한국전문물리치료학회지 2017년 24권 4호 77-83
Phys Ther Korea 2017;24(4):77-83
ISSN (Print) 1225-8962, ISSN (Online) 2287-982X
https://doi.org/10.12674/ptk.2017.24.4.077

Effect of Horizontal Adduction Force on Infraspinatus and Deltoid Activities During the Side-Lying Wiper Exercise Using Pressure Biofeedback

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Abstract

Background: Shoulder external rotation exercises are commonly used to improve the stabilizing ability of the infraspinatus. Although the side-lying wiper exercise (SWE) is the most effective shoulder external rotation exercise to maximize infraspinatus activity, the effect of adduction force on the infraspinatus and posterior deltoid has not been demonstrated.

Objects: This study was conducted to investigate whether horizontal adduction force increases infraspinatus activity and decreases posterior deltoid activity.

Methods: Twenty-eight healthy subjects (male: 21, female: 7; age=23.5±1.8 years; height=170.1±7.4 ㎝; weight=69.4±9.6 ㎏) were recruited. Subjects were asked to perform the SWE under two conditions: (1) general SWE and (2) SWE with adduction force using pressure biofeedback. Surface electromyography (EMG) signals of the infraspinatus and posterior deltoid were recorded during SWE. Paired t-tests were used to compare the EMG activity of the infraspinatus and posterior deltoid between the two conditions.

Results: Posterior deltoid muscle activity was significantly decreased following SWE with adduction force (7.53±4.52%) relative to general SWE (11.68±8.42%) ($p<.05$). However, there was no significant difference in the infraspinatus muscle activity between the SWE with adduction force (28.33±12.16%) and the general SWE (26.54±13.69%) ($p>.05$).

Conclusion: Horizontal adduction force while performing SWE is effective at decreasing posterior deltoid activity.

Keywords: Adduction force; Infraspinatus; Posterior deltoid; Rotator cuff exercise; Shoulder external rotation exercise.

Introduction

Rotator cuff (RC) muscles are important in ensuring the dynamic stability of the shoulder, as they keep the humerus in the glenoid fossa with the proper path of the instant center of rotation (PICR) during shoulder motion (Ha et al, 2013; Page et al, 2010). Sufficient strength in the external rotation (ER) of the RC is essential to approximate force and prevent joint distraction (Reinold et al, 2004). Muscle imbalance in the dynamic stabilizers can lead to functional instability (Barden et al, 2005; Page et al, 2010). A previous study found that the anterior instability of the humeral head is prevented by the posterior RC, which is made up of the infraspinatus and teres minor muscles (Page et al, 2010). The infraspinatus muscle is especially important in this regard, as its role is to externally rotate and depress the head of the humerus (Sahrmann, 2002). Hence, ER exercises are commonly used to improve the sta-

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ISSN (Print) 1225-8962, ISSN (Online) 2287-982X
https://doi.org/10.12674/ptk.2017.24.4.077

bility of the infraspinatus and the teres minor and to restore the balance of force couples during shoulder RC retraining programs (Bitter et al, 2007; Reinold et al, 2004). RC dysfunction can cause force couple imbalance, including increased humeral head translation in the PICR and the impingement of the subacromial structure (Bitter et al, 2007).

The posterior deltoid is a powerful secondary external rotator (Sahrmann, 2002). However, an over-used posterior deltoid can cause tightness and increased anterior humeral gliding (Lim et al, 2014; Sahrmann, 2002; Yamauchi et al, 2016). During impaired shoulder ER, the posterior deltoid is more dominant than the primary dynamic stabilizers, that is, the infraspinatus and the teres minor. However, the dominant posterior deltoid muscle can pull the scapular toward the humerus, causing anterior humeral gliding (Jaggi and Lambert, 2010; Sahrmann, 2002). Previous studies have reported that patients with shoulder impingement syndrome (SIS) see changes in the relative contribution of the deltoid and RC muscles during shoulder movement, which can lead to superior and anterior humeral head translation (Koppenhaver et al, 2015; Yamauchi et al, 2016). Therefore, the selective strengthening of the infraspinatus muscle is recommended for rehabilitation (Ha et al, 2013).

Many studies have examined the effect of shoulder ER exercises in the treatment of RC damage (Ballantyne et al, 1993; Ha et al, 2013; Jaggi and Lambert, 2010; Kuhn, 2009; Reinold et al, 2004). In particular, Bitter et al (2007) emphasized that adduction force is important to decrease deltoid action. Ha et al (2013) demonstrated that the side-lying wiper exercise (SWE), which is performed with 90° shoulder flexion supported with the opposite hand, is the best exercise to increase selective infraspinatus function among various strengthening methods. Further, the SWE was found to be the most effective exercise to maximize infraspinatus activity (Ha et al, 2013). However, the previous studies have not focused on how to control the compensation of the posterior deltoid using adduction force.

To prevent the compensation of the uncontrolled movement, some studies have used various types of biofeedback system (Koh et al, 2016; Lim et al, 2014; Reinold et al, 2004; Roy et al, 2010). Thus we designed a new method using a visual pressure biofeedback unit (VPBU). By maintaining as much arm weight as possible during ER, the exercising arm can be continuously supported on the opposite palm. Previous studies have used pressure biofeedback to control and reduce movement (Koh et al, 2016; Lim et al, 2014). However, a pressure biofeedback system has yet to be coupled with visual smart electricity. Thus, herein, the effect of adduction force on infraspinatus and deltoid activities during the SWE using a VPBU was studied.

Methods

Subjects

In total, Twenty-eight healthy subjects (male: 21, female: 7; age=23.5±1.8 years; height=170.1±7.4 ㎝; weight=69.4±9.6 ㎏) younger than 30 years of age participated in this study. At least 16 participants were required to attain a level of .05 and power of .8 (Ha et al, 2013). All subjects were recruited from Yonsei University. Subjects were excluded if they had (1) a history of shoulder surgery, (2) current pain in the shoulder, and/or (3) neurological or musculoskeletal problems that would interfere with shoulder ER during the SWE (Bitter et al, 2007; Ha et al, 2013). Ethical approval was obtained from the Institutional Review Board of Yonsei University (approval number: 1041849-201706-BM-057-01/0).

Instrumentation and data reduction

Surface electromyography (EMG) data were recorded using TeleMyo 2400T (TeleMyo 2400T, Noraxon, Scottsdale, AZ, USA) from the infraspinatus, posterior deltoid, and pectoralis major. Each subject's skin was shaved and cleaned with an alcohol swab to reduce skin impedance, and the surface electrode pairs were fixed at an interelectrode dis-

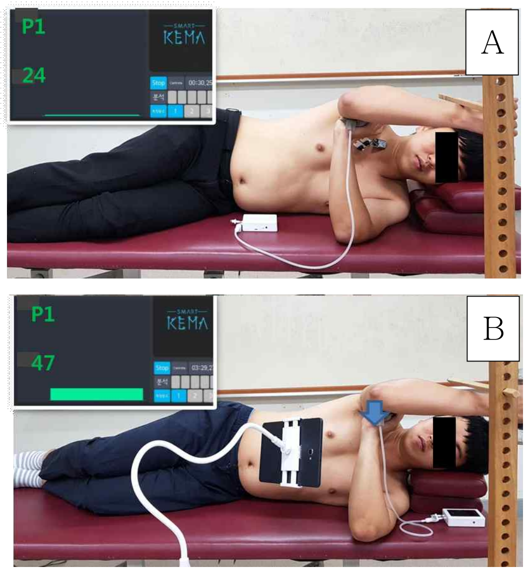

Figure 1. A: General side-lying wiper exercise (SWE), B: SWE with adduction force.

tance of 2 ㎝ (Bitter et al, 2007; Ha et al, 2013).

Each participants' dominant arm was measured (Bitter et al, 2007). The electrode for the infraspinatus was placed 4 ㎝ inferior to the scapular spine and parallel to the lateral aspect of the infrascapular fossa, the electrode for the posterior deltoid was placed 2 ㎝ inferior to the lateral border of the scapular spine and angled obliquely to the muscle fibers, and the electrode for the pectoralis major was placed 2 ㎝ from the axillary fold over the chest wall horizontally. The EMG activity of the muscles was filtered (20-300 ㎐) and sampling a rate of 1,000 ㎐. The EMG signal was converted into a root-mean-square (RMS) signal to quantify the raw signal, which sampled the RMS signal at 50 ㎳.

To normalize the data, the RMS of a five seconds maximum voluntary isometric contraction (MVIC) was measured three times for each muscle. The infraspinatus was placed on at a 0° abduction angle with resistance applied above the wrist to internally rotate the shoulder. The posterior deltoid was placed at a 90° abduction angle prone with resistance applied above the distal humerus to ensure horizontal shoulder adduction (Reinold et al, 2004). The pectoralis major was placed at a 90° abduction angle with the flexion of the shoulder and elbow in supine position with resistance applied above the distal humerus to ensure horizontal shoulder abduction (Reinold et al, 2004).

Procedures

The dominant arm of each participant was measured. All subjects were tested in side-lying position with a target bar in reach of the radial border of the wrist. For the starting position of the SWE, the subject took a side-lying position with his or her dominant shoulder facing upward so that the dominant shoulder and elbow were in a 90° flexed position with 90° internal rotation (Ha et al, 2013). The palm of the opposite hand supported the distal humerus of the dominant arm. A smart KEMA pressure sensor was located between the distal humerus of the dominant arm and the palm of the opposite hand to measure the pressure of the dominant arm and to provide biofeedback. Two different conditions of the SWE were performed: (1) for the general SWE, the subject was asked to support the dominant arm with the palm of the opposite hand, and the SWE was performed without visual feedback (Ha et al, 2013); (2) for the SWE with adduction force, a VPBU was used while the subject held his or her arm down (Figure 1).

The subjects practiced the SWE three times to become familiar with the exercise before testing. The subjects held a 1-㎏ dumbbell during all shoulder ER tests. The subjects were asked to externally rotate their dominant arm until they touched the target bar with their radial wrist and to maintain this position for five seconds. The subjects were also asked to hold their dominant arm with the palm of their opposite hand and to perform two different SWEs (Ha et al, 2013). For the SWE with adduction force, while holding down the arm, each subject was asked to note his or her force in the 90° internal shoulder rotation position on the Smart KEMA pressure sensor; after, the pressure of the arm weight was confirmed. Then, the subject was asked to watch a tablet connected to the VPBU to check his or her pressure biofeedback and to externally rotate his or her shoulder to the target bar while maintaining the pressure of the arm weight.

Only the middle three seconds of the five seconds were used for the EMG analysis. A metronome was used to control the contraction period. The subjects were asked to repeat each test three times, resting for 30 seconds after each trial (Ha et al, 2013).

Digital visual pressure biofeedback unit (VPBU)

A smart KEMA pressure sensor (Factorial Holdings Co., Ltd., Seoul, Korea) was used to measure and control the pressure of the dominant arm weight. Smart KEMA VPBUs consist of a distal device and pressure pads (width: 15 ㎝; length: 6 ㎝; height 3 ㎝). The pressure unit is ㎜Hg (range: 0-258.57 ㎜Hg), and the pressure signal is transferred to a tablet through a Bluetooth connection. These data were recorded and analyzed with the Smart KEMA application software (Factorial Holdings Co., Ltd.).

Statistical analysis

The data are shown as mean±standard deviation. Paired t tests were used to compare the EMG activities of the infraspinatus and the posterior deltoid between the general SWE and the SWE with adduction force using a VPBU. The α level was set at .05 to determine statistical significance. SPSS version 23 (SPSS Inc., Chicago, IL, USA) was used for this analysis.

Results

Infraspinatus EMG

The EMG data of the infraspinatus were normalized and are presented in Table 1. There was no significant difference in the infraspinatus activity between the SWE with adduction force (28.33±12.16%) and the general SWE (26.54±13.69%)(Table 1).

Posterior Deltoid EMG

The EMG data of the posterior deltoid were normalized and are presented in Table 1. The posterior deltoid activity was significantly lower in the SWE with adduction force (7.53±4.52%) than the general SWE (11.68±8.42%)(Table 1).

Pectoralis major EMG

The EMG data of the pectoralis major were normalized and are presented in Table 1. The pectoralis major activity was significantly higher in the SWE with adduction force (8.07±4.55%) than the general SWE (4.5±2.34%)(Table 1).

Discussion

Previous studies have emphasized the primary torque-producing role of the posterior deltoid, suggesting that the posterior deltoid should be minimized and the infraspinatus should be selectively exercised (Bitter et al, 2007; Ha et al, 2013; Reinold et al, 2004). In this study, we investigated the effect of adduction force on the EMG activities of the infraspinatus and the posterior deltoid during the SWE using a VPBU.

Bitter et al (2007) found a significant decrease in the middle deltoid with and without adduction force during sitting external rotation, but no significant

Table 1. Electromyographic data of three muscles and pressure value for two different exercise (N=28)

Parameter	SWE[a]	SWE with adduction force	p-value
Infraspinatus (%MVIC[b])	26.54±13.69[c]	28.33±12.16	.493
Posterior deltoid (%MVIC)	11.68±8.42	7.53±4.52	.001*
Pectoralis major (%MVIC)	4.5±2.34	8.07±4.55	<.001*
Pressure (㎜Hg)	24±10	47±6	

[a]side-lying wiper exercise, [b]percent maximal voluntary isometric contraction, [c]mean±standard deviation, *p<.05.

difference was found between the activity of the posterior deltoid and that of the infraspinatus. Unlike in the previous study, the normalized EMG value of the posterior deltoid significantly decreased in the SWE with horizontal adduction force (7.53±4.52%) compared to the general SWE (11.68±8.42%). It might be the way efficiently to prevent humerus translation by posterior deltoid. However, infraspinatus activity was not significantly different between the SWE with adduction force (28.33±12.16%) and the general SWE (26.54±13.69%).

Adduction might stimulate the pectoralis major antagonist and reduce the posterior deltoid to induce proper co-contraction. Muscular co-contraction is essential for stability (Lee et al, 2006; McGill et al, 2003). Gribble et al (2003) demonstrated that the co-contraction of agonist and antagonist muscles plays a role in increasing the accuracy of arm movement (Gribble et al, 2003). In this study, the ratio of posterior deltoid and pectoralis major activities was close to 1 (the SWE with adduction force: 1.26, the general SWE: 3). This means that a similar intensity was used for posterior deltoid (7.53 %MVIC) and pectoralis major activity (8.07 %MVIC) during the SWE with adduction force (Table 1). This reduces humerus translation and helps ensure that shoulder ER in the glenohumeral joint is stable and accurate.

We predicted that the infraspinatus would increase as the posterior deltoid decreased, but the infraspinatus did not significantly increase. These findings have several explanations. First, the teres minor might be used as the external rotator instead of the infraspinatus. Steenbrink et al (2009) indicated that the co-contraction force of the teres minor is important to ensure glenohumeral stabilization when the infraspinatus stops functioning. Therefore, in this study, if subjects had inhibited deltoid activity due to a weak infraspinatus, then they would use their teres minor more to perform shoulder ER to the target bar. Kurokawa et al (2014) indicated that the greatest abduction of the infraspinatus occurs at 0° and that of the teres minor occurs at 90°; however, no study has been conducted on the activity of the teres minor at 90° of abduction along with flexion in the shoulder. We did not measure the activity of the teres minor, so further study should consider the activity of this muscle during the SWE.

In previous studies, the amount of pressure applied to the opposite palm during the general SWE was not studied, but this was measured in the current study (mean value: 24 ㎜Hg). To prevent the overuse (greater than 10% of MVIC) of the pectoralis major due to excessive adduction force, we allowed subjects to maintain the adduction force of their arm weight (mean value: 47 ㎜Hg). Maintaining excessive pressure when applying adduction force can lead to increased pectoralis major activity as the muscle acts as an antagonist of shoulder ER. Jaggi and Lambert (2010) mentioned that using the pectoralis major could cause the recurrent instability of polar pathologies, such as trauma, neurological dysfunction, and muscle patterning. Therefore, clinicians should consider a patient's condition when applying adduction force during the SWE.

In this study, using a VPBU during the SWE showed more favorable results in terms of the proper contribution of muscles than performing the SWE without a VPBU. Many studies have used biofeedback for muscle learning, controlling muscles, reducing compensation, and effectively strengthening target muscles (Koh et al, 2016; Lim et al, 2014; Reinold et al, 2004; Roy et al, 2010). For example, Faucett et al (2002) used a biofeedback training protocol for muscle learning therapy. In addition, Koh et al (2016) demonstrated that using a VPBU is effective for increasing gluteus maximus activity and pelvic sway during the clam exercise. Further, Roy et al (2012) demonstrated that individuals with SIS can improve compensatory kinematic deficits after performing unsupervised movement training with visual feedback using a mirror. Clinically, having patients perform the SWE with adduction force using a VPBU can reduce the compensatory movement of the posterior deltoid and allow them to effectively perform unsupervised training with a stabilized humerus.

This study has limitations that should be considered. First, only healthy subjects participated; healthy shoulders and injured shoulders were not compared. Second, we did not measure the activity of the teres minor muscle. This muscle might be important when acting as an external rotator in the shoulder. Third, we could not prove the long-term effect of performing the SWE with adduction force. Further studies should determine the effect of the SWE on individuals with injured shoulders.

Conclusion

In conclusion, we demonstrated that adduction force can help reduce compensatory posterior deltoid activities. Using a VPBU helps subjects maintain adduction force and perform unsupervised training. We suggest that clinicians use abduction force with the SWE to efficiently apply shoulder ER exercises.

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This article was received October 2, 2017, was reviewed October 2, 2017, and was accepted November 11, 2017.