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The Effect of a Combination of Scapular Protraction With Resistance and Forward Flexion of the Shoulder on Serratus Anterior Muscle Activity

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Abstract

Background: The functioning of the serratus anterior (SA) muscle is essential to normal scapulohumeral rhythm during forward flexion (FF) of the shoulder. Also, SA weakness and overuse of the upper trapezius (UT) is observed in patients with shoulder dysfunction and trapezius myalgia. We designed a combination exercise involving FF and scapular protraction with resistance (CFFSP) to activate the SA muscle and to deactivate the UT muscle.

Objects: The purpose of this study was to determine whether or not CFFSP would be more effective in activating the SA muscle than FF alone and FF with scapular protraction (FFP).

Methods: Nineteen subjects (12 men and 7 women) participated in this study and performed FF, FFP, and CFFSP at 120°. Surface electromyography was applied to the SA, UT, and pectoralis major (PM) muscles, as was one-way analysis of variance (ANOVA) with repeated measures. Statistical significance was set at .05. Bonferroni adjustment was used to counteract the problem of multiple comparisons, with a statistical level of significance of .017 (.05/3).

Results: A statistically significant difference was found in relation to the three positions for the SA muscle ($p<.001$) and the SA/UT ratio ($p=.005$) using ANOVA. Significantly different results, depending on the position, were also demonstrated using the Bonferroni post-hoc test for the SA muscle (FF=28.27±16.20, FFP=45.66±15.81, and CFFSP=62.4±27.21) and for the SA/UT ratio (FF=3.04±2.14, FFP=3.61±2.38, and CFFSP=5.95±3.01). Significant differences between the three positions was not found regarding the average amplitude of SA/PM muscle ratio (SA/PM: $p=.060$).

Conclusion: We recommend the use of CFFSP to strengthen the SA muscle at 120°.

Key Words: Forward flexion, Protraction, Serratus anterior, Upper trapezius.

Introduction

Functioning of the serratus anterior (SA) muscle contributes to the ability to maintain a normal scapulothoracic position and motion, such as upward rotation, protraction, and posterior tilt during forward flexion (FF) of the shoulder (FFS) (Decker et al, 1999; Ludewig and Cook, 2000; Ludewig et al, 2004; Marshall and Murphy, 2006; Park and Yoo, 2011; Thigpen et al, 2010). SA muscle function is essential to ensure normal scapulohumeral rhythm during FFS.

Scapular motion during FFS should be commenced at various shoulder flexion angles (Ludewig and Cook, 2000; Lukasiewicz et al, 1999). Scapular upward rotation and posterior tipping markedly increase at an angle of 120° during FFS (Ludewig and Cook, 2000; Lukasiewicz et al, 1999). Moseley et al (1992) reported that average SA muscle activity equated to 96% of maximum manual muscle strength at an angle between 120° and 150° during FFS. Impaired SA

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muscle function is associated with abnormal scapulohumeral rhythm during FFS (Ludewig and Cook, 2000; Ludewig et al, 2004).

Identification of the most effective exercise with which to activate the SA muscle during functional movement, including FFS, has been investigated in many studies (Cools et al, 2007; Decker et al, 1999; Hardwick et al, 2006; Ludewig et al, 2004; Martins et al, 2008; McClure et al, 2004). Various SA muscle exercises, such as FF, humeral elevation push-up plus, weight-resisted elevation of the humerus and wall slide, have been introduced.

It was reported in previous studies that the push-up plus exercise was effective in SA muscle strengthening (Hardwick et al, 2006; Lehman et al, 2006; Ludewig et al, 2004; Sandhu et al, 2008). However, Hardwick et al (2006) observed that the wall slide exercise was more effective in activating the SA muscle than the push-up plus exercise in a humeral position above 90° during FFS. It was also found that the push-up plus exercise was more efficient in ensuring SA muscle activation than the conventional push-up plus exercise in a humeral position of 120° in FFS (Hwang et al, 2016). Therefore, SA muscle exercises performed above 90° FFS are considered more effective in activating the SA muscle than those at 90° FFS.

Weakness in the SA muscle contributes to excessive contraction of the upper trapezius (UT) (Ludewig et al, 2004) and pectoralis major (PM) muscles (Kim et al, 2010; Park et al, 2013) during FFS. Excess activation of the UT muscle, combined with decreased control with the SA muscle, has been proposed as a contributing factor to abnormal scapular motion during FFS (Cools et al, 2007; McClure et al, 2004; Ludewig and Cook, 2000; Lukasiewicz et al, 1999; Peat and Grahame, 1977). In addition, SA muscle weakness and overuse of the UT muscle has been observed in patients with shoulder dysfunction (Martins et al, 2008) and trapezius myalgia (Vollenbroek-Hutten et al, 2006). Weakness of the SA muscle may cause shoulder pathologies, such as subacromial impingement, bursitis, and rotator cuff injury. Therefore, strengthening the SA muscle and reducing the UT/SA muscle ratio during FFS is essential in preventing the incidence of shoulder pathology (Ludewig et al, 2004).

We designed a combination exercise involving FFS and scapular protraction with resistance (CFFSP) to activate and deactivate the SA and UT muscles, respectively. This exercise combines FF and self-resistive scapular protraction, involving the use of the opposite hand in close kinetic chain exercise, i.e., pushing against a wall. The study objective was to determine whether or not CFFSP would activate the SA muscle more effectively than FF and FF with scapular protraction (FFP). We hypothesized that SA muscle activity would be greatest during CFFSP exercise.

Methods

Subjects

Nineteen subjects (12 men and 7 women) aged 21~32 years, with a mean age of 22.5±2.0 years, who were students at Yonsei University, Wonju Campus, South Korea, voluntarily participated in this study. Inclusion criteria included being healthy, free of metabolic, neuromuscular, and musculoskeletal disorders, no history of shoulder pain, and the absence of pain in any part of the body at the time of testing. Exclusion criteria included the presence of pain in the shoulder region and a previous history of shoulder surgery. The mean height and weight of the subjects was 168.9±7.3 ㎝ and 66.4±14.4 ㎏, respectively (Table 1). The study was approved by the

Table 1. General characteristics of the subjects (N=19)

Parameters	Mean±SD[a]
Age (year)	22.5±2.0
Height (㎝)	168.9±7.3
Weight (㎏)	66.4±14.4

[a]mean±standard deviation.

Institutional Review Board of Yonsei University (1041849-201603-BM-008-01).

Instrumentation and data reduction

Activation of the UT, SA, and PM muscles was measured by surface electromyography (EMG) (TeleMyo 2400T, Noraxon, Scottsdale, AZ, USA). Two separate bipolar (20 ㎜ center-to-center) surface electrodes were placed two centimeters apart on the SA muscle in the dominant arm, just below the axilla at the level of the inferior angle of the scapula, anterior to the latissimus dorsi. UT muscle electrodes were attached at a point approximately halfway between the acromion and the spinous processes of the seventh cervical vertebrae. The electrodes for the PM muscle (sternal fiber) were attached to the chest wall, horizontal to the arising muscle mass (2 ㎝ from the axillary fold) (Criswell, 2010).

The signals were collected using MyoResearch XP Master Edition (Noraxon Inc., Scottsdale, USA). A bandpass filter of between 20 ㎐ and 450 ㎐ was applied to the raw EMG signals and the root mean square values were calculated using a 50 ㎳ window.

The processed data were recorded at a sampling rate of 1000 ㎐. Maximum voluntary contraction (MVC) was performed to normalize the EMG signals. Each subject was asked to position the shoulder flexed at 120° for the purpose of measuring MVC in the SA muscle. Maximum resistance against scapular protraction was applied to the elbow by the examiner (Kendall et al, 2005). MVC in the PM muscle was determined while the subjects adducted their shoulders to a 90° flexion angle with their palms pressed together. Resistance was applied by the examiner by pushing the palms of the participants together, while in the supine position (Dark et al, 2007). MVC in the UT muscle was measured during resisted isometric scapular elevation. The participants were seated during scapular elevation (Kendall et al, 2005). Each MVC was collected for a period of five seconds and the mean values from the middle three seconds were averaged to calculate the mean value. All data are expressed as a percentage of the MVC.

Procedures

Each exercise was performed three times, with a resting time of three minutes between them. Prior to the trials, the order of the exercises was assigned, based on a random number generated using Microsoft Excel ver. 2010 (Microsoft Corporation, Washington, US) to eliminate any order effects. The subjects sat with their backs placed flat against a chair in an upright sitting position with the hip and knee joints at 90° flexion. The participants positioned their feet shoulder width apart and in contact with the floor, with the two femurs in a parallel position. The target bar was placed next to the subjects to control the plane and degree of flexion. An angle of 120° shoulder flexion was measured in each subject using a smartphone inclinometer to determine the height of the horizontal bars.

Forward flexion

The subjects were instructed to lift the arm with the elbows extended and pronation of the forearm and wrist in a neutral position, while brushing against the vertical pole with the dorsal side of the forearm to maintain the shoulder in the sagittal plane. The subjects maintained the FF posture for five seconds, while slightly touching the horizontal bar which was placed at 120° shoulder flexion.

Forward flexion with scapular protraction

The study participants were asked to lift their arm with the elbow extended and protract the scapular without trunk rotation (protraction). With pronation of the forearm and wrist in a neutral position, they simultaneously lifted the arm, while brushing the vertical pole with the dorsal side of the forearm to maintain the shoulders in the sagittal plane. They maintained FF with protraction for five seconds, while slightly touching the horizontal bar which was placed at 120° shoulder flexion.

Combination exercise involving forward flexion of the shoulder and scapular protraction with resistance

The subjects were instructed to grip the back of the dominant hand (the right side in every instance) with the palm of the non-dominant hand. They lifted the arm with the elbow extended and the wrist in a neutral position. The wrist brushed along the vertical pole during the lifting process, while the dominant hand simultaneously pushed down on the non-dominant hand. Thereafter, the non-dominant hand pulled up the dominant hand (resistance against protraction). The subjects maintained FF with resistance against protraction for five seconds while touching the horizontal bar slightly during 120° shoulder flexion. The subjects sat with their backs placed flat against a chair in an upright sitting position and wrist touch horizontal bar and vertical pole during maintaining FF with resistance against protraction in order to prevent compensative motion in scapular and trunk.

Statistical analysis

SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) was used to analyze any differences between the SA/UT and the SA/PM ratio. The Kolmogorov-Smirnov test was conducted to ensure normal distribution of the variables and this was confirmed. Thus, a parametric statistical test was conducted. One-way analysis of variance (ANOVA) with repeated measures was applied. Statistical significance was set at .05. Bonferroni adjustment was used to eliminate any differences and statistical significance was set at .017 (.05/3).

Results

The average amplitude of SA, PM, UT muscle activity and standard deviation according to the position used are shown in Table 2. A statistically significant difference between the three positions with respect to average amplitude of the SA muscle and the SA/UT muscle ratio was demonstrated using ANOVA ($p<.017$). Significantly different results, again dependent on the position used, were observed using the Bonferroni post-hoc test for the average amplitude of the SA muscle (FF vs. FFP: $p=.034$ and FF vs. CFFSP: $p<.001$; Table 2; Figure 2), and for the SA/UT ratio (FF vs. FFP: $p=.009$ and FF vs. CFFSP: $p=.019$; Table 3; Figure 3). Significant differences between the three positions was not found regarding the average amplitude of the PM, UT muscles and the SA/PM muscle ratio (PM: $p=.840$, UT: $p=.114$, SA/PM: $p=.060$; Table 3; Figure 4).

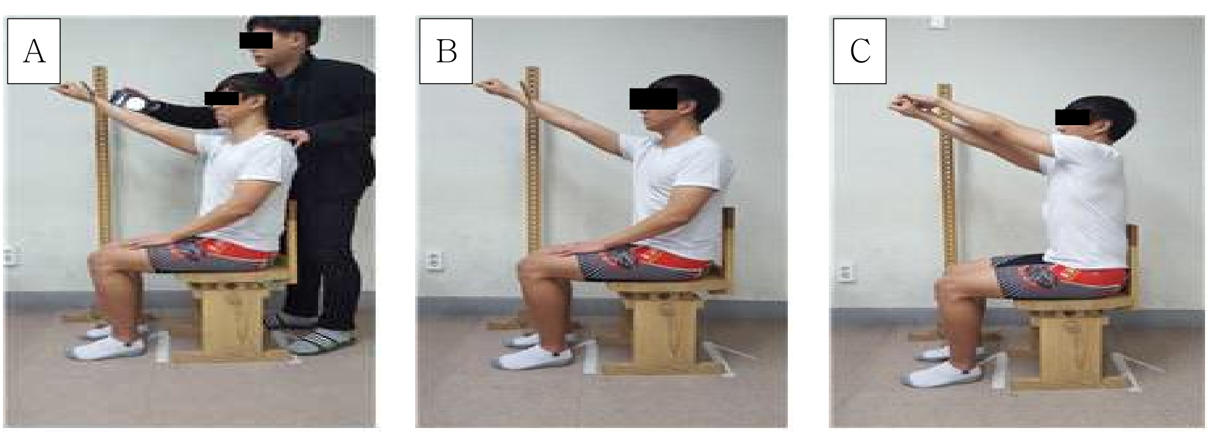

Figure 1. The serratus anterior muscle being exercised in three positions (A) forward flexion, (B) forward flexion with protraction, and (C) combination exercise involving forward flexion of the shoulder and scapular protraction with resistance.

Table 2. A depiction of the average amplitude of serratus anterior, pectoralis major, and upper trapezius muscle activity and standard deviation according to the position used

Muscle	Position (%MVC[a])			F	p
	FF[b]	FFP[c]	CFFSP[d]		
SA[e]	28.27±16.20[f]	45.66±15.81	62.45±27.21	13.290	<.001*
PM[g]	15.78±9.75	16.06±10.05	17.62±11.15	.170	.840
UT[h]	12.97±12.79	20.65±17.42	12.65±7.01	2.260	.114

[a]maximal voluntary contraction, [b]forward flexion, [c]forward flexion with scapular protraction, [d]combination exercise involving forward flexion of the shoulder and scapular protraction with resistance, [e]serratus anterior, [f]mean±standard deviation, [g]pectoralis major, [h]upper trapezius, *$p<.017$.

Table 3. The average and standard deviation of the serratus anterior/upper trapezius and the serratus anterior/pectoralis ratio, according to the position used

Muscle	Position			F	p
	FF[a]	FFP[b]	CFFSP[c]		
SA[d]/UT[e]	3.04±2.14[f]	3.61±2.38	5.95±3.01	5.890	.005*
SA/PM[g]	2.53±2.19	3.88±2.75	4.97±4.02	2.974	.060

[a]forward flexion, [b]forward flexion with scapular protraction, [c]combination exercise involving forward flexion of the shoulder and scapular protraction with resistance, [d]serratus anterior, [e]upper trapezius, [f]mean±standard deviation, [g]pectoralis major, *$p<.017$.

Discussion

Activity in the SA muscle was shown to be greatest during CFFSP exercise in this study. To the best of our knowledge, this is the first study in which the activity of the SA, UT, and PM muscles has been investigated and the ratio of the activity in the SA/UT muscles and that in the SA/PM muscles has been investigated during CFFSP compared FF and FFP. Activation of the SA muscle is essential for the rehabilitation of shoulder dysfunction caused by weakness in this muscle and by muscle strength

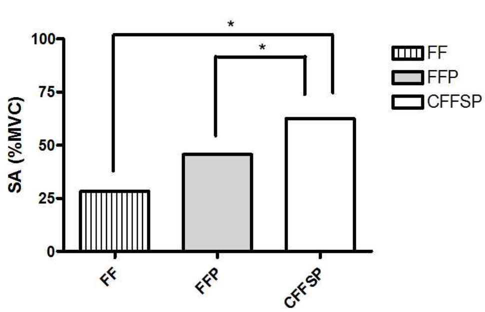

Figure 2. A comparison of SA muscle activity using the three different exercises (CFFSP: combination exercise involving forward flexion of the shoulder and scapular protraction with resistance, FF: forward flexion, FFP: forward flexion with scapular protraction, SA: serratus anterior, MVC: maximal voluntary contraction).

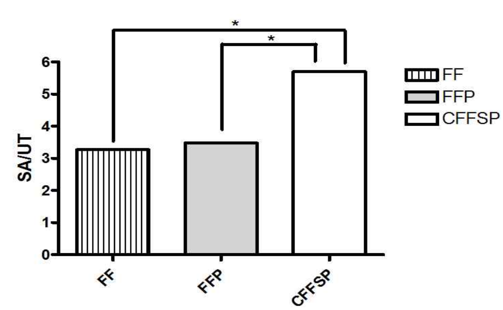

Figure 3. A comparison of SA/UT muscle activity using the three different exercises (CFFSP: combination exercise involving forward flexion of the shoulder and scapular protraction with resistance, FF: forward flexion, FFP: forward flexion with scapular protraction, SA: serratus anterior, UT: upper trapezius).

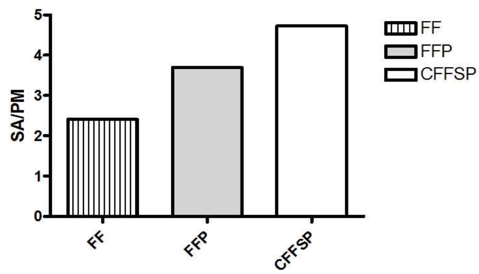

Figure 4. A comparison of SA/PM muscle activity using the three different exercises (CFFSP: combination exercise involving forward flexion of the shoulder and scapular protraction with resistance, FF: forward flexion, FFP: forward flexion with scapular protraction, PM: pectoralis major, SA: serratus anterior).

imbalance in the scapulothoracic and glenohumeral joints (Cools et al, 2004; Madeleine et al, 2008).

In previous studies, the push-up plus exercise was reported to be the effective exercise for the purposes of activating the SA muscle (Lehman et al, 2006; Ludewig et al, 2004; Sandhu et al, 2008). In recent studies (Castelein et al, 2016; Ha et al, 2012; Hardwick et al, 2006; Hwang et al, 2016; Park et al, 2013; Park et al, 2014a), exercise to accompany the functional movement, such as shoulder flexion, was reported to be effective in activating the SA muscle. Choung et al (2013) reported that 130° shoulder flexion resulted in greater activation of the SA muscle than 90° shoulder flexion in the sagittal plane (MVC of 60.7% at 130° and MVC of 51.3% at 90°). Hardwick et al (2006) observed that the wall slide exercise with shoulder flexion up to 120° was more effective in activating the SA muscle (MVC of 58.3%) than the push-up plus exercise (MVC of 31.3%). And wall slide exercise more activated activity of middle SA than wall push-up (MVC of 63.5% and MVC of 43.1%) (Park et al, 2014b). The CFFSP exercise is similar to pushing against a wall (used in the wall slide exercise) because one hand pushes forward (protraction) while the opposite hand pulls to provide resistance. Thus, our data reflect a high degree of activation of the SA muscle with the use of CFFSP (MVC of 62.5%).

Patients with shoulder dysfunction can more easily perform the wall slide exercise (leaning into the wall against partial gravity) than the push-up plus exercise (leaning into the floor against full gravity) (Hardwick et al, 2006). CFFSP can easily be performed in any position anywhere, using resistance applied by the opposing hand. Therefore, patients can easily perform the exercises because additional tools, such as a wall, floor, or dumbbell, are not required.

The value of the SA/UT ratio during CFFSP was more significant than that recorded during FF and FFP. Activation of the UT muscle during CFFSP (MVC of 12.7%) was lower than that for the UT muscle during FFP (MVC of 20.7%). There are several reasons for this. Firstly, the focus is on scapular protraction as the opposite hand is pulling during CFFSP. This may decrease activation in the UT muscle because shoulder elevation is limited in focused scapular protraction during CFFSP. Secondly, the opposite hand is involved in close kinetic chain exercises. CFFSP cause the scapular to be pushed during close kinetic chain exercises which have been shown to stimulate the mechanoreceptors, thus contributing to shoulder joint stabilization (De Mey et al, 2014). Improving the stability of the closed kinetic chain exercises (resistance against protraction during CFFSP) may contribute to increasing and decreasing SA and UT muscle activity, respectively.

There were several limitations to the current study. Firstly, we only considered the SA, UT, and PM muscles, and did not investigate activity in other muscles which might also have affected scapular control, such as the lower trapezius, rhomboids, and levator scapulae. Secondly, we did not investigate scapula kinematics during the study. Future studies need to be conducted so that scapular kinematics can be evaluated in order to assess scapular movement during CFFSP in comparison with that recorded using other methods. Thirdly, only healthy and relatively young subjects (21~32 years) were recruited into our study. Thus, our findings cannot be generalized to individuals with shoulder dysfunction or to other patient populations.

Further research is required to investigate the effect of CFFSP on SA muscle activity in individuals with shoulder dysfunction. FF with resistance against protraction is selected by individuals duirng CCFSP. Thus, this study cannot be generalized to each individual. Further research is required to control the pressure of FF with resistance during CFFSP.

Conclusion

This is the first study in which the activity of the SA muscle, the ratio of the activity in the SA/UT muscles and that in the SA/PM muscles has been investigated during CFFSP compared FF and FFP. Activation of the SA muscle significantly increased in the CFFSP compared to that in the FF and FFP, and the activity was significantly greater in the CFFSP. The results suggest that CFFSP is effective exercise to strengthen the SA muscle at 120°.

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