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Serratus Anterior Muscle Activity During Selected Rehabilitation Exercises*

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ABSTRACT

The purpose of this study was to document the electromyographic activity and applied resistance associated with eight scapulohumeral exercises performed below shoulder height. We used this information to design a continuum of serratus anterior muscle exercises for progressive rehabilitation or training. Five muscles in 20 healthy subjects were studied with surface electrodes for the following exercises: shoulder extension, forward punch, serratus anterior punch, dynamic hug, scaption (with external rotation), press-up, push-up plus, and knee push-up plus. Electromyographic data were collected from the middle serratus anterior, upper and middle trapezius, and anterior and posterior deltoid muscles. Each exercise was partitioned into phases of increasing and decreasing force and analyzed for average and peak electromyographic amplitude. Resistance was provided by body weight, an elastic cord, or dumbbells. The serratus anterior punch, scaption, dynamic hug, knee push-up plus, and push-up plus exercises consistently elicited serratus anterior muscle activity greater than 20% maximal voluntary contraction. The exercises that maintained an upwardly rotated scapula while accentuating scapular protraction, such as the push-up plus and the newly designed dynamic hug, elicited the greatest electromyographic activity from the serratus anterior muscle.

Normal shoulder motion results from a complex interplay of the scapulohumeral, acromioclavicular, sternoclavicular, and scapulothoracic articulations. The coordination of these articulations provides the shoulder with an ample range of motion necessary for overhead sporting activities. Proper positioning of the humerus in the glenoid cavity, known as scapulohumeral rhythm,[6] is critical to the proper function of the glenohumeral joint during overhead motion. A disturbance in normal scapulohumeral rhythm may cause inappropriate positioning of the glenoid relative to the humeral head, resulting in injury.[16,18,22]

One of the primary muscles responsible for maintaining normal rhythm and shoulder motion is the serratus anterior.[8,32] Lack of strength or endurance in this muscle allows the scapula to rest in a downwardly rotated position, causing the inferior border to become more prominent (scapular winging).[32] Scapular winging may precipitate or contribute to persistent symptoms in patients with orthopaedic shoulder abnormalities.[19] Thus, the injured shoulder with subsequent immobilization or disuse may benefit from a rehabilitation program that reconditions the serratus anterior muscle.

Shoulder exercises intended to strengthen the serratus anterior muscle and other scapular stabilizers have been included in shoulder rehabilitation protocols.[4,16,23,25,26,29,34] Exercise selection has been based on EMG data[4,23,25,33] or clinical experience.[26,29,34] Several researchers have recommended that exercises be performed with the arm below 90° of humeral elevation during the initial stages of rehabilitation to prevent excessive strain on the rotator cuff and shoulder ligaments.[15,23,27,32] Despite these recommendations, a progression of shoulder rehabilitation exercises that specifically target the serratus anterior muscle while constraining humeral elevation below shoulder height has not, to our knowledge, been investigated. The purpose of this study was to document the EMG activity and applied resistance associated with eight scapulohumeral exercises performed below shoulder height that target the serratus anterior muscle and to design a continuum of serratus anterior muscle exercises for progressive rehabilitation or training.

MATERIALS AND METHODS

Subject Preparation

Twenty male subjects (age, 30.4 ± 5.1 years [average ± SD]; height, 1.8 ± 0.1 meters; weight, 80.1 ± 9.6 kg) with

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no history of shoulder injury gave their written informed consent to participate in this study. Before testing, all subjects participated in an orientation session to practice the exercise techniques and maximum voluntary contraction (MVC) protocols.

Pregelled, silver-silver chloride bipolar surface electrodes (NDM, Dayton, Ohio) were placed over five muscles: the upper trapezius, middle trapezius, anterior deltoid, posterior deltoid, and middle serratus anterior. Surface electrodes were used because they are noninvasive and provide a reliable means to access the greatest portrayal of motor unit activity of a superficial muscle.[10] The electrodes were placed according to the method described by Basmajian and DeLuca,[3] with an interelectrode distance of approximately 25 mm. Electrode placements are described in Table 1 and in a previous study.[12] Electrode placements were confirmed from a manual muscle test of the primary muscle.

Experimental Protocol

On the day of testing, the subject warmed up by walking on a treadmill at a self-selected pace for 5 minutes. The testing session began with a series of five isometric MVCs for each muscle. The 3-second maximum contractions were interspersed with 3 to 5 seconds of rest. Maximum voluntary contraction protocols for all muscles are described in Table 1. All MVCs were performed in a joint configuration that maximized EMG activity. Resistance was provided by chains mounted to a wall and aligned parallel to the line of pull. A consistent shoulder joint position was ensured by placing rigid wedges between the trunk and arm.

Applied force and EMG data were collected (1000 Hz) for eight exercises that were performed below shoulder height. Applied force was measured with a force plate (Bertec Corp., Columbus, Ohio) or a force transducer (Entran Devices Inc., Fairfield, New Jersey) (maximal range, ±1115 N) placed in series with an elastic resistance device (Body Lines, Innovation Sports, Irvine, California). The EMG data (bandwidth 10 to 2000 Hz) were collected using Myosoft software (Noraxon USA Inc., Scottsdale, Arizona). The input impedance of the EMG amplifier was less than 10 megaohms, with a common-mode rejection ratio of 85 dB and a gain of 1000.

To assist in the delineation of exercise phases, a lateral view of each subject was recorded using a 30-Hz video camera. A manual timing signal was recorded with the Myosoft software and video camera, providing for synchronization of video and EMG data.

All exercises were completed in a slow, controlled manner with the aid of a metronome. Each phase of the exercises was performed at 54 beats per minute (bpm), except the press-up (60 bpm), shoulder extension (100 bpm), and serratus anterior punch (100 bpm) exercises. The exercises using the elastic resistance device for resistance were performed at a distance where the subject could perform no more than 10 repetitions while maintaining consistent metronome speed. The exercise order was randomly selected for the first subject and subsequently balanced to eliminate any order effects. The exercises were performed as follows.

The *push-up plus* began with the subject in a prone position with the hands shoulder-width apart and the chest near the ground.[25] The subject then extended his elbows to a standard push-up position and continued to rise up by protracting the scapula. The subject returned to the starting position by retracting the scapula and flexing the elbows.

The *knee push-up plus,* a modification of the push-up plus, was performed exactly like the push-up plus except that body weight was supported by the hands and knees, rather than the hands and feet.

The *press-up* was performed from a seated position, with feet off the floor, hands at the level of the buttocks, and the trunk and elbows slightly flexed.[31] The subject then slowly raised his body up off the chair by straightening his arms. The subject held this position for 3 seconds and then slowly returned to the starting position.

Shoulder extension was performed while the subject stood with his chest facing the wall, knees slightly bent, and feet shoulder-width apart in a split stance.[13,23] The lead leg was the leg opposite the hand gripping the elastic

TABLE 1
Muscles Tested, Electrode Position, and MVC Protocol

Muscle	Electrode position	MVC joint position	MVC Action
Upper trapezius	At the angle of the neck and shoulder, over the belly of the muscle in line with the muscle fibers.	Arms fully extended, subject standing on two chains grasping the handles at mid-thigh.	Shoulder shrug (Scapular elevation and retraction)
Middle trapezius	Centered vertically between the medial border of the scapula and the spines of the thoracic vertebrae (T-1 to T-6).	Elbow flexed 15°, shoulder flexed 90° and internally rotated 45°.	Scapular retraction
Anterior deltoid	Two to three finger-breadths below the acromion process, over the muscle belly, in line with the fibers.	Elbow flexed to 90°, no shoulder flexion.	Shoulder flexion
Posterior deltoid	Two finger-widths behind the angle of the acromion, over the muscle belly, in line with the fibers.	Elbow flexed 90°, shoulder abducted 45°, and internally rotated 45°.	Shoulder extension
Serratus anterior	Below the axilla, anterior to the latissimus, placed vertically over the ribs 4–6.	Elbow flexed 45°, shoulder abducted 75° and internally rotated 45°.	Scapular protraction

resistance device, and the other leg was behind the midline of the sagittal plane. The handle of the elastic resistance device was grasped at waist height with the elbow flexed 90° and the humerus in the neutral position. With the arm kept at the side of the body, the subject fully extended the humerus while flexing the elbow and then slowly returned to the starting position.

The *serratus anterior punch* was performed while the subject stood with his back to the wall, knees slightly bent, and feet shoulder-width apart in a split stance.[29] The handle of the elastic resistance device was grasped at shoulder height with the elbow fully extended, the humerus was internally rotated 45°, and the scapula was in a retracted position. The subject then protracted and retracted the scapula.

The *forward punch* was performed as the subject stood with his back to the wall, with knees slightly bent and feet shoulder-width apart in a split stance.[5,34] The subject grasped the elastic resistance device with his arm at the side of his body and his elbow flexed 90°. The subject flexed the shoulder and extended the elbow until his hand was at shoulder height with the elbow slightly flexed.

Scaption was performed while standing with the knees slightly bent and the feet shoulder-width apart.[31] A dumbbell was firmly grasped in one hand at the side of the body with the elbow fully extended and the shoulder externally rotated 45° (thumb up). The subject performed humeral elevation in the scapular plane up to shoulder height, then slowly returned to the starting position.

The *dynamic hug* was performed while standing with the back toward the wall, knees slightly bent, and the feet shoulder-width apart. The subject began with the elbow flexed 45°, the arm abducted 60°, and the shoulder internally rotated 45°. The subject then horizontally flexed the humerus by following an arc described by his hands (hugging action) (Fig. 1). Once the subject's hands touched together (maximum scapular protraction), he slowly returned to the starting position.

Analysis

Each exercise was divided into phases of increasing and decreasing force. The press-up exercise had an additional isometric phase called the press-up hold.[25] The push-up and plus phases for the knee push-up and push-up plus exercises were further divided into phases of increasing and decreasing force. The increasing force phase of the push-up began with the chest near the ground (bottom) and ended with the arms fully extended (top). The increasing force phase of the push-up plus began with the arms fully extended and continued until the scapulae were maximally protracted (plus). The decreasing force phase of the push-up plus and push-up were simply the reverse, with one repetition ending as the chest neared the ground. The same phase demarcations were used for the knee push-up plus.

All EMG data were processed with a 50-ms, root-mean-square, moving window algorithm. The window duration was chosen to smooth random myoelectric signals such that the resulting envelope was as repeatable as possible

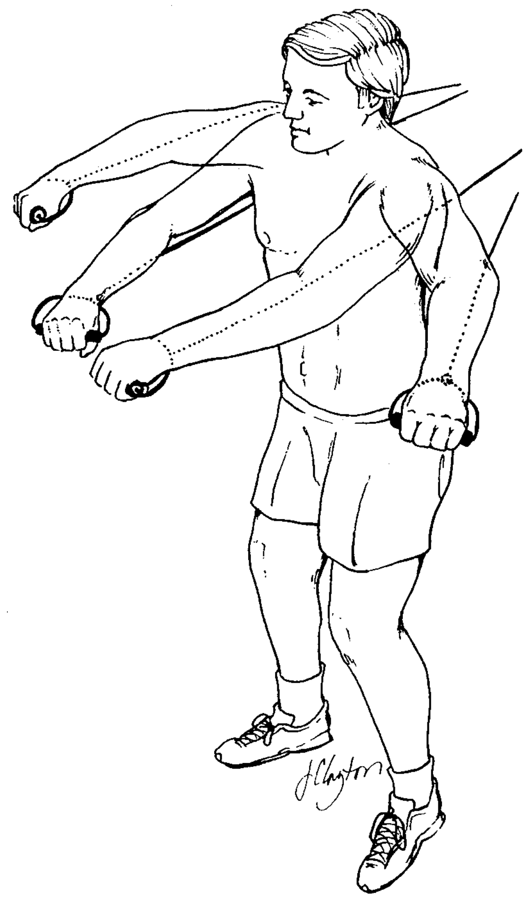

Figure 1. The dynamic hug exercise horizontally flexes the humerus at a constant 60° of humeral elevation while the hands follow an imaginary arc until maximum protraction is attained.

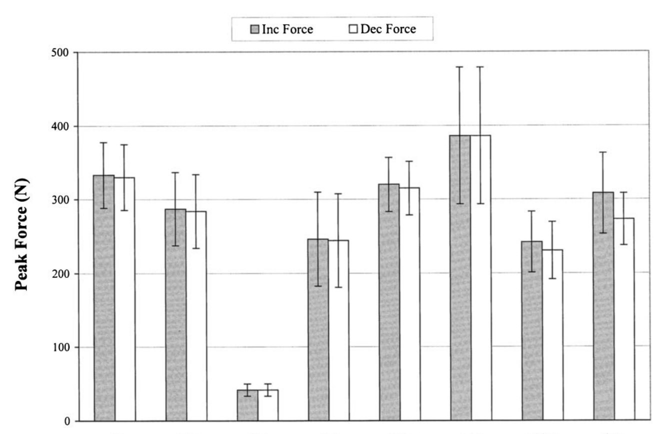

Figure 2. Mean peak force (in newtons) and standard deviations for the increasing (Inc Force) and decreasing force (Dec Force) phases for the eight shoulder rehabilitation exercises: forward punch (FP), serratus anterior punch (SAP), scaption (SCP), shoulder extension (SE), dynamic hug (HUG), press-up (PRU), knee push-up plus (KPU+), and push-up plus (PU+).

without compromising true muscle activity.[11] Maximum EMG reference values were calculated for each muscle using the average of the five peak EMG signals and represented 100% MVC. Muscle activity during the exercise was categorized as minimal (0% to 20% MVC), moderate (21% to 50% MVC), or marked (>50% MVC).[23]

Ten trials of EMG and force data for each subject were analyzed to determine average and peak amplitudes for all exercises during each phase. In an effort to be clinically relevant, we expressed the EMG data as a percentage of MVC (%MVC) and provided a relative measure of muscle activity. Exercises that stimulated muscles with moderate or marked average amplitudes (>20% MVC) in both the increasing and decreasing force phases were reported.

Statistics

Descriptive statistics were calculated for peak and average amplitudes of muscle activity and force within each phase for all muscles. Statistical trends of peak and average serratus anterior muscle activity, for both the increasing and decreasing force phases, were determined through simple regression analyses. The mean EMG activity of each exercise was rank ordered, and the least-squares statistical method was used to determine significant linear relationships. An adjusted r^2 value near 1.0 indicated a strong relationship between the ranked exercise order and progressive serratus anterior muscle activity. The level of statistical significance was set at $P \leq 0.05$.

RESULTS

Group means and standard deviations for the applied peak force are graphically presented in Figure 2. Mean peak force (for one arm) ranged from 42 N in scaption to 386 N in the press-up. All other exercises resulted in a peak force ranging from 225 to 325 N.

Group means and standard deviations for average and peak EMG activity are presented in Table 2. Only those muscles that elicited average EMG activity greater than 20% MVC during both the increasing and decreasing force phases are presented.

As is typical with EMG data, there was substantial intersubject variation in muscle activity for the serratus anterior muscle, with coefficients of variation ranging from 28% to 97%. However, reliability for average and peak amplitude was excellent, as indicated by intraclass correlation coefficients that ranged from $r = 0.977$ to 0.990. Thus, despite the large variability between subjects, EMG activity was highly consistent and reproducible within subjects for all exercises.

Serratus anterior muscle activity ranged from 3% to 109% MVC. The dynamic hug, scaption, serratus anterior punch, and the knee and push-up plus exercises resulted in the greatest muscle activity for the serratus anterior muscle. The push-up plus elicited the greatest average serratus anterior muscle activity (63% MVC), and the dynamic hug the greatest peak serratus anterior muscle activity (109% MVC), both in the increasing force phase.

Upper trapezius muscle activity ranged from 5% to 97% MVC. Scaption and the dynamic hug exercises resulted in the highest activity for the upper trapezius muscle. Scaption elicited the greatest average (44% MVC) and peak (97% MVC) upper trapezius muscle activity, both during the increasing force phase.

Middle trapezius muscle activity ranged from 9% to 91% MVC. Scaption was the only exercise that consistently elicited activity greater than 20% MVC. Scaption had the greatest average (41% MVC) and peak (91% MVC) middle trapezius muscle activity, both during the increasing force phase.

Anterior deltoid muscle activity ranged from 7% to 185% MVC. The forward punch, serratus anterior punch, scaption, dynamic hug, press-up, and the knee and push-up plus exercises demonstrated muscle activity above 20% MVC. The push-up plus evoked the largest average (103% MVC) and peak (185% MVC) anterior deltoid muscle activity, both in the increasing force phase.

Posterior deltoid muscle activity ranged from 6% to 124% MVC. The shoulder extension and scaption exercises consistently elicited EMG activity greater than 20% MVC. Shoulder extension evoked the greatest average (43% MVC) and peak (124% MVC) posterior deltoid muscle activity, both in the increasing force phase.

Continuum Design

The four regression analyses of the rank-ordered exercises on serratus anterior muscle EMG activity are displayed in Figures 3 through 6. All regression analyses demonstrated a significant linear trend ($P = 0.05$) and accounted for 64% to 86% of the variance in EMG activity.

The four regression analyses were incorporated into an overall continuum for serratus anterior muscle activity. Muscle activity was rank-ordered by exercise, with equal weighting given to average and peak EMG amplitudes, and to increasing and decreasing force phases (Table 3). The exercise that consistently elicited the greatest EMG activity for the serratus anterior muscle represented the top-ranking exercise. The forward punch and press-up had the same mean ranking. Because the forward punch had a higher peak EMG magnitude, it was given the higher rank in the overall continuum.

DISCUSSION

We designed a continuum of scapulohumeral exercises based on serratus anterior muscle activity. The importance of a conditioned serratus anterior muscle has been highlighted in EMG studies of sports such as swimming,[28] throwing,[9] and tennis.[30] A fatigued serratus anterior muscle will reduce scapular rotation and protraction and allow the humeral head to translate anteriorly and superiorly, possibly leading to secondary impingement and rotator cuff tears.[1] This study provides the clinician with several serratus anterior muscle exercises that can be implemented within a range of motion that is mechanically optimal for early shoulder rehabilitation.

The push-up plus, dynamic hug, serratus anterior punch, scaption, and the knee push-up plus exercises em-

TABLE 2
Means and Standard Deviations (in Parentheses) Expressed as a Percentage of MVC for Peak and Average Amplitude in Muscles with Average Amplitudes Greater than 20% MVC

Exercise	Muscle	Peak amplitude			
		Increasing	Decreasing		
Forward punch	Anterior deltoid	177.8 (79.0)	136.4 (69.1)		
Serratus anterior punch	Anterior deltoid	160.7 (79.3)	129.3 (62.9)		
	Serratus anterior	94.4 (30.8)	76.5 (27.5)		
Scaption	Upper trapezius	97.0 (41.1)	83.7 (40.9)		
	Middle trapezius	91.1 (34.6)	75.4 (28.2)		
	Anterior deltoid	183.3 (91.8)	157.2 (84.2)		
	Posterior deltoid	76.6 (41.8)	62.9 (34.6)		
	Serratus anterior	92.2 (28.5)	85.8 (28.6)		
Shoulder extension	Posterior deltoid	123.7 (75.4)	81.2 (54.8)		
Dynamic hug	Upper trapezius	51.8 (27.9)	46.0 (23.3)		
	Anterior deltoid	173.8 (82.3)	129.1 (70.8)		
	Serratus anterior	109.0 (30.7)	74.1 (24.7)		
		Bottom to Hold	Hold	Hold to Bottom	
Press-up	Anterior deltoid	104.1 (78.2)	123.0 (84.6)	53.8 (41.5)	
		Top to Bottom	Bottom to Top	Top to Plus	Plus to Top
Knee push-up plus	Anterior deltoid	89.5 (55.6)	127.0 (72.7)	82.8 (57.0)	70.6 (44.7)
	Serratus anterior	47.3 (16.7)	68.5 (22.4)	72.0 (27.0)	65.3 (28.4)
Push-up plus	Anterior deltoid	147.6 (81.7)	185.2 (85.1)	170.5 (80.5)	142.0 (68.8)
	Serratus anterior	73.0 (29.2)	100.0 (37.5)	104.0 (38.0)	91.6 (33.1)

phasized scapular rotation and protraction and elicited the greatest serratus anterior muscle activity. The results of the push-up plus and scaption exercises are in agreement with previous studies that have recommended both of these exercises for scapular strengthening.[4,20,25] An unreported knee push-up plus was determined to be more user friendly than the push-up plus because it used less applied force and elicited similar EMG amplitudes. This study also provides support for the previously unsubstantiated serratus anterior punch[29] and dynamic hug exercises, since they both resulted in marked serratus anterior muscle activity.

In contrast, the forward punch, shoulder extension, and press-up exercises did not activate the serratus anterior muscle above minimal EMG levels. The EMG activity we saw during the forward punch exercise was similar to that reported in a paper by Hintermeister et al.,[12] despite the fact that they reported lower applied forces. In addition to the small scapular range of motion provided by the forward punch, the pectoralis major muscle may have been used as the prime mover and may account for the low serratus anterior muscle EMG amplitudes. The shoulder extension and press-up exercises used the serratus anterior muscle eccentrically as an antagonist to control scapular retraction. Low EMG amplitudes were expected because, at a given load, eccentric muscle actions demonstrate lower amplitudes than concentric muscle actions.[24] Thus, for these two exercises, EMG amplitude may not be an optimal tool to measure exercise proficiency.

A primary emphasis in shoulder rehabilitation is to restore the strength and coordination of the upper trapezius and serratus anterior muscles because they work together to upwardly rotate the scapula for overhead movements. Scaption and the dynamic hug exercises both activated the upper trapezius and serratus anterior muscles above minimal levels to perform upward scapular rotation. Furthermore, scaption was the only exercise to activate the middle trapezius muscle above 20% MVC. These results were similar to those of other studies where progressive humeral elevation in the scapular plane induced middle and upper trapezius and serratus anterior muscle activity.[2,14,22] Thus, while both exercises may be used to effectively train the natural force couple between the serratus anterior and the upper trapezius muscles, scaption may be more effective.

Interestingly, the knee and push-up plus did not substantially recruit the upper trapezius muscle, even though

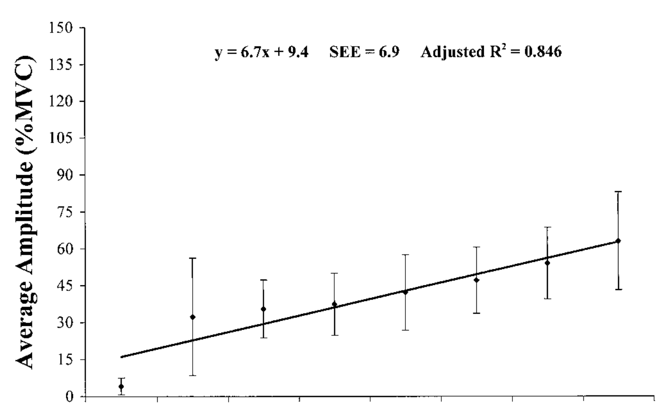

Figure 3. Average EMG amplitude (%MVC) and standard deviations recorded from the serratus anterior muscle during the increasing force phase for eight exercises. A significant linear trend (P = 0.05) was demonstrated for the rank-ordered data. See legend at Figure 2 for abbreviations. SEE, standard error of estimate.

TABLE 2
Continued

Average amplitude			
Increasing	Decreasing		
77.5 (32.9)	43.1 (20.1)		
81.0 (41.6)	58.3 (26.6)		
47.0 (13.5)	31.4 (9.8)		
43.7 (19.0)	31.3 (13.6)		
41.3 (15.0)	28.4 (9.9)		
83.3 (40.5)	52.4 (26.3)		
30.3 (17.1)	20.4 (10.4)		
37.3 (12.6)	24.2 (7.9)		
42.8 (31.2)	22.6 (15.5)		
23.1 (12.6)	20.3 (8.9)		
89.7 (43.8)	50.2 (26.0)		
54.1 (14.6)	28.1 (9.5)		
Bottom to Hold	Hold	Hold to Bottom	
51.1 (40.1)	52.2 (34.8)	53.8 (41.5)	
Top to Bottom	Bottom to Top	Top to Plus	Plus to Top
42.5 (27.7)	61.7 (34.7)	45.1 (29.2)	36.0 (21.2)
22.9 (7.9)	33.9 (10.1)	42.1 (15.4)	35.2 (12.7)
73.9 (43.8)	100.2 (47.8)	102.9 (50.5)	75.5 (37.4)
35.3 (14.0)	52.1 (16.9)	63.1 (19.9)	53.0 (17.7)

the scapula maintained an upwardly rotated position throughout both exercises. Load-bearing exercises for the shoulder, regardless of whether the hand is fixed or moving,[7] are intended to promote proximal humeral stability with scapular stabilization.[17] Increased proximal joint stability, derived from body weight compressing the joint, may retain upward scapular rotation, resulting in reduced levels of upper trapezius muscle activity.

All exercises induced either anterior or posterior deltoid muscle activity greater than 20% MVC. This finding highlights the important relationship between the deltoid and scapular rotator muscles during humeral elevation. The deltoid muscles attain maximum range of motion and power production when the scapula is upwardly rotated throughout humeral elevation.[14,22] Because of the angle of pull of the deltoid, marked activity of this muscle may cause superior humeral migration and, thus, shoulder pain.[17,27] However, these muscles provide scapulohumeral stability in the range of 30° to 60° of abduction by compressing the humerus into the glenoid.[21] Therefore, exercises that begin with, and maintain, humeral elevation (such as the dynamic hug) may assist the rotator cuff muscles with joint stability and avoid excessive superior shear forces that may be detrimental to rehabilitation.

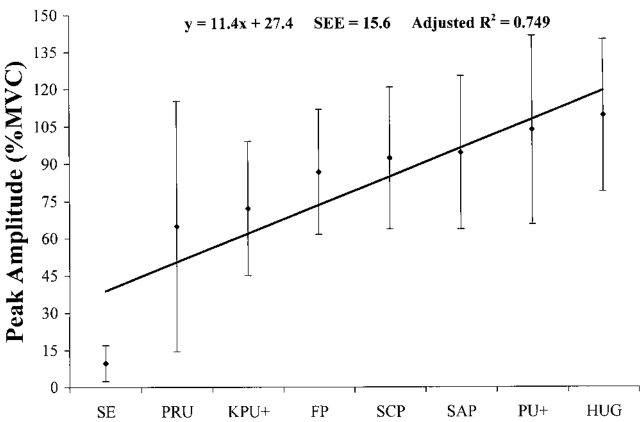

Figure 4. Peak EMG amplitude (%MVC) and standard deviations recorded from the serratus anterior muscle during the increasing force phase for eight exercises. A significant linear trend ($P = 0.05$) was demonstrated for the rank-ordered data. See legend at Figure 2 for abbreviations. SEE, standard error of estimate.

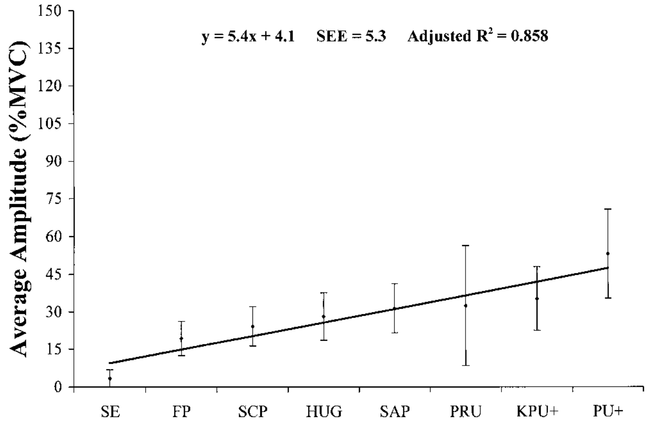

Figure 5. Average EMG amplitude (%MVC) and standard deviations recorded from the serratus anterior muscle during the decreasing force phase for eight exercises. A significant linear trend ($P = 0.05$) was demonstrated for the rank-ordered data. See legend at Figure 2 for abbreviations. SEE, standard error of estimate.

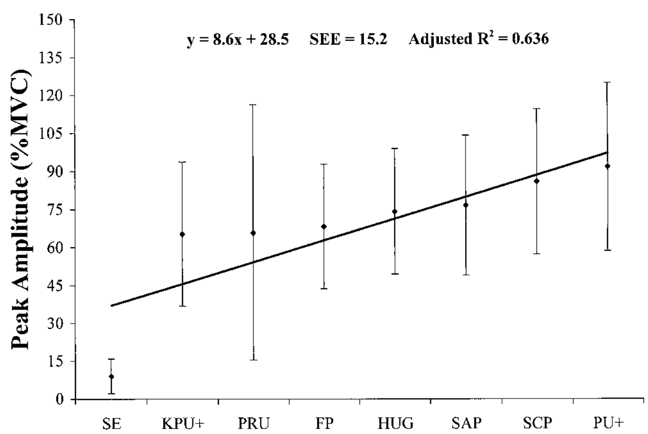

Figure 6. Peak EMG amplitude (%MVC) and standard deviations recorded from the serratus anterior muscle during the decreasing force phase for eight exercises. A significant linear trend ($P = 0.05$) was demonstrated for the rank-ordered data. See legend at Figure 2 for abbreviations. SEE, standard error of estimate.

TABLE 3
Final Rank Order of Exercises for Activating the Serratus Anterior Muscle

Final order	Exercise	Increasing force phase[a]		Decreasing force phase	
		AA	PA	AA	PA
1	Push-up plus	1	2	1	1
2	Dynamic hug	2	1	5	4
3	Serratus anterior punch	3	3	4	3
4	Scaption	5	4	6	2
5	Knee push-up plus	4	6	2	7
6	Forward punch	6	5	7	5
7	Press-up	7	7	3	6
8	Shoulder extension	8	8	8	8

[a] AA, average amplitude; PA, peak amplitude.

Peak and average EMG amplitudes, from both force phases, were integrated into an overall exercise continuum. In a dynamic situation, the relationship between EMG activity and muscle force is multifactorial.[3] However, investigators have generally inferred muscular tension to increase, whether linearly or nonlinearly, with the EMG signal.[3,12] Thus, exercises with greater peak EMG amplitudes may be important for strength training or used to determine a safe upper limit for postsurgical muscle activity. The average EMG amplitude represents the arithmetic mean of muscular activity within a force phase and may be important for endurance training. Exercises with larger average amplitudes may offer greater muscular challenges and require greater physiologic efforts. If either the peak or average EMG amplitude is of primary concern in a rehabilitation protocol, one of the four parameter and phase-specific continuums may be applied rather than the overall continuum.

Applied force was not included in the overall design of the continuum because each exercise demonstrated scapular movements that were different in magnitude and direction (for example, protraction, depression). Exercises that did not use scapular protraction, rotation, or a combination, elicited minimal levels of serratus anterior muscle activity, regardless of the peak force. Therefore, it may be more important to select an exercise based on the direction of the applied force and the associated scapular actions, while adjusting the resistance to accommodate individual needs.

SUMMARY

Average and peak serratus anterior muscle activity was documented for eight shoulder rehabilitation exercises performed below 90° of humeral elevation, and an exercise continuum was designed. The data illustrate that substantial serratus anterior muscle activity can be achieved in a range of motion that is recommended and safe for most patients with shoulder lesions. The selection of an appropriate exercise progression focused on serratus anterior muscle activity but may depend on other factors as well (for example, shear or compressive forces, user friendliness, or number of muscles recruited). However, the exercise continuum is used most efficiently when the clinician chooses an exercise that matches the movement limitations and goals of the patient.

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