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Original Article

Effect of the Shoulder Flexion Angle in the Sagittal Plane on the Muscle Activities of the Upper Extremities when Performing Push-up plus Exercises on an Unstable Surface

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Abstract. [Purpose] The purpose of this study was to investigate the effect of the shoulder flexion angle on the muscle activities of the upper extremities when performing the push-up plus exercise (PUPE) on an unstable surface with the forearm in the external rotation position. [Subjects] The subjects were conducted on 15 normal male adults. [Methods] A sling device was used for the unstable surface, and PUPE was performed with the forearm in the external rotation position. The shoulder flexion angles measured in the sagittal plane were 110°, 90°, and 70°. Electromyography was used for a comparitive analysis of the muscle activities of the serratus anterior (SA), the pectoralis major (PM), and the upper trapezius (UT). [Results] In the intra-group comparison, the muscle activity of SA was statistically the highest when the shoulder-flexion angle was 110°. [Conclusion] performing PUPE on an unstable surface, the muscle activity of the SA is activated the most when the shoulder flexion angle is 110° and the forearm is in the external rotation position.

Key words: Push-up plus exercise, Serratus anterior, Electromyography

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INTRODUCTION

To provide stability, the scapular stabilizers of the shoulder complex work together with the rotator cuff muscles, which include the serratus anterior (SA), upper trapezius (UT), and lower trapezius (LT)[1)]. Imbalance and weakening of the strength of the SA and UT lead to scapular dysfunction[2)]. The SA plays an important role in the initial stabilization of the scapula, as it is an important protractor muscle in the scapulothoracic joint, and it has a good leverage effect in protraction of the shoulder, as its fulcrum is at the axis of the vertical rotation of the acromioclavicular joint[3)]. A closed kinetic chain exercise that is effective for scapular stabilization is the push-up, which has recently evolved into the push-up plus exercise (PUPE). PUPE is a modified version of the normal push-up exercise, which includes maximum scapula protraction when the elbow joint is in extension[4)]. Lee et al.[5)] stated that holding a push-up bar when performing PUPE is more effective than performing it on a flat surface. Yoon et al.[6)] and Lee et al.[7)] reported that the three positions of the forearm, neutral, internal rotation, and external rotation, have different effects on the stability of the scapulothoracic joint. The PUPE with the forearm in external rotation is more effective at strengthening the SA. However, there has been insufficient research on changes in the shoulder flexion angle when the forearm is in the external rotation position. Therefore, this study used a sling device to create an unstable surface during PUPE, to explore the effects on the shoulder muscles of different shoulder flexion angles (110°, 90°, and 70°) in the sagittal plane with the forearm in the external rotation position.

SUBJECTS AND METHODS

The study subjects were 15 male students in their 20s who were attending Chungbuk Y University. The average age of the subjects was 22.8±2.0 years, and their average height and weight were 176.8±5.6 cm and 69.7±9.2 kg, respectively. The exercise method and the purpose of the study were explained to the subjects before the experiment, and they provided voluntary consent by signing a consent form, in accordance with the Declaration of Helsinki. Based on the selection criteria, the selected subjects had the muscle strength and joint range of motion (ROM) necessary to perform the required exercise, and they presented no scapula winging symptoms nor pain in the neck or shoulder joints. Subjects who had engaged in muscle-strengthening exercise in the past six months or who had orthopedic or neurological damage were excluded.

To provide an unstable surface during PUPE, a sling device (Nordisk Terapi AS. KilsundSenteret, 4920 Stand) was used. In the start position, the subjects placed their hands

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and feet shoulder-width apart in a quadruped position, ensuring that their weight was supported by both hands and both knees. To maintain a neutral position in the cervical vertebrae, they flexed the head to ensure that the cervical and lumbar vertebrae were in a straight line. Holding the sling with both hands, the subjects externally rotated their forearms, maintaining the shoulder angle in the sagittal plane at 70°, 90°, or 110°. After the start signal, the subjects performed the PUPE and maintained the position for five seconds. If the subjects could not maintain the standard start position, exercise position, or finishing position, the data were not collected. The experimenter had the subjects repeat the exercise three times to ensure an accurate position, with two minutes of rest after each performance. After receiving verbal instructions and a demonstration, the subjects were given ten minutes to familiarize themselves with the change in position from the quadruped position to the PUPE. During that time, the experimenters made sure that subjects' backs were not raised too high.

In order to measure muscle activity, a MP150 (BIOPAC System Inc. Santa Barbara, CA, USA) was used for electromyography (EMG). Surface electrodes were attached over the SA, UT, and pectoralis major (PM). The EMG signals were collected by the MP150 system and converted into digital signals, which were processed using the Acqknowledge software (version 4.01). The average value of the EMG signals of each subject was expressed as a percentage of the maximum value of isometric contraction (%MVIC).

To examine the muscle activities of the upper extremities as the shoulder flexion angle changed in the sagittal plane, repeated one-way ANOVA was used for analysis. This study used SPSS 12.0 for Windows for the statistical processing, with a significance level, α, of 0.05.

RESULTS

The comparison of the muscle activity of the SA among the different shoulder angles showed it was at its highest ($p<0.05$) when the shoulder flexion angle was 110° (Table 1).

Table 1. Comparison of the muscle activities among the different shoulder-flexion angles (%)

	110°	90°	70°
SA**	86.9±12.6	68.0±12.2	56.6±11.5
PM	53.8±18.5	59.5±22.4	59.2±25.0
UT	10.3±15.7	6.6±3.8	6.3±3.9

SA: serratus anterior muscle; PM: pectoralis major muscle; UT: upper trapezius muscle. **: repeated ANOVA, $p<0.01$

DISCUSSION

This study investigated the influence of three different shoulder flexion angles, 110°, 90°, and 70° on the muscle activities of the SA, PM, and UT during PUPE on an unstable surface (a sling) with the forearm in external rotation.

In order to stabilize the shoulder complex and place a strong emphasis on the SA, exercises that can selectively stabilize the SA have been studied[2]. Exercises on an unstable surface can strengthen the scapular muscles and enhance the stability of the trunk and scapula joint more than exercises on a stable surface[8]. In particular, they increase the muscle activity of many scapular muscles, including the SA[9]. Lee et al.[5] reported that PUPE strengthens the SA and that the muscle activity of the SA was highest when the forearm was externally rotated during the PUPE. Park and Yoo[10] reported in their study that push-up exercise is more effective than push-up plus exercise (PUPE) at activating the serratus anterior muscle. In particular, they noted that exercising on an unstable surface is more effective than on an stable surface. Oh et al.[11] suggested that performing sling exercise therapy on an unstable surface increases the stability of joints in the body more than on a fixed surface, as a dynamic exercise method that strengthens various muscles. Ludewig et al.[12] had 30 healthy adults perform the push-up exercise, and reported that this was the best exercise for strengthening the serratus anterior muscle as it increased SA activation and reduced that of the upper trapezius muscle. Choi[13] conducted a study in which patients with chronic (over three months) shoulder joint pain performed push up exercises for seven weeks, and reported that there were no differences in muscular activation of the anterior deltoid and lower trapezius muscles, but there was a statistically significant reduction in the activation of the upper trapezius muscle. In addition, there was a statistically significant increase in the activation of the serratus anterior muscle.

Yoon et al.[6] stated that external rotation of the forearm was associated with the highest muscle activities in push-up exercises, and Lee et al.[7] also noted that on both unstable and stable surfaces, external rotation of the forearm resulted in the highest muscle activity. Lee et al.[5] stated that holding a push-up bar while performing PUPE was more effective than performing on a flat surface. Yoon et al.[6] and Lee et al.[7] reported that the three positions of the forearm, neutral, internal rotation, and external rotation, had different effects on the stability of the scapulothoracic joint, and PUPE with the forearm in the external rotation position was the most effective at strengthening the SA. Moon[14] conducted an experiment in which PUPE was carried out on a stable surface with the forearm in the neutral position, at shoulder angles of 110°, 90°, or 70°. He found that the muscle activity of the SA was highest at 110°. In the present study, the muscle activity of the SA was found to be the highest when the shoulder flexion angle was 110°. The fact that the highest muscle activity for the SA occurred at 110° seems to be due to the length of the SA muscle at 110° as opposed to 70° or 90°. This is because a number of cross-bridges are created by the connection of actin and myosin filaments in the sarcomere. The number of sarcomeres determines the contraction distance of the muscle, and controlling the number of sarcomeres can adjust the functional length of skeletal muscles. Thus, if the muscle is fixed at a short length, the number of sarcomeres decreases, but if the muscle is elongated, then the number of sarcomeres increases[15]. Therefore, performing PUPE on an unstable surface with a shoulder flexion angle of 110° and with an externally rotated forearm can be considered to be effective a enhancing the stability of the shoulder complex.

One limitation of the study is that the number of subjects was small and restricted to normal male adults; therefore, the results cannot be generalized. A second limitations is that the handle of the sling was made of thin cloth, which made it prone to slippage and difficult to control. In future, more studies of the effects of stable and unstable surfaces and various hand positions on the muscles around the scapula should be conducted.

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