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Effect of the Abdominal Drawing-in Maneuver on the Scapular Stabilizer Muscle Activities and Scapular Winging During Push-up Plus Exercise in Subjects With Scapular Winging

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Abstract

Background: Scapular winging is a prominence of the entire scapular medial border, mainly caused by insufficient activity of the serratus anterior (SA) and imbalance of scapulothoracic muscles. Push-up plus (PUP) exercise has been commonly used to increase SA muscle activity. The facilitation of abdominal muscle may affect scapular muscle activity by myofascial connections. Thus, the sequential activation of the turnk muscles is suggested to facilitate the transition of proper force from upper limb and restore force couple of scapular muscles. The abdominal drawing-in maneuver (ADIM) has been effective in improving activation of the deep trunk muscles during movement.

Objects: The aim of this study was to determine the effect of ADIM on the activity of the upper trapezius (UT), lower trapezius (LT), and SA during PUP exercises in subjects with scapular winging.

Methods: Fourteen men with scapular winging (determined as a of distance between the scapular medial border and thoracic wall over 3 ㎝) volunteered for our study. The subjects performed the PUP exercise with and without ADIM. Surface electromyography was used to collect the electromyography data of the UT, LT, and SA. A scapulometer was used to measure the amount of scapular winging.

Results: SA activity was significantly greater and scapular winging significantly lower during the PUP exercise with ADIM than during those without ADIM.

Conclusion: PUP exercise with ADIM can be used as an beneficial method to improve SA activation and to reduce the amount of scapular winging in subjects with scapular winging.

Key Words: Electromyography; Serratus anterior; Shoulder rehabilitation exercise.

Introduction

Scapular winging (SW), defined as a prominence of the entire medial border of the scapula, is mainly caused by insufficient activity of the serratus anterior (SA) muscle (Henry and Westervelt, 2005; Martin and Fish, 2008). The SA muscle is one of the most important muscles used for scapular stabilization because the SA inserts on the scapular medial border and inferior angle and originates from the 1st to 8th ribs (Neumann, 2013). Excess upper trapezius (UT) activation or reduced activation of the lower trapezius (LT) and SA may contribute to abnormal scapular motion, scapular dysfunction, and pain and attempt to compensate for the weak SA (Sahrmann, 2002). Thus, therapeutic exercise for recovering the scapular stabilizer muscle function is an important part of the rehabilitation program (Bang and Deyle, 2000).

Open and closed kinetic chain exercises to increase SA muscle activity have been examined by many previous researchers (Cools et al, 2007; Decker et al, 1999; Hardwick et al, 2006; Martins et al, 2008). The push-up plus (PUP) exercise as a key exercise in shoulder rehabilitation exercise is based on the high

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activity of various shoulder muscles, including the SA (Moseley et al, 1992). Furthermore, the PUP exercise was found to elicit SA activity was greater than 20% maximal isometric voluntary contraction as compared to a number of rehabilitation exercises (Decker et al, 1999). Therefore, the PUP exercise has been widely used to correct scapular kinematics and enhance the SA activity in patients with SW (Hardwick et al, 2006; Park et al, 2013).

Previous study reported that activation of trunk muscle may affect the scapular muscle activity by myofascial connections (Myers, 2009). Therefore, the facilitation of the abdominal muscles is recommended to restore force couples of scapular muscle (UT, LT and SA) (Kibler and Sciascia, 2010). Trunk stability is asked to transfer force and energy to the upper extremities during movement or exercise (Hirashima et al, 2002; Jang et al, 2015; Kibler et al, 2006). The scapulothoracic muscles and joints are an anatomo-functional connection of the trunk and the upper limbs (Kibler and Sciascia, 2010). Many studies regarding the transversus abdominal muscle have focused on motor control and order of muscle activation during the spine stabilization (Hodges and Richardson, 1999). A previous study reported that the UT, LT, and middle trapezius muscle activities were affected by adding pelvic and thoracic supports (Jang et al, 2015). The abdominal drawing-in maneuver (ADIM), a core stabilization exercise, has been more effective than other core stabilization exercises in improving lumbopelvic stability and optimal co-activation of the deep trunk muscles during movements (Richardson et al, 2002). Previous investigators reported that ADIM is effective in stabilizing the lumbopelvic region during limb movements as compared to abdominal bracing (Suehiro et al, 2014). For proper performance of ADIM, a real-time ultrasound imaging is an effective visual feedback device and a useful clinical teaching device for physical therapists (Hodges and Richardson, 1996).

No previous studies have examined the effect of ADIM on the activities of the scapular stabilizer muscles during PUP exercises. Thus, this study aimed to compare the muscle activities of the UT, LT, and SA, UT/LT and UT/SA ratios, and amounts of SW during the PUP exercise with and without ADIM. We hypothesized that ADIM during the PUP exercise would increase the activities of the LT and SA and reduce the UT activity and UT/LT, UT/SA ratios, and amount of SW compared with the preferred PUP exercise in subjects with SW.

Methods

Subjects

G-power Software (ver. 3.1.6; Franz Faul, University of Kiel, Germany) was used for power analyses. A necessary sample size of 9 subjects was gained from a pilot study of 4 subjects to achieve an effect size of .83, with a power of .8 and a significance level of .05. Thus, 14 men with SW were recruited into the study (age=22.0±3.1 years, height=173.4±5.1 ㎝, weight=71.5±6.2 ㎏, body mass index=23.8±2.4 ㎏/㎡, amount of SW=3.2±.1 ㎝). The SW side was all used in all tests. If the subjects had bilateral SW, we used the worse side when a bilateral comparison indicated a difference of over <.1 ㎝ in the amount of SW.

The inclusion criteria were as follows: (1) SW was determined if the distance of between medial border of scapula and thoracic wall was over 3 ㎝ (Park et al, 2007) and (2) normal range of motion of shoulder internal rotation and horizontal adduction to rule out dominance of the deltoid (Warner et al, 1997). The exclusion criteria were as follows: (1) past to present shoulder pain or dysfunction, (2) history of shoulder or abdominal or back injury or surgery, (3) signs and symptoms of cervical pain, (4) adhesive capsulitis, thoracic outlet syndrome, or a current complaint of numbness or tingling in the upper limbs (Park et al, 2013), and (5) presence of a winged scapula due to a long thoracic nerve denervation (Choi et al, 2016). The participants were provided with a detailed explanation of this study process and safety instructions and were asked to sign a written consent prior to voluntary participation. The protocol was approved by the Yonsei University Wonju Institutional Review Board (approval number: 1041849-201701-BM-003-04).

EMG recording and data processing

A Noraxon TeleMyo-DTS (Noraxon, Inc., Scottsdale, AZ, USA) was used to collect surface EMG data from the scapular stabilizer muscles (UT, LT, and SA) on the more prominent side of SW. EMG data were analyzed using the Noraxon MyoRexearch 1.08 XP software. The EMG signals were amplified, band pass-filtered (20 and 450 ㎐), and notch-filtered (60 ㎐) before being recorded digitally at 1000 ㎐ and processed into root-mean-square data with a window of 50 ㎳. Skin preparation included shaving of the hair and scrubbing of the skin with a cotton wool dipped in alcohol to decrease impedance before data collection. The disposable Ag/AgCl surface electrodes were attached to each muscle at standardized placements (Criswell, 2010). The electrodes for the UT were placed halfway between the C7 spinous process and the scapular acromion. The electrodes for the LT were placed approximately 5 ㎝ down from the scapular spine, next to the medial edge of the scapula at a 55° oblique angle. The electrodes for the SA were placed just below the axillary area, at the level of the inferior tip of the scapula, and medial to the latissimus dorsi (Criswell, 2010). Two active electrodes were attached nearly 2 ㎝ apart in the direction of the muscle fibers.

The maximal voluntary isometric contractions (MVICs) were initiated to normalize the EMG signal amplitude in the UT, LT, and SA according to standardized procedures recommended by previous research studies (Ekstrom et al, 2005; Kendall et al, 1993). To gain the MVIC for the UT, each subject was asked to perform a 90° shoulder abduction with manual resistance to the head after the neck was first side-flexed to the same side, rotated to the opposite side, and extended in the sitting position with no back support (Ekstrom et al, 2005). To obtain the MVIC for the LT, the subject was tested in the prone position. The subject's arm was placed diagonally overhead, in line with the lower fibers of the trapezius muscle during external rotation while resistance was applied distal to the elbow (Ekstrom et al, 2005). The MVIC for the SA was performed with the subject sitting and the shoulder rotated internally and abducted at 125° in the scapular plane. Manual resistance was applied proximal to the subject's elbow by the researcher (Kendall et al, 1993). EMG data for each muscle were obtained for 5 sec, and a 1 min break time was given between trials to minimize muscle fatigue (Vera-Garcia et al, 2010). All average amplitude values were calculated for the middle three sec of the two trials during exercise and expressed as %MVIC.

Scapular winging measurement

A scapulometer was used to determine SW after visual screening (Figure 1). The subject was in a quadruped position with 90° flexion of hip, knee, and shoulder joint. The investigator used a vertical ruler combined with a horizontal ruler to measure the distance between the medial edge of scapula and thoracic wall (Park et al, 2007). The horizontal ruler was placed across both the right and left scapula, and the lower part of vertical ruler was fixed to the spinous process of the thoracic vertebra in the center of the scapula. SW was defined as a of distance ≥3 ㎝ (Park et al, 2007). We proved the test-retest reliability of the scapulometer for measuring the amount of SW.

Figure 1. Measurement of scapular winging.

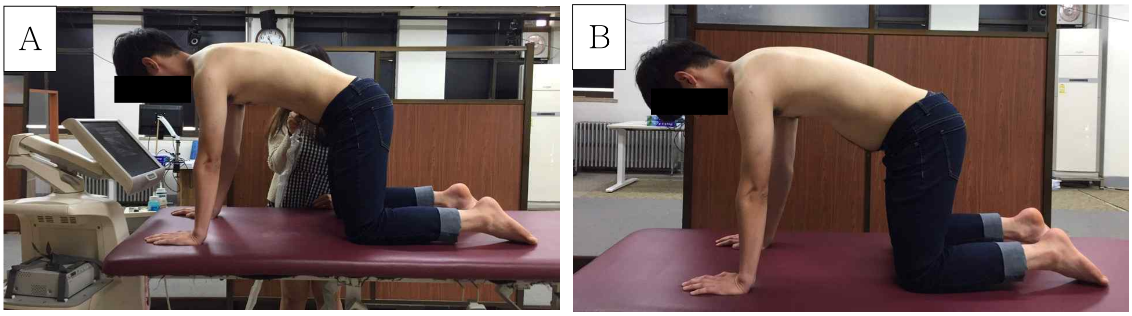

Figure 2. Push-up plus exercise (A: without abdominal drawing-in maneuver, B: with abdominal drawing-in maneuver).

The intra-class correlation coefficient (ICC) was .80 (95% confidence interval; CI: .48∼.93). The standard error of the measurement (SEM) was .15 ㎝, and the minimal detectable change (MDC) was .42 ㎝.

Procedures

The subjects familiarized themselves with the PUP exercise and ADIM for 20 min to perform the exercises properly before data collection. After familiarization, a 10 min rest time was given. The EMG data on the preferred PUP exercise was collected before the data collection on the PUP exercise with ADIM. The subjects were cued to start the exercise when they heard the command “start” and maintained the quadruped position and full protraction of scapula during the exercise. The PUP exercise with and without ADIM were performed for the 5 sec of the three trials (Figure 2). SW was measured immediately after 3 trials of the PUP exercise with and without ADIM.

Preferred push-up plus exercise

The subject assumed a quadruped position with both the hands and knees shoulder-width apart. The hip and knee joint flexions were at 90° in the quadruped position with 90° of shoulder flexion, while the head and pelvis were positioned in a neutral state. The subject maintained the ankle joint in a plantarflexion position and the elbow joint in a full extension position. To maintain the cervical spine in a neutral posture, the cervical spine and thoracic spine were aligned in a straight line. We instructed the subjects to “give an extra push” to protract the scapula maximally.

Push-up plus exercise with abdominal drawing-in maneuver

After the collection of EMG data on the preferred PUP exercise in the quadruped position, the subjects were familiarized with the typical clinical instructions and visual feedback of ADIM from ultrasound imaging to achieve a proper ADIM performance ability. When the subjects could not maintain the ADIM during the exercise period, the test was immediately stopped. With the subject in the quadruped position, ultrasonography (SonaAce X8, Medison Co. Ltd., Seoul, Korea) was used for visual feedback and monitoring of the ADIM during the PUP exercise. An ultrasound transducer was located on the anterolateral abdominal wall approximately 2.5 ㎝ under the inferior tip of the ribs and approximately 15 ㎝ lateral to the umbilicus during ADIM (Misuri et al, 1997). A real-time ultrasound imaging is indicated on the ultrasound machine screen placed in a position that was easily visible for the subject from the quadruped position. The images were obtained at rest, with the subjects exhaling during the contraction, while maintaining the ADIM (Hides et al, 2007). Before starting the ADIM, the subjects were instructed to cough so they can see the movement of their abdominal muscles on the monitor. The investigators instructed the subjects to pull the navel in and up without allowing any movement at the pelvis, rib, or spine and to maintain the abdominal contraction while continually breathing normally after the navel has been drawn close to the spine (O’sullivan, 2000). Ultrasound images of each muscle thickness were monitored to confirm that the thickness of the muscle layers (transverse abdominis, internal oblique abdominis, and external oblique abdominis) was increased by the principal investigator and, Furthermore, an image of the muscle layer was shown to the subjects to provide a visual feedback during the PUP exercise with ADIM. The principal investigator explained the transverse abdominis, internal oblique abdominis, and external oblique abdominis layers and instructed on the maximal preferential activation of the transverse abdominis. A previous study reported that the correct ADIM trials in the ADIM with typical clinical feedback and real-time ultrasound imaging augmented feedback were greater compared to those with a typical clinical feedback including verbal and tactile cues only (Henry and Westervelt, 2005). We discarded the data to perform the correct ADIM when the thickness of the transverse abdominis and internal oblique abdominis was not increased, that of the external oblique abdominis muscle was increased, or a pelvic movement in the posterior direction was shown, or the subjects took a deep inhalation followed by breath holding as determined by palpation (Henry and Westervelt, 2005).

Statistical Analysis

The SPSS software ver. 23.0 (SPSS Inc., Chicago, IL, USA) was used to assess all statistical analyses. The one-sample Kolmogorov-Smirnov test was used to assess the normality of distribution. Test-retest reliability of SW measurement in 2 conditions (with ADIM and without ADIM) of the PUP exercise was assessed using ICC, 95% CI, SEM, and MDC. SEM was calculated to assess absolute consistency ($SEM=SD\times\sqrt{1-ICC}$), MDC (95% CI) ($MDC_{95}=SEM\times1.96\sqrt{2}$) (Ries et al, 2009). The effect size index (ESI) was calculated to decide meaningful changes between the PUP exercise with ADIM and without ADIM. Because all dependent variables were confirm the normality of distribution, a paired t-test was used to assess the statistical significance of the UT, LT, and SA activities, UT/LT and UT/SA ratios, and amount of SW between the preferred PUP exercise and the PUP exercise with ADIM with a significance level of .05.

Results

Muscle activity and muscle activity ratios

Table 1 and Figure 3 shows the %MVIC of the UT, LT, and SA as well as the UT/LT and UT/SA ratios during the exercises. There were no significant differences in the UT and LT activities between the preferred PUP exercise and the PUP exercise with ADIM (p>.05). The SA activity was significantly greater during the PUP exercise with ADIM than during the preferred PUP exercise (p=.02). The

Table 1. Outcomes of the electromyography activities of the upper trapezius, lower trapezius, and serratus anterior and the amount of scapular winging during preferred push-up plus exercise and push-up plus exercise with abdominal drawing-in maneuver

Variables	Preferred PUP[a]	PUP with ADIM[b]	p
UT[c] (%MVIC[d])	4.40±2.87[e]	4.02±1.91	.536
LT[f] (%MVIC)	6.38±8.43	11.67±16.97	.098
SA[g] (%MVIC)	31.88±17.64	40.15±18.06	.018*
UT/LT	.18±.16	.12±.08	.132
UT/SA	1.26±1.36	.90±.79	.194
SW[h] (㎝)	2.86±.33	2.6±.35	<.001*

[a]push-up plus exercise, [b]abdominal drawing-in maneuver, [c]upper trapezius, [d]maximal volutary contraction, [e]mean±standard deviation, [f]lower trapezius, [g]serratus anterior, [h]scapular winging, *p<.05.

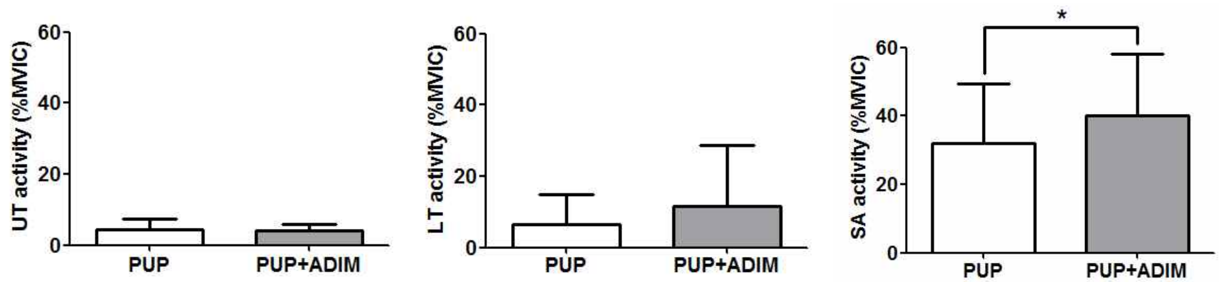

Figure 3. Comparisons of muscle activities in the UT, LT, and SA between the preferred PUP exercise and PUP exercise with ADIM (MVIC: maximal voluntary isometric contraction, UT: upper trapezius, LT: lower trapezius, SA: serratus anterior, PUP: push-up plus, ADIM: abdominal drawing-in maneuver), $^*p<.05$.

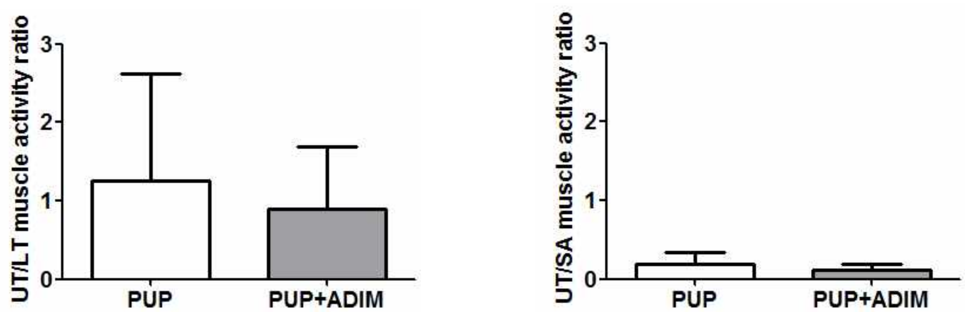

Figure 4. Comparisons of the UT/LT and UT/SA muscle activity ratios between the preferred PUP exercise and PUP exercise with ADIM (UT: upper trapezius, LT: lower trapezius, SA: serratus anterior, PUP: push-up plus, ADIM: abdominal drawing-in maneuver).

UT/LT and UT/SA ratios were not significantly different between the preferred PUP exercise and the PUP exercise with ADIM ($p>.05$) (Figure 4).

Scapular winging

The SW was 2.86±.33 ㎝ after the preferred PUP exercise and 2.6±.35 ㎝ after the PUP exercise with ADIM. The amount of SW was significantly lower during the PUP exercise with ADIM than during the preferred PUP exercise ($p<.001$, ESI=.61) (Figure 5).

Discussion

The aim of this study was to investigate the effect of ADIM on the activities of the UT, LT, and SA, UT/LT and UT/SA muscle activity ratios, and amounts of SW during PUP exercises in subjects with SW. Increased UT activity and decreased LT and SA activity may be cause SW. Thus, muscle activity ratios of UT/LT and UT/SA are useful for determining the extent of the relationship of scapulothoracic muscle during PUP exercise with and without ADIM. The results indicate that the PUP exercise with ADIM demonstrated a significantly greater SA muscle activity compared with the preferred PUP exercise. The amount of SW was significantly lower in the PUP exercise with ADIM than in the preferred PUP exercise in the subjects with SW. Our outcomes partially supported our hypothesis. To our knowledge, this is the first study to identify this strategy using ADIM to increase SA muscle activity and decrease the amount of SW in subjects with SW during PUP exercises with ADIM.

In this study, the PUP exercise with ADIM had no significant effect on the UT and LT muscle activities and UT/SA and UT/LT muscle ratios. These results did not support our study hypothesis that UT muscle activity and UT/SA and UT/LT muscle ratios would decrease and that LT muscle activity

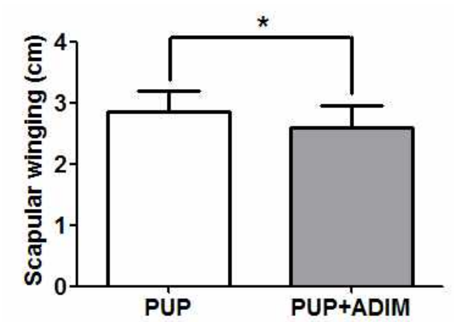

Figure 5. Comparisons of the amount of scapular winging between the preferred PUP exercise and PUP exercise with ADIM (PUP: push-up plus, ADIM: abdominal drawing-in maneuver), *p<.05.

would increase in PUP exercise with ADIM compared with those in the preferred PUP exercise. UT muscle activity increased to compensate for the weak SA during the PUP exercise in the subjects with SW (Decker et al, 1999). However, proximal stability (due to abdominal muscle contraction) could facilitate distal movements and inhibit unwanted movements (UT muscle activity). A previous study also indicated that UT activity decreases in isometric shoulder abduction with external stabilization of the trunk and pelvis (Maenhout et al, 2009). However, this study results did not decrease the UT muscle activity during the PUP exercise with ADIM. The possible mechanism for this varying outcome between our results and those of the previous study is the different muscle activities. The UT muscle is one of the main scapular upward rotators during active arm movements (Ekstrom et al, 2003). However, PUP is an exercise focused on the SA. Thus, the UT (preferred PUP: 4.40 %MVIC, PUP with ADIM: 4.02 %MVIC) was not activated to the levels consistent with the SA (PUP with ADIM: 40.15 %MVIC, preferred PUP exercise: 31.88 %MVIC). Thus, UT activity may have differed if the subjects had performed active arm movements with and without ADIM. Kim et al (2012) showed that the muscle activity of the LT was significantly greater during arm lifts with ADIM than during those without ADIM. However, in this study, LT activation did not change during the PUP exercise with ADIM. PUP exercise is a close chain and stabilization exercise that provides stability and maintains posture rather than an open chain exercise using a large force, such as arm lift exercises (Rogol et al, 1998). Thus, much muscle activity of the LT may be not required during the PUP exercise with and without ADIM.

SA muscle activity during the PUP exercise with ADIM was significantly greater (by 20.6%) compared with that during the preferred PUP exercise. This finding supports our research hypothesis that SA activity would increase more in the PUP exercise with ADIM than in the preferred PUP exercise. Toro et al (2016) reported that SA activity was significantly greater by 48.3% in knee push-up exercises with conscious contraction of the abdominal muscles than in those without conscious contraction of the abdominal muscles. They explained that the reason for such result was attributed to the synergism of the abdominal and scapulothoracic muscles, which was described as a strategy of anticipatory postural correction reached during the exercise by improving muscle activation in a proximal-to-distal sequence (Magarey and Jones, 2003). In addition, Kim et al (2012) showed that arm lift with ADIM was significantly greater than that without ADIM in the SA muscle activity. The increased SA muscle activity during the PUP exercise with ADIM may be explained by the enhanced lumbopelvic stability. Sequential muscle activation of trunk muscles may promote the transfer of proper forces from upper limbs (Hirashima et al, 2002; Jang et al, 2015; Kibler et al, 2006). It has been well known that ADIM enhances lumbopelvic stability by transverse abdominis and internal oblique abdominis activations and increases intraabdominal pressure (Richardson et al, 2002). An improved lumbopelvic stability because of ADIM might have provided the stable base; thus, SA muscle activity increased. Though in this study, the thickness of the TrA and IO was not measured while the subjects were performing the PUP exercise with ADIM, the thickness of both muscles was monitored by the principal investigator.

The amount of SW after the PUP exercise with ADIM was lower by 9% compared with that after the preferred PUP exercise. This outcome supports our research hypothesis that the amount of SW would decrease more in the PUP exercise with ADIM than in the preferred PUP exercise. No previous studies have investigated the amount of SW during PUP exercises with ADIM. Therefore, it is not possible to compare our results to those of other studies. However, this result can be explained by the increased activity of the SA. SW can be caused by a long thoracic nerve palsy, dominant deltoid decreased activation, and/or weakness of the SA (Martin and Fish, 2008). In this study, subjects with long thoracic nerve denervations were excluded; stiffness and/or shortness of the deltoid was also ruled out. Therefore, it can be indicated that the significantly increased SA activity was responsible for the decreased SW during the PUP exercise with ADIM (Martin and Fish, 2008).

However, our study has several limitations. First, this study was a cross-sectional study; thus, the long-term effects of the PUP exercise with ADIM cannot be determined. Second, we used the surface EMG for data collection. Therefore, crosstalk from the adjacent muscles may affect the EMG measurement. Third, our results cannot be generalized to other patient groups because only men with SW were recruited. symptoms. Fourth, we did not measure the kinematic data and movement of scapula during exercises. Fifth, we did not randomize the order of the exercises (PUP exercise with and without ADIM). Further studies should consider performing randomization of order of the exercises to examine the effect of ADIM during PUP exercise more exactly. Although we did not randomized, we reasoned that performing PUP exercise without ADIM first can avoid the findings in current study from being influenced by potential learning effect. Thus, our outcomes were not interfere by lack of randomization. Further studies should investigate the long-term effects of the ADIM during PUP exercise in patient with various clinical symptoms. Furthermore, the kinematic data and movement of scapula should be measured during exercises.

Conclusion

The effects of the PUP exercise with ADIM on the scapular stabilization muscles (UT, LT, and SA) and SW were identified in the subjects with SW. SA muscle activity was significantly greater in the PUP exercise with ADIM than in the preferred PUP exercise; the amount of SW was significantly lower in the PUP exercise with ADIM than in the preferred PUP exercise. Therefore, if a subject has scapular winging, the PUP exercise with ADIM can be suggested to improve the activation of the targeted SA and reduce the amount of SW.

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