Electromyographic Activity in the Immobilized Shoulder Girdle Musculature During Scapulothoracic Exercises

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Objective: To quantify the electromyographic activity in the shoulder girdle musculature during scapulothoracic exercises performed in a shoulder immobilizer in asymptomatic men.

Design: Descriptive.

Setting: Motion analysis laboratory at a tertiary care center.

Participants: Five asymptomatic male volunteers ages 24 to 32 years.

Intervention: Fine-wire (supraspinatus, infraspinatus, upper subscapularis) and surface (deltoids, trapezi, biceps, serratus anterior) electrodes recorded electromyographic activity from each muscle during scapular clock, elevation, depression, protraction, and retraction exercises completed during a single testing session in random order.

Main Outcome Measure: Mean peak normalized (percentage of maximal voluntary contraction [MVC]) electromyographic activity of each muscle during each exercise.

Results: Biceps activity was uniformly low (<20% MVC), whereas upper subscapularis activity was uniformly high (40%–63% MVC). Both scapular depression and protraction elicited low activity (<20% MVC) in the supraspinatus, infraspinatus, anterior deltoid, and biceps brachii muscles, while generally producing greater than 20% MVC activity in the trapezi and serratus. Scapular depression produced the largest serratus anterior activity (47% MVC).

Conclusions: These data are the first to describe the electromyographic activity during scapulothoracic exercises while in a shoulder immobilizer. Based on electrophysiologic data in normal volunteers, our findings suggest that during periods of shoulder immobilization: (1) scapular depression and protraction exercises could potentially be safely performed after rotator cuff repair to facilitate scapulothoracic rehabilitation, (2) all exercises studied could potentially be safe after superior labral anteroposterior shoulder repair, and (3) all exercises studied should be avoided after subscapularis repair. Further investigation in symptomatic individuals may facilitate refinement of these recommendations.

Key Words: Electromyography; Exercise; Rehabilitation; Scapula; Shoulder.

Shoulder immobilization is commonly used to protect healing tissues after shoulder injury or surgery. During this period of days to weeks, deconditioning of the immobilized shoulder muscles may result in weakness and loss of normal neuromuscular control. Conversely, overactivity of immobilized muscles during the acute healing phase may be injurious. In either case, the recovery process may be impeded.

Previous research from our laboratory has demonstrated that the immobilized shoulder girdle musculature is not electrically silent during contralateral (ie, nonimmobilized) upper-limb movements. During such motions, the immobilized deltoid, supraspinatus, infraspinatus, and biceps electromyographic activity rarely exceeded 20% of a maximal voluntary contraction (MVC), whereas trapezi muscles electromyographic activity ranged from 20% to 60% MVC. Consequently, we concluded that cross-body, straightforward, or downward reaches performed with the nonimmobilized upper limb may be prescribed as early rehabilitative exercise during periods of shoulder immobilization. The purpose of such exercise would be to reactivate the scapular stabilizer muscles in a protected environment while minimizing activation of the healing rotator cuff, anterior deltoid, or biceps brachii muscles.

Early shoulder girdle muscle reactivation may also be possible via scapulothoracic exercises performed by the immobilized shoulder girdle musculature. Kibler et al have proposed that “closed kinetic chain” exercises such as the scapular clock are appropriate for early shoulder rehabilitation, based in part on preliminary data indicating that rotator cuff and scapular stabilizer muscle electromyographic activity during these exercises was generally less than 20% MVC. However, these data were collected in nonimmobilized shoulders and did not include the subscapularis. The primary purpose of the current investigation was to quantify the electromyographic activity in the immobilized shoulder girdle musculature during a series of isolated scapulothoracic motions. In addition to previously studied muscles, this investigation included examination of the upper subscapularis due to the increasingly recognized importance of this muscle in the nonsurgical and surgical treatment of shoulder disorders. It was anticipated that the results of this investigation would have important clinical implications with respect to initiating early shoulder rehabilitation during periods of immobilization. More specifically, exercises that sufficiently activate the scapular stabilizer muscles while minimizing potentially injurious activation of the rotator cuff, biceps, and anterior deltoid muscles may be added to the contralateral arm cross-body, straightforward, and downward reaches as part of an early shoulder rehabilitation program.

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METHODS

Participants

Five healthy, right-hand dominant men, ages 24 to 32 years, volunteered to participate. Subjects were recruited from our institution via advertisement. We enrolled the first 5 men meeting the following inclusion criteria: (1) right-hand dominant, (2) no history of right shoulder or neck injury or pain requiring formal medical treatment or activity modification, (3) full, pain-free, bilateral shoulder range of motion (ROM) at the time of enrollment, and (4) no contraindications to fine-wire placement or completion of basic scapulothoracic ROM. The study group was limited to men in order to control for potential sex effects and due to difficulty obtaining unimpeded fine-wire and shoulder immobilizer placement in women wearing sports bras during a pilot investigation performed in our lab. We chose to study 5 subjects for 2 primary reasons. First, the study design was descriptive and reflected the primary purpose of providing the first documented characterization of electromyographic patterns during these exercises performed in a shoulder immobilizer. These data would provide a basis for further comparative research, potentially including symptomatic populations. Second, our previous research examining shoulder muscle activity during contralateral shoulder movements suggested that 5 subjects would be adequate to identify general electromyographic patterns with each of the exercises utilized in this investigation. For these reasons, we felt that a preinvestigation power analysis was unnecessary. Due to the study design, the institutional review board at our institution approved the investigation, and all subjects completed a written informed consent process prior to participation.

Testing Procedure

Using standard procedures, we placed fine-wire electrodes (diameter, .30mm; 27 gauge) into the right supraspinatus, infraspinatus, and upper subscapularis muscles (USSC), and Ag-AgCl surface electrodes were placed onto the right anterior deltoid, middle deltoid, posterior deltoid, upper trapezius, lower trapezius, middle trapezius, serratus anterior, and biceps brachii. Electrode placement was confirmed using electromyography and muscle activation, and all leads were secured with adhesive tape. For data reduction, the electromyographic activity of each muscle’s MVC was determined by subtracting the quiescent (prone resting) signal from the peak 1-second electromyographic activity recorded for that muscle during 2 voluntary 4-second maximal isometric contractions. Quiescent signals were collected in the prone resting position to avoid displacement of the supraspinatus, infraspinatus, and USSC fine-wire electrodes using a supine position. A standard, postoperative shoulder immobilizer was placed onto each subject’s right shoulder girdle using a standard technique, and active scapular motions confirmed maintenance of electromyographic signals. Standing rests electromyographic signals were then recorded during relaxed standing in the immobilizer.

Subjects then completed 1 set of 10 consecutive repetitions of each study motion with the immobilized right upper limb while electromyographic activity was recorded from the 11 immobilized right shoulder muscles. A 5-minute rest period was provided between sets. Six isolated scapulothoracic exercises were investigated: (1) scapular clock counterclockwise: starting from resting neutral position, subject moves right shoulder forward, upward, backward, downward, then forward in a circumferential counterclockwise motion, (2) scapular clock clockwise: similar to scapular clock counterclockwise but in the opposite direction, (3) scapular depression: from neutral position, subject depresses shoulder downward, then returns to starting position, (4) scapular elevation: from neutral position, subject elevates (ie, shrugs) shoulder, then returns to starting position, (5) scapular protraction: from neutral position, subject protracts shoulder, then returns to starting position, and (6) scapular retraction: from neutral position, subject retracts shoulder, then returns to starting position. These motions were chosen because they could be easily completed while in an immobilizer and are hypothesized to be important for scapular stabilization early in the shoulder rehabilitation process. All motions were completed in a standing position. Each subject received instruction in the exercise by the primary investigator and was allowed to practice to preference (typically 3–5 repetitions) before data collection. Subjects were instructed to initiate and “drive the motions from the shoulder blade” and let the rest of the arm follow, and to attempt to achieve the maximal qualitatively smooth amplitude in all motions. All motions were done at the subject’s self-selected speed.

The order of exercises completed by each subject was randomized to control for order effects.

Electromyographic Signal Collection and Data Reduction

We collected electromyographic signals using an electromyography system and a custom software data acquisition program. All electrodes provided a direct current (surface) or alternating current (fine-wire electrodes) coupled, low gain, high common mode rejection rate (gain, ×20; minimum, 110dB) preamplifier with a double differential input, and were connected to a backpack. The backpack was connected to the computer by a single thin, flexible, .24cm diameter coaxial cable. The electromyographic signals were bandpass filtered with the bandpass set at 20 to 1000Hz and the data acquisition program acquired the analog data at 2kHz. Signals were processed using a custom computer program. For each test motion, the mean peak 1-second electromyographic activity in the 11 target muscles was generated by collecting peak 1-second electromyographic signal generated for each muscle by each subject during the exercise, normalizing by the prone quiescent signal to generate as a percentage of MVC, and then averaging the normalized peak electromyographic activity across the 5 subjects.

RESULTS

The mean peak electromyographic activity for each muscle during each of the 6 scapulothoracic exercises varied across muscles (fig 1). Deltoid, infraspinatus, and biceps brachii activity was less than 20% MVC for all exercises, with the exception of the anterior deltoid during scapular clock counterclockwise (28% MVC) and scapular clock clockwise (26% MVC). By comparison, USSC activity was uniformly high during all motions, ranging from 40% MVC during scapular depression to 63% MVC during scapular clock clockwise. Serratus anterior, supraspinatus, and trapezius activity varied more between exercises. Serratus anterior activity ranged from 18% MVC during scapular elevation to 47% MVC during scapular depression, supraspinatus activity from 13% MVC during scapular depression to 53% during scapular clock clockwise, and trapezius activity from 16% MVC for middle trapezius during scapular depression to 91% for upper trapezius during scapular clock counterclockwise. Of note is the fact that the supraspinatus qualitatively generated more activity during the 2 clock exercises than during the cardinal plane motions.
DISCUSSION

Shoulder immobilizers are commonly utilized postinjury and postsurgery to rest and protect healing tissues, particularly the anterior deltoid, supraspinatus, infraspinatus, USSC, and/or biceps brachii. Our previous investigation suggested that deliberately performed contralateral upper-limb motions could be used during shoulder immobilization as part of acute phase rehabilitation. \(^8\) Cross-body, straightforward, and downward reaches performed with the nonimmobilized upper limb elicited less than 20% MVC electromyographic activity in the anterior deltoid, supraspinatus, infraspinatus, and biceps brachii while producing electromyographic levels greater than 20% MVC in the trapezius muscles on the immobilized side. Electromyographic activity levels less than 20% MVC fall within the range of electromyographic activity previously reported for Neer phase I supine and upright exercises and are generally regarded as safe during the acute postinjury or postoperative period. \(^5,18-20\)

Unfortunately, during that investigation, we did not examine the subscapularis, and none of the contralateral motions investigated elicited meaningful (ie, >20% MVC) activity in the serratus anterior. These 2 muscles are important due to the increased recognition and repair of subscapularis tears, and the well-recognized importance of the serratus anterior for scapular stabilization. \(^10-12,19-21\)

The current research expands our previous findings by suggesting that several ipsilateral scapulothoracic exercises may be safely performed during immobilization, whereas others should be avoided in specific clinical circumstances. Patients with supraspinatus injury and/or repair potentially could safely perform scapular depression and scapular protraction exercises, while avoiding scapular clock, scapular elevation, and scapular retraction exercises. Both the scapular depression and scapular protraction exercises elicit less than 20% MVC electromyographic activity in the infraspinatus, biceps brachii, and anterior deltoid (see fig 1). Consequently, these exercises could potentially be considered safe in 1- or 2-tendon rotator cuff repairs (arthroscopic or open), as well as repairs of concomitant superior labral anteroposterior shoulder (SLAP) lesions. During scapular depression and scapular protraction, trapezius and serratus anterior activity is generally greater than 20% MVC, with the single exception being middle trapezius during scapular depression (16% MVC). Of all the scapulothoracic exercises, scapular depression elicited the greatest serratus anterior activity at 47% MVC, which is of sufficient magnitude for neuromuscular re-education. \(^19-21\)

In the patient with an isolated SLAP lesion, all 6 scapulothoracic exercises may be considered safe from an electrophysiologic standpoint (<20% MVC). \(^5,18-20\) On the contrary, for the patient with a USSC repair (either primary or as part of an open Bankart repair), our data suggest that none of the 6

**Fig 1.** Peak 1-second normalized electromyographic activity from the 11 study muscles (N=5 subjects) during 6 scapulothoracic exercises. NOTE: Values are mean ± standard error of the mean.

**Fig 2.** Side view demonstrating how holding the hand away from the abdomen during the scapulothoracic exercises may reduce the electromyographic activity in the upper subscapularis to safer levels.
exercises as performed in this investigation would be safe in the acute postoperative setting. The electromyographic activity in the USSC ranged from 40% MVC during scapular depression to 63% MVC during scapular clockwise. These electromyographic levels are considered “moderate” to “high” and therefore potentially injurious to a healing muscle-tendon unit.5,18-20 The reason for the uniformly moderate-to-high electromyographic activity in the USSC exercises during scapulothoracic exercises is unknown. However, given the known function of the subscapularis as an internal rotator, we hypothesize that our findings may in part be a consequence of an interaction between the immobilization and the method of exercise.11,13,21 During all exercises, the palm of the immobilized upper limb rested on the subject’s abdomen while in the immobilizer. Although subjects were only instructed to maintain the hand in its starting position, it is possible that each subject started his scapulothoracic exercises by pressing the palm against the abdomen to close the “kinetic chain” and facilitate initiation of the motion from the scapula as instructed.3,7,9,17 This maneuver requires isometric internal rotation force generation by the USSC and may account for the electromyographic activity we observed. If this were the case, then performing isolated scapulothoracic exercises in the immobilized shoulder with the hand held away from the abdomen could significantly reduce the USSC electromyographic activity to safe levels (fig 2). This hypothesis, as well as the electromyographic changes that this position change may elicit in the other shoulder muscles, remains to be investigated.

Kibler et al9 have published the only previous data reporting electromyographic activity in the shoulder during scapulothoracic exercises performed by asymptomatic, nonimmobilized subjects. The only comparable exercise was the scapular clockwise exercise performed with the hand on a table top or wall, for which Kibler reported electromyographic activity of less than 20% MVC for the upper trapezius, lower trapezius, anterior deltoid, posterior deltoid, subscapularis, infraspinatus, and serratus anterior. The middle trapezius, middle deltoid, biceps brachii, and USSC were not reported. Our findings for scapular clock counterclockwise and clockwise are similar, with the exception that in our investigation, upper trapezius ranged from 60% to 91% MVC, lower trapezius from 41% to 47% MVC, anterior deltoid 28% to 29% MVC, and supraspinatus 48% to 53% MVC (see fig 2). The increased electromyographic activity in these muscles during our investigation is likely due to our instructions to subjects to achieve the maximal amplitudes of motion they could achieve while maintaining qualitatively smooth motion. This was done to place muscles into the extremes of their length-tension curves, thus eliciting maximal electromyographic activity.13 We did this to present the worst-case scenario for our asymptomatic subjects in terms of generating high, potentially injurious levels of electromyographic activity. Consequently, it is possible that scapulothoracic exercises such as scapular clock counterclockwise and clockwise, scapular elevation, and scapular retraction as performed in this investigation may generate “safe” levels of electromyographic activity when done in less extreme ROMs.

Study Limitations

Two limitations of this investigation are worthy of note. First, some researchers and clinicians might consider the study population to be relatively small (ie, 5 subjects). However, there is no universally agreed on number of subjects that would be deemed necessary for an investigation such as this. Based on our previous experience using this study model, we felt that 5 subjects would provide an acceptable indication of the worst-case scenario of electromyographic activity in the muscles of interest, as reflected in the mean peak normalized electromyographic activity.8 At this time, there is no proof that increasing the number of subjects would substantially change our results. Second, the current data were collected in asymptomatic individuals. Because this line of research is novel, we felt that characterization of the extent and patterns of electromyographic activity in a relatively homogenous, asymptomatic population was necessary. The majority of electromyography research on which physiatrists currently base rehabilitation programs is based on investigation of asymptomatic subjects.5,9,11,18-21 Clearly, future investigations targeting symptomatic persons performing shoulder rehabilitation exercises with or without a shoulder immobilizer would advance our understanding of the symptomatic shoulder and potentially facilitate refinement of our rehabilitation programs.

CONCLUSIONS

This investigation is the first to describe the electromyographic activity of the shoulder musculature during scapulothoracic exercises completed while in a shoulder immobilizer. Our electrophysiologic findings in asymptomatic subjects suggest that early activation of the immobilized shoulder girdle musculature may be safely achieved by performing scapular protraction and depression exercises. Early activation of the serratus anterior is best achieved with the ipsilateral scapular depression exercise, and that of the lower trapezius with the contralateral upper limb cross-body reach exercise evaluated in our previous study.8 All of the scapulothoracic exercises could potentially be considered electrophysiologically “safe” for patients with SLAP lesions, or after takedown and repair of the anterior deltoid. Conversely, none of these exercises should be considered safe during early rehabilitation of a USSC injury or repair. Investigation of symptomatic populations may facilitate further refinement in these recommendations.

References


Suppliers
a. Nicolet Biomedical, 5255 Verona Rd, Bldg 2, Madison, WI 53711-4495.

b. MA300; Motion Lab Systems, 15045 Old Hammond Hwy, Baton Rouge, LA 70816-1244.

c. LabView, version 6.1; National Instruments Corp, 11500 N Mopac Expwy, Austin, TX 78759-3504.

d. Matlab version 6.0; The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.