially safe in the postoperative immobilization period. Such training may help preserve muscle strength in the forearm, arm, and some shoulder muscles and prevent the negative side effects of muscle disuse. Maximal gripping activities and resisted shoulder adduction, however, are not recommended. The authors believe the results of this study to suggest that rehabilitation protocols could be modified on the basis of the specifics of an individual’s injury and also promote the design of a shoulder orthosis that provides semi-immobilization of the upper limb.

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