The effect of leg angle during push-up plus exercise on shoulder stabilization muscle activity

SANGYONG LEE, PhD, PT¹), JANGGON KIM, PhD, PT¹)*

¹) Department of Physical Therapy, U1 University: 12 Youngdong-eup, Youngdong-gun, Chungbuk, Republic of Korea

Abstract. [Purpose] This study investigated the effect of different leg angles during push-up plus exercise on shoulder stabilization muscle activity. [Participants and Methods] Fifteen healthy adult males participated in this study. The smartphone application Clinometer was used to measure leg angles of 70°, 90°, and 110° during push-up plus exercise. The muscle activities of the serratus anterior, upper trapezius fibers, and pectoralis major muscles involved in shoulder stabilization were analyzed using surface electromyogram. [Results] Leg angle significantly affected serratus anterior muscle activity, but it did not affect activities of the upper trapezius fibers or pectoralis major muscles. Post-hoc analysis revealed that serratus anterior muscle activity at the leg angle of 110° was significantly higher than at leg angles of 70° and 90°. [Conclusion] A higher leg angle during push-up plus exercise is a more effective intervention for the serratus anterior muscle activity. Key words: Leg angle, Push-up plus, Shoulder stabilization

INTRODUCTION

Stabilization muscles of the shoulder complex act together with the rotator cuff muscles to provide stability. Imbalance and weakening of the force couple of the serratus anterior (SA) muscle and upper trapezius (UT) fibers degrade shoulder function¹). The SA muscle plays an important role in primary stabilization of the shoulder bone. It is an important protraction muscle for the shoulder chest joint and has good lever action in the protraction around the vertical axis of rotation of the acromioclavicular joint²). A weakened SA muscle is commonly observed in baseball players with shoulder instability, individuals with shoulder impingement syndrome, and swimmers with shoulder pain. Decreased muscular activity of SA is found to be correlated with abnormal motion of the shoulder³,⁴). Closed chain arm exercises to improve bone stabilization in the shoulder often include push-up plus exercise, which are modified general push-ups with maximum protraction of the scapula with the elbow joint extended⁵). Togu exercise is a form of closed chain shoulder exercise using unstable support surface for hands such as slings for push-up plus exercise⁶–⁸). Although studies have examined different elements of push-up plus as the Togu exercise, study on the effect of leg angle on muscle activity during the push-up plus is limited. Few studies have researched the effect of leg angle on muscle activity during push-up plus exercise. To address this gap, the current study investigated the effect of three different leg angles (70°, 90°, and 110°) during push-up plus exercise on shoulder stabilization muscles.

PARTICIPANTS AND METHODS

Fifteen healthy adult males attending the U University in Chungcheongbuk-do, Korea participated in this study. Mean age, height, and weight were 22.0 ± 2.0 years, 174.0 ± 4.2 cm, and 64.1 ± 7.7 kg, respectively. Participants were excluded if they had past or current pain or dysfunction in the shoulder bones and joints, received a shoulder surgery within past six...
months, or had a history of damage or instability of the shoulder joints. Ethical approval for the study was granted by the U1 University Institutional Review Board. All participants read and signed consent forms prior to participation, in accordance with the ethical standards of the Declaration of Helsinki.

An electric up-down table (TT1000, Entec, Korea) was used to change the angle of the leg, and a goniometer application for smartphones (Clinometer, plaincode, Germany) was used to measure the leg angle. Smartphone arm band (NCS-01, Nexo, China) was used to wear smartphone. Electromyography (EMG) using the MP150 BIOPAC System (BIOPAC Systems, Inc., USA) measured muscle activities. The surface electrodes were attached to the SA muscle, pectoralis major (PM) muscle, and UT fibers. The SA muscle of a surface electrode was attached to the anterior part of the latissimus dorsi muscle at rib level height (ribs 5 and 6), 2 cm into the medial part of the anterior axillary border for the PM, and to the central-posterior part of the UT muscle (between the C7 and acromion spinous processes). Electromyography signals were collected using a sampling rate of 1,000 Hz and then processed using full-wave rectification. The data were analyzed using AcqKnowledge® version 3.81 (Biopac Systems, Santa Barbara, CA, USA) software. Band pass filtering was applied at 30–500 Hz and then again at 60 Hz to remove noise. The measured raw data were converted into the root mean square and the measured values obtained for the four seconds at the center of the movement (excluding the first and last three seconds) were used as the measurement result for 10 seconds for the purpose of standardizing the collected data. The obtained the root mean square values were divided by the maximum voluntary isometric contraction (MVIC) and normalized to the % MVIC value in order to calculate the result.

Before the experiment, a smartphone goniometer was attached to each participant using a smartphone arm band three centimeters above the lateral malleoli. With feet placed on the electric up-down table, the electric up-down table was raised from the ground so that the leg angle could be changed to 70°, 90°, and 110°. The leg angle is between the line perpendicular to the ground and the line that connects hip and lateral malleoli. Muscle activity was measured for each leg angle of 70°, 90°, and 110°. Participants put both hands on the floor at shoulder width, keeping arms perpendicular to the floor and fully extending elbows. They performed the push-up plus exercise while maintaining this posture. Participants were instructed to keep the shoulder joint, hip joint, knee joint and ankle joint as straight as possible. If the participant failed to keep correct posture, data were not collected. Participants performed the push-up plus exercise and maintained the posture for 10 seconds and repeated the process three times with break in between exercises.

The effect of leg angle on muscle activities of shoulder stabilization muscles were analyzed by a one-way repeated measures analysis of variance (ANOVA). A Bonferroni correction was performed as a post-hoc test. Statistical analysis was performed using Microsoft Excel 365 (Microsoft office Inc., Korea), and the significance level (α) was set at 0.05.

RESULTS

The results revealed significant differences in SA muscle activity (p<0.05), but there were no significant differences in the activities of the UT fibers and PM muscles (p>0.05). Post-hoc analysis showed that SA muscle activity at the leg angle of 110° was significantly higher than at 70° and 90° (p<0.05; Table 1).

Table 1. Comparison of SA, PM, and UT muscle activities by leg angle (unit: %)

|        | 70°      | 90°      | 110°     | post-hoc     |
|--------|----------|----------|----------|--------------|
| SA     | 55.6 ± 19.0 | 70.2 ± 21.5 | 84.6 ± 14.4 | 70°, 90°<110°** |
| PM     | 23.9 ± 16.7 | 23.3 ± 15.4 | 28.1 ± 12.4 |              |
| UT     | 7.5 ± 4.1   | 13.1 ± 12.5 | 18.9 ± 19.9 |              |

Mean ± SD. SA: Serratus anterior; PM: Pectoralis major; UT: Upper trapezius fibers, **p<0.01, repeated measures one-way analysis of variance.

DISCUSSION

In general, when the SA muscle is weakened, the UT fibers are activated, and a full upward rotation of the shoulder bone cannot be made. Change in the normal movement of the shoulder causes shoulder bones to rise instead of rotating upward, resulting in a shrugging motion9). To activate weak SA muscles, Ellenbecker et al.10) recommended push-up plus exercise as an effective closed chain exercise to train SA muscles and scapular stabilizing synergists.

Although Ludewig et al.11) reported that excessive activity of UT fibers occurs in patients with an imbalance of SA muscle, activity of UT fibers was not significantly different in the current study. This result may have occurred because the participants were healthy young adults and had no SA muscle imbalance. Furthermore, the lack of significant difference in PM muscle activity is consistent with the findings of Park et al.12) They found that in participants performing push-up plus exercise, the PM muscle contributed more to the centering and dynamic stabilization of upper arm bones during bending and stretching of the elbow joint rather than to the static stabilization of the shoulder bones. In the current study, SA muscle activity at the leg angle of 110° was significantly higher than at 70° and 90°, which is consistent with the findings of Lear and
Gross\textsuperscript{13}, which showed that as leg angle increased, the load on the shoulder joint increased and, as a result, ground reaction force increased.

It is important to note that the results of this study cannot be generalized because the participants were healthy adult men in their 20s and the sample size was limited. Similar to the approach used in the study by Lear and Gross\textsuperscript{13}, the study participants were asked to extend their arms forward and parallel to each other, to the width of their shoulders, and then to bend forward and hold on to their ankles, while keeping the trunk and pelvis straight between their shoulders and ankles. When the straight line could not be maintained, the pelvis of each participant was lifted up by the operator to maintain a straight line, and then supported with their hands. However, the participants found it difficult to ensure that the line remained completely straight. This was a study limitation.

The push-up plus exercises were demonstrated to have a positive effect on muscular stabilization of the shoulder in the current study. An increase in SA activity correlated with an increase in leg angle. Although further study is necessary in a population with shoulder injury, increase in the leg height during push up plus exercise may benefit higher level patients such as athletes with shoulder instability.

\textit{Conflict of interest}

None.

\textbf{REFERENCES}

1) Martins J, Tucci HT, Andrade R, et al.: Electromyographic amplitude ratio of serratus anterior and upper trapezius muscles during modified push-ups and bench press exercises. J Strength Cond Res, 2008, 22: 477–484. [Medline]  [CrossRef]

2) Neumann DA: Kinesiology of the musculoskeletal system: foundation for physical rehabilitation. St. Louis: Mosby. 2002, pp 123–144.

3) Glousman R, Jobe F, Tibone J, et al.: Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. J Bone Joint Surg Am, 1988, 70: 220–226. [Medline]  [CrossRef]

4) Scovazzo ML, Browne A, Pink M, et al.: The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. Am J Sports Med, 1991, 19: 577–582. [Medline]  [CrossRef]

5) Ellenbecker TS, Davies GJ: Closed kinetic chain exercise: a comprehensive guide to multiple joint exercise. Illinois: Human Kinetics Publishers, 2001.

6) Kim EY, Park HG, Ahn BH: Comparative studies of muscle activity on upper extremity between push-up bend and push-up plus movement according to change of supporting base interval. J Korean Phys Ther Sci, 2008, 15: 31–41.

7) Kim JS, Lee DY: Effect of the shoulder stabilizer muscle activity during a push-up-plus on a different condition surface. J Digit Convergence, 2012, 10: 399–405.

8) Lee KC, Bae WS: Effect of push-up plus exercise on serratus anterior and upper trapezius muscle activation based on the application method of Togu. J Korean Soc Integr Med, 2016, 4: 29–36. [CrossRef]

9) Comerford MJ, Mottram SL: Functional stability re-training: principles and strategies for managing mechanical dysfunction. Man Ther, 2001, 6: 3–14. [Medline]  [CrossRef]

10) Ellenbecker TS, Davies GJ: Closed kinetic chain exercise: a comprehensive guide to multiple joint exercise. Champaign: Human Kinetics, 2001.

11) Ludewig PM, Cook TM: Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther, 2000, 80: 276–291. [Medline]

12) Park JS, Jeon HS, Kwon OY: A comparison of the shoulder stabilizer muscle activities during push-up plus between persons with and without winging scapular. Phys Ther Korea, 2007, 14: 44–52.

13) Lear LJ, Gross MT: An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther, 1998, 28: 146–157. [Medline]  [CrossRef]