한국전문물리치료학회지 2017년 24권 4호 11-19
Phys Ther Korea 2017;24(4):11-19
ISSN (Print) 1225-8962, ISSN (Online) 2287-982X
https://doi.org/10.12674/ptk.2017.24.4.011

Comparison of the Effects of Closed Kinetic Chain Exercise and Open Kinetic Chain Exercise According to the Shoulder Flexion Angle on Muscle Activation of Serratus Anterior and Upper Trapezius Muscles During Scapular Protraction

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Abstract

Background: Methods for exercising serratus anterior (SA) and upper trapezius (UT) muscles are important for the recovery of patients with various shoulder disorders, yet the efficacy of closed or open kinetic chain exercises have not yet been evaluated.

Objects: The purpose of this study was to compare the activation of the SA and UT muscles during scapular protraction considering both closed and open kinetic chain exercises.

Methods: Thirty subjects were randomly divided into experimental groups (closed kinetic chain exercise) and control groups (open kinetic chain exercise) in which scapular protraction was performed at 90° or 125° shoulder flexion. Electromyographic activity data were collected from the SA and UT muscles per position and exercise method.

Results: Separate mixed 2-way analysis of variance showed significant differences in the activation of the SA ($F_{1,28}=6.447$, $p=.017$) and the UT ($F_{1,28}=35.450$, $p=.001$) muscles between the groups at 90° and 125° shoulder flexion. Also, the SA/UT ratio measures at 90° and 125° shoulder flexion significantly differed between the groups ($F_{1,28}=15.457$, $p=.001$). That is, the closed chain exercise was more effective than open chain exercise for strengthening the SA muscle and controlling the UT muscle, 125° of shoulder joint was more effective than 90°.

Conclusion: The findings suggest that scapular protraction with shoulder 125° flexion at the closed kinetic chain exercise may be more effective in increasing SA muscle activation and decreasing UT muscle activation as well as increasing the SA/UT ratio than open kinetic chain exercise.

Key Words: Closed kinetic chain; Open kinetic chain; Serratus anterior; Upper trapezius.

Introduction

The serratus anterior (SA) muscle plays an important role in stabilizing the shoulder joint and scapula in complement to the upper trapezius (UT) muscle while fixing the inner side of the scapular and the lower angle to the thorax in upper limb movements. The SA muscle is the first to contract when the scapula moves for the stability of the shoulder joint, and in upward rotation it acts as a coupling force with the lower trapezius and cooperates with the pectoralis minor. It acts as a synergistic muscle (Castelein et al, 2016; Kibler and Sciascia, 2010). The problem of contraction timing of SA muscle and hyperactivity of the UT muscle causes various problems in hypomobility of the shoulder joint, increasing of anterior tilting of shoulder joint, and injuries such as winging scapula and impingement syndrome as well

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This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2017R1D1A3B03031876).

as the appropriated muscle tension length and motor recruitment sequence between the SA and the UT muscles (Larsen et al, 2013; Page, 2011).

The problem of imbalance between the SA and UT muscles with shoulder-joint-related injuries must be solved, and it is necessary to strengthen SA muscle and UT muscle activity rather than strengthening the entire shoulder muscle during rehabilitation. The importance of this issue has been mentioned in previous studies (Decker et al, 1999; Kibler and Sciascia, 2010). For example, shoulder protraction, such as a push-up motion, is often used as a closed kinetic chain exercise method for strengthening the SA. To effectively strengthen the SA, a stable and unstable support surface are compared. Various studies have been conducted on the shoulder joint and the muscles around the scapula, including the application of the open kinetic chain exercise method using a sling (Cools et al, 2003; Park et al, 2005; Schory et al, 2016).

Closed kinetic chain exercise has the advantage of simultaneously increasing proprioceptive stimulation and stability due to intra-articular compression, as the weight is supported by applying resistance to the proximal part, while the distal portion is fixed (Tucci et al, 2017). Hardwick et al (2006) reported that closed kinetic chain exercise, such as wall the push-up plus, can increase muscle activity in the SA during shoulder rehabilitation programs. Park and Yoo (2011) found that this is a functional biomechanical posture that is effective for strengthening the SA muscle and controlling the UT muscle. In addition, Ludewig et al (2004) reported that the wall push-up plus exercise can be divided into wall push-ups plus and floor push-up plus and that the muscle activity of the SA is effectively improved in floor push-ups plus. However, when it is difficult to support the shoulder, the wall push-up plus method is suitable.

Open kinetic chain movement is effective in strengthening the agonistic muscles with the use of the distal part in a state in which the proximal part is fixed (Kim et al, 2008). Castelein et al (2016) reported that open kinetic chain exercise using elastic bands was more effective than closed kinetic chain exercises, such as wall push-ups plus or floor push-ups plus, in a standing posture. It was reported that the open kinetic chain exercise method using the elastic band during exercise increased the muscle activity of the SA by 36% and that the SA-to-pectoralis-minor ratio increased by 64%. Park et al (2005) reported that open chain exercise using a sling on unstable support surfaces was effective in increasing muscle activity in the SA and reducing hyperactivity in the UT muscle.

In addition, Moon et al (2013) showed that there is no difference in the muscle activity of the SA according to the shoulder angle between two kinetic chain exercises, however, a low angle like 70° in open kinetic chain exercise and a high angle like 110° in closed chain exercise were both effective in strengthening in the SA muscle and controlling the overactivated UT muscle. The study of Choung et al (2013) reported that the muscle activity of the SA and UT was increased by increasing the angle of shoulder flexion during scapular protraction exercise in the sagittal and coronal planes. In this study, based on the universality and availability of shoulder forward flexion angle, 90° and 125° of shoulder flexion were respectively selected for performing scapular protraction in standing posture.

According to the results of previous studies, the muscle activity of the SA increased with an increasing shoulder joint angle during the push-up exercise, but the difference between closed kinetic chain movement and the open kinetic chain exercise method is not clearly understood. Although there is a question about selective SA strengthening exercises that can solve the problem of the simultaneous increase in muscle activity of the SA and the antagonistic muscles, studies on the difference between closed kinetic chain exercise and open kinetic chain exercise seem to be insufficient. The purpose of this study was to investigate the difference between closed kinetic chain exercise and open kinetic chain exercise methods and the effect of the shoulder joint flexion angle on the muscle activity of the SA and UT in scapular protraction exercises.

Methods

Subjects

This study was conducted with 30 adults who agreed to the experiment with a sufficient explanation about the purpose and methods of the study. Consent form was obtained and the subjects voluntarily participated in the experiment, the University Institutional Review Board approved the study (approval number: 2017-053). The subjects were randomly divided into two groups, the experimental group and the control group. Subjects were included if they had (1) no pain in the shoulder and neck, (2) no restrictions in the range of motion of both shoulder joints, (3) less than 6 hours of upper limb muscle movement in the last week, (4) no abnormality in upper extremity sensation, (5) and no open wounds that would interfere with electrode attachment. Table 1 shows the general characteristics of the study subjects.

Instrumentations

Surface electromyography

In this study, we measured the muscle activity of the SA and UT using surface electromyography (EMG) (Telemyo 2400T, Noraxon Inc., Scottsdale, AZ, USA). Before adhering the surface electrodes, hair was removed with a razor and disinfected with alcohol. The surface electrodes were attached to the SA and UT muscles, respectively (Criswell, 2010). The distance between the two surface electrodes was set at 2 ㎝. They were attached parallel to the muscle fibers and secured with adhesive tape to prevent cable movement during exercise. The collected data were analyzed using MyoResearch software (Noraxon Inc., Scottsdale, AZ, USA). The sample collection rate was 1500 ㎐, and the root mean square was calculated using a 20 to 450 ㎐ filter. Before measuring the muscle activity of the SA and UT, the maximum voluntary isometric contraction was measured for the SA muscle (ICC=.96) and UT muscle (ICC=.91) with reference to a study by Ekström et al (2005).

Goniometer

A goniometer was used to measure the range of motion for the shoulder joint at 90° and 125° of flexion in shoulder protraction. The posture of the subject was measured by positioning at shoulder width and the axis of the goniometer by the lateral center of the acromion of shoulder joint. The stationary arm was parallel to the lateral trunk, and the moving arm was parallel to the lateral parallel line of the upper arm. The subjects actively flexed the shoulder joint at the end of the 90° and 125° ranges of motion, and they were verbally instructed so that they could assume the correct postures.

Procedures

Before the application of the intervention, closed kinetic chain exercise and open kinetic chain exercise were fully explained to the subjects. Closed kinetic chain exercise and open kinetic chain exercise were applied to each subject equally in terms of posture, method, procedure, and time. The subject's basic pos-

Table 1. General characteristics of subjects (N=30)

Parameters	Experimental group (n_1=15)	Control group (n_2=15)	t	p
Gender (male/female)	8/7	7/8		
Age (year)	20.20±.77[a]	19.87±.51	1.387	.176
Height (㎝)	174.53±6.6	173.7±6.2	.341	.736
Weight (㎏)	70.87±8.2	70.47±5.5	.156	.877

[a]mean±standard deviations.

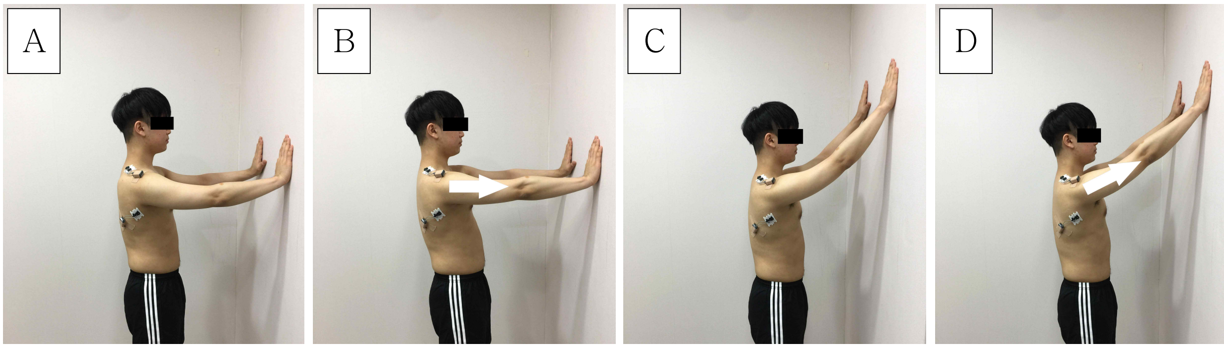

Figure 1. Close kinetic chain exercise (A: shoulder flexion at 90° ready position, B: shoulder flexion at 90° scapular protraction position, C: shoulder flexion at 125° ready position, D: shoulder flexion at 125° scapular protraction position).

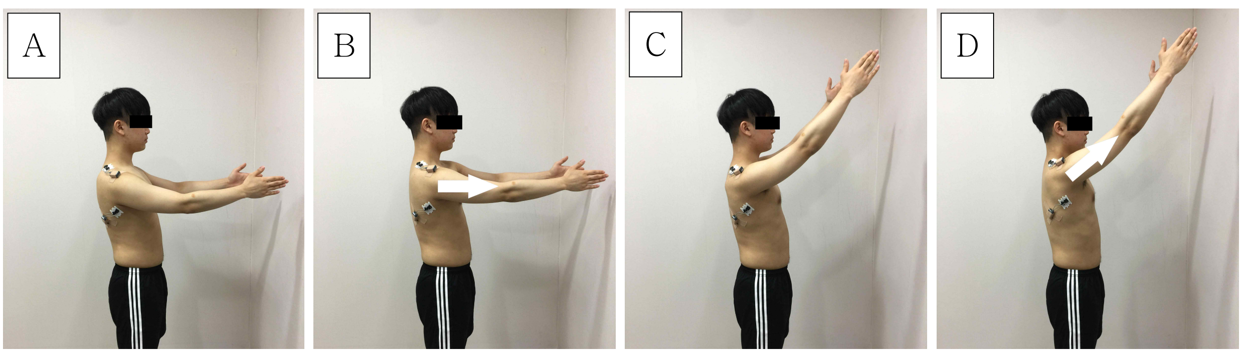

Figure 2. Open kinetic chain exercise (A: shoulder flexion at 90° ready position, B: shoulder flexion at 90° scapular protraction position C: shoulder flexion at 125° ready position, D: shoulder flexion at 125° scapular protraction position).

ture was positioned so that 15° forward of the gaze in a standing posture could be observed with both feet at shoulder width and to limit the movement of the upper part of the trunk by applying force to the abdominal muscles to inhibit the trunk extension. In addition, scapular protraction was performed gradually, and there was no difficulty for the subjects during the movement. The two interventions led to maximum active muscle contraction. All measurements were made between the beginning and ending verbal instructions. Muscle contraction was performed for 5 seconds, and 1 second was discarded before and after the 3-second interval was normalized. The total number of measurements was three. To avoid fatigue during the measurement, there was 1 minute of rest.

Close kinetic chain exercise

The subject was placed in a standing posture with a shoulder flexion of 90°, and the palm was placed on the wall with the elbow joint fully extended. The subject was instructed to push the wall with the hand, leaning back to avoid flexion of the elbow joint, and scapular protraction was carried out with the scapula facing forward. The subject faced the wall and flexed the shoulder by 125° in a standing posture, and the elbow joint was fully extended so that the palm was leaned against the wall. The subject was instructed to push with the palm and lean to avoid flexion of the elbow joint, and scapular protraction was carried out with the scapula facing forward (Figure 1).

Open kinetic chain exercise

The elbow joint was kept in a fully flat state with 90° of flexion in the subject's shoulder joint. The upper limb protraction was directed to the fingertips. The subject held the elbow joint in full extension with the

Table 2. Comparisons EMG activity of serratus anterior and upper trapezius muscle in both groups

Variable	Angle	Experimental group	Control group	Group effect		Position effect		Interaction effect	
				F (1,28)	p	F (1,28)	p	F (1,28)	p
Serratus anterior	90	31.80±4.03[a]	26.27±3.36	348.061	.001*	110.074	.001*	6.447	.017*
	125	58.73±4.77	49.67±4.32						
Upper trapezius	90	24.60±3.13	33.47±3.27	129.891	.001*	77.169	.001*	35.450	.001*
	125	26.53±3.75	43.53±4.24						

[a]mean±standard deviations, *p<.05.

Table 3. Comparisons EMG activity ratio of serratus anterior and upper trapezius muscle in both groups

Variable	Angle	Experimental group	Control group	Group effect		Position effect		Interaction effect	
				F (1,28)	p	F (1,28)	p	F (1,28)	p
SA/UT[a] ratio	90	2.05±.32[b]	.79±.15	241.818	.001*	4.156	.051	15.457	.001*
	125	2.24±.35	.73±.95						

[a]serratus anterior/upper trapezius, [b]mean±standard deviations, *p<.05.

shoulder joint flexion at 125°. The shoulder joints were bent at 125° with the elbow joints unbent and the upper limbs reaching in the direction of the fingertips, allowing the scapula to be protracted (Figure 2).

Statistical analysis

The age, height, and body weight of the subjects were independent-t tests. In order to compare the muscle activity of the SA and UT in the closed kinetic chain exercise (experimental group) and the open kinetic chain exercise (control group) with the shoulder at 90° and 125° angles, two-way analysis of variance was used, and a Bonferroni test was performed in a post-analysis when the individual effect was significant. The collected data were analyzed with the statistical program SPSS version 18.0 (SPSS Inc., Chicago, IL., USA). Statistical significance was set at p<.05.

Results

There was a significant group effect for the SA muscle (F=348.061, p=.001) and position effect for the SA muscle (F=.110.074, p=.001). There were also significant interaction effects for the SA muscle (F=6.447, p=.017). In other words, both 90° and 125° of shoulder joint flexion significantly increased SA muscle activity compared to the open kinetic chain exercise method (Table 2).

There was a significant group effect for the UT muscle (F=129.891, p=.001) and position effect for the UT muscle (F=77.169, p=.001). There were also significant interaction effects for the UT muscle (F=35.450, p=.001). This indicates that the muscle activity of the UT in shoulder joints at both 90° and 125° of flexion was significantly lower than that of the open kinetic chain exercise (Table 2).

There was a significant group effect for the SA/UT ratio (F=241.818, p=.001) and an interaction effect for the SA/UT ratio (F=15.457, p=.001). However, there was no significant position effect for the SA/UT ratio (F=4.156, p=.001). The results of this study show that in the shoulder joint at 90° and 125° of flexion, the ratio of SA to UT activity in closed kinetic chain exercise was significantly higher than that of the open chain method (Table 3).

Discussion

The strengthening and motor control of SA muscle is essential in physiotherapy for various shoulder disorders (Decker et al, 1999; Miyasaka et al, 2017; Park and Yoo, 2015). Although strengthening the SA muscles keeps pace with neuromuscular control exercise of the hyper-activity of UT muscle, informations regarding the proper flexion angle of the shoulder joint in closed or open chain exercise methods during the pushing movement of the SA muscle are still insufficient. Previous studies have therefore measured muscle activities and the ratio of the two muscles using EMG in movements involving sticking out the shoulders. This is usually to identify effective methods of reinforcing the SA muscle and adjusting the UT muscle. As a result, it has been discovered that the closed chain movement method is more effective than the open chain method, and the muscular activity of the SA increases at 125° (an angle greater than 90°).

Cools et al. (2003) observed that patients with shoulder pain have decreased muscle activity of the SA muscle and increased muscle activity of the UT, which the ability to control shoulder related muscles is reduced, resulted in excessively overactivated of the UT muscle during shoulder flexion. Choi et al. (2015) reported that the controlled movement of the UT muscle and strengthening of the SA muscle were important in stabilizing the shoulder joint by solving the problem of shoulder-related upper limb and increasing the cooperation in the upward rotation of the scapula.

Although previous studies have reported results for various postures (Schory et al, 2016), the results are different depending on the exact physical posture and the compensatory action in the application method. The results of comparisons in the standing posture and the protocol data are still lacking. Although the scapular protraction exercise in the standing posture can be performed in a narrow space and has the merit of being easily applied in clinical practice, most studies are performed on the push-up action in the prone position. Kim et al (2008) reported that the muscle activity of the shoulder and the muscles around the shoulder was significantly different according to differences in the hand position and the exercise method during the push-up operation of the closed chain movement method. Oh et al (2003) reported that open chain exercise using a sling increases the muscle activity of the pectoralis major muscle. Cools et al (2003) reported that delayed muscle activity showed a uncontrolled motor control about the UT muscle in patients with shoulder impingement syndrome. However, it should be considered that many patients with shoulder pain have difficulty supporting their shoulder joints due to pain and instability in the prone position. In the standing posture involving partial compression and resistance seem to be highly realistic. Therefore, measures in standing position were selected and applied for the scapular protraction exercise in this study.

With surface EMG, it is difficult to measure number of motor unit and rate of muscle firing, but it is generally reported to be suitable for measuring the muscle contraction through muscle activity (De Luca, 1997). And also, it is well known that isometric contraction is proportional to the muscle activity in surface EMG (De Luca, 1997; Soderberg and Knutson, 2000). Kim et al (2008) measured the position of electrodes on the SA and UT muscles using data from Criswell (2010). Therefore, in this study, the positions of the electrodes for surface EMG were determined by referring to the measurement methods of Criswell (2010) and Moseley et al (1992). In previous studies similar to this study, surface EMG was used to measure muscle activity in the SA and UT.

As a result of this study, it was found that the closed kinetic chain exercise method increased the muscle activity of the SA and decreased the muscle activity of the UT in comparison to the open kinetic chain exercise method. When the shoulder flexion angles were 90° and 125°, the muscle activity of the SA was increased by 19% and 20%, respectively, and the muscle activity of the UT was decreased by 37% and 69%, respectively. In addition, the SA-to-UT ratio of activity is about twice that of the open chain movement when the shoulder flexion angles are 90° and 125°. It was found that 125° increases activity more than 90° in closed kinetic chain exercise. And also, it was confirmed that the SA muscle was relatively increased with decreasing UT muscle at the scapular protraction from the ratio of SA/UT results.

Recently, Pirauá et al. (2014) reported similar results on the advantages of closed kinetic chain motion for selective muscle activation of the SA. This suggests that the closed kinetic chain exercise method is more effective for the exercise control and neuromuscular control of the SA and UT than the open kinetic chain exercise method and may also help the stability of the shoulder joint and scapula. In addition, the size of muscle activity increases, as the forward flexion of the shoulder joint increases, are thought to be caused by the more motor unit recruitments in the SA muscle to overcome the instability of the shoulder complex part.

Physiologically, the SA muscle corresponds to weaker phasic muscles and the UT tends to be tonic (Kisner and Colby, 2002; Page et al, 2010). Abnormal recruitment patterns are associated with abnormal movements of cooperating muscles during functional movements. Inequalities, such as muscle weakness of the SA and hyperactive muscle contraction of the UT, have been reported to negatively affect not only shoulder pain but also result in rounded shoulders and turtle neck postures (Kisner and Colby, 2002). For this reason, the strengthening of the SA muscle is a problem to be solved. Therefore, the exercise method for strengthening the SA muscle, which is a phase muscle showing rapid muscle fatigue, should be performed gradually. In this study, gradual exercise of the shoulder muscles was also applied.

The limitations of this study are as follows. First, there is a small problem that this study did not resolve uncontrolled scapular movement such as arm sway and different speed for the scapular protraction, and anthropometric part of subjects for the more precise measurement. Second, we did not control the motion by using a quantitative motion analyzer. Third, muscle activity was measured only in the movement of two muscles, the SA and UT. Fourth, the study subjects were healthy adults. Therefore, it seems that there are limitations in generalizing this study. In future studies, a more accurate intervention and measurement method could be achieved by controlling the compensatory action of the shoulder muscles using a motion analyzer in a variety of daily activities in addition to the movement of the shoulders.

Conclusion

The purpose of this study was to investigate effective exercise methods for selective strengthening of the shoulder and surrounding scapular muscles in musculoskeletal disorders, which are often encountered during rehabilitation for patients with shoulder joint problems. This study was not a pushing condition in weight bearing of prone position, but a pushing against the wall in standing position, and also, the closed chain exercise was more effective than open chain exercise for strengthening the SA muscle and controlling the UT muscle, 125° of shoulder joint was more effective than 90°. Therefore, we propose that scapular protraction with 125° flexion of the shoulder joint is suitable for strengthening of SA muscle and control of UT muscle using the closed kinetic chain exercise method.

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This article was received October 10, 2017, was reviewed October 10, 2017, and was accepted November 14, 2017.