J. Phys. Ther. Sci.
25: 833–837, 2013

Surface EMG during the Push-up plus Exercise on a Stable Support or Swiss Ball: Scapular Stabilizer Muscle Exercise

Sung-Hwa Seo, PhD, PT[1)], In-Ho Jeon, PhD, MD[2)]* Yong-Ho Cho, PhD, PT[3)], Hyun-Gi Lee, PhD, PT[4)], Yoon-Tae Hwang, PhD, PT[5)], Jee-Hun Jang, PhD[6)]

[1)] *Department of Medical Science, GyeongJu University*
[2)] *Department of Orthopedic Surgery, Asan Medical Center, College of Medicine, University of Ulsan: 88 Olympic-ro, 43-Gil, Songpa-gu, Seoul 138-738, Republic of Korea. TEL:+82 10-7295-5637*
[3)] *Department of Physical Therapy, Kyungbuk College*
[4)] *Department of Health Promotion, Kyungook National Hospital*
[5)] *Department of Physical Therapy, Gangneung Yeongdong College*
[6)] *Department of Sports Leisure, Kwangdong University*

Abstract. [Purpose] Scapular stabilizer strengthening exercise is crucial for shoulder rehabilitation. The purpose of this study was to compare two types of push-up plus exercises, on a stable and unstable bases of support, using surface electromyography (EMG), to suggest an effective shoulder rehabilitation program. [Subjects and Methods] Ten healthy men volunteered for this study. All volunteers performed two sets of push-up plus exercise (standard push up and knee push up) on stable and unstable bases of support. The muscle activities of five important scapular stabilizer muscles (upper trapezius, middle trapezius, lower trapezius, serratus anterior, latissimus dorsi) were recorded during the exercise. [Results] The upper trapezius showed greater mean electric activation amplitude in the scapular retraction posture than in the scapular protraction posture, and the serratus anterior showed greater mean electric activation amplitude in the scapular protraction posture than in the scapular retraction posture. The root-mean-square normalized EMG values of the muscles were greater during the exercise performed on the unstable support than those on the stable support. [Conclusion] The standard push-up plus exercise on an unstable base of support helps to increase muscle activity, especially those of the upper/middle trapezius and serratus anterior.
Key words: Scapular stabilizer, Push-up plus, Surface EMG

(This article was submitted Jan. 17, 2013, and was accepted Mar. 8, 2013)

INTRODUCTION

Strengthening of scapular stabilizer muscles plays a crucial role in the treatment of various shoulder pathologies, such as scapular dyskinesia, multidirectional instability, secondary impingement syndrome and postoperative conditions[1)].

The serratus anterior is one of the most important muscles responsible for scapular stabilization[2, 3)]. Weakness of this muscle causes the scapula to rest in a downwardly rotated position, causing scapular winging[3)]. Scapular winging may contribute to persistent symptoms in patients with secondary impingement or scapulothoracic dyskinesia[4)]; thus, an exercise program to restore the serratus anterior muscle tone is an important item of rehabilitation[5)]. The trapezius muscle is also of substantial importance in the painful shoulder condition, contributing to abnormal rotation of the scapula[6, 7)]. In patients with painful shoulder, the loss of scapular muscles coordination and balance has been described in the literature[7–10)].

Push-up exercise is known to be one of the most effective and popular exercises for the strengthening of scapular stabilizer muscles[11, 12)]. Push-ups can be performed either on a stable support such as floor or wall, or on an unstable support, such as a Swiss ball. However, it is not known which exercise is beneficial for specific scapular stabilizer muscles. Previous studies have failed to address and compare which phases of push-up plus exercise contribute to muscle activation, or which specific muscles are activated on stable and unstable bases of support.

The purpose of this study was to measure the differences between two types of push-up plus exercises in terms muscle activities measured by surface EMG in order to suggest the best scapular stabilizer strengthening exercise program, and provide clinicians with insight on clinically relevant scapular stabilizer exercise program for the treatment of various shoulder pathologic conditions.

SUBJECTS AND METHODS

The subjects were ten healthy male volunteers. They were evaluated clinically by one orthopedic consultant to confirm the absence of alterations to upper limb struc-

*To whom correspondence should be addressed.
E-mail: jeonchoi@gmail.com

tures. Volunteers with a history of shoulder, elbow, wrist, hand disease or previous operation, cervical spine injury or sustained pain were excluded. The average age of the participants was 24.6 years. Details of their physical constitution are as follows: height, 176.2 ± 3.67 cm; weight, 75.7 ± 5.16 kg; chest circumference, 91.8 ± 5.99 cm; shoulder width, 35.4 ± 1.71 cm (Mean ± SD). First, maximum voluntary isometric contraction (MVIC) was measured. To isolate the activation of the five muscles (upper trapezius, middle trapezius, lower trapezius, serratus anterior, and latissimus dorsi), specific positions for MVIC were selected based on McLean and Kendal[13, 14].

The upper trapezius was tested with the volunteer seated, the shoulder abducted to 90°, and the head in a neutral position. Resistance was applied downward on the shoulder[13]. The middle trapezius was tested with the subjects lying prone on a treatment table, and the shoulder externally rotated and horizontally abducted to 90°. Resistance was applied distal to the elbow[14]. The lower trapezius was tested with the shoulder in external rotation and the arm abducted to 125°. Resistance was applied distal to the elbow[14]. The MVIC of the serratus anterior was tested with the subjects seated on a table, the shoulder internally rotated and abducted to 125° in the scapular plane. Resistance was applied proximal to the elbow[14]. Lastly, the MVIC of the latissimus dorsi was conducted by resisting subjects as they attempted a pull-down maneuver with the upper arms abducted to 90°[15]. Resting time of at least 1 minute was provided between MVIC tests to avoid fatigue.

The chair height and the Swiss ball (55 cm diameter) height were standardized and identical in all trials. A minimum of 3 minutes of rest was given between exercises to prevent the influence of fatigue on electromyographic amplitude changes.

All subjects were educated about the exercise program for this study and performed standardized supervised practice before the test. After MVIC measurement, the subjects were given an educational session about the exercise program and performed the standardized push-up plus exercise three times. In actual measurement, the subjects were asked to follow the exercises two times in random order and we collected and calculated the average value for final data[12].

Surface EMG was recorded over the five important scapular stabilizers; the upper trapezius, middle trapezius, lower trapezius, serratus anterior, latissimus dorsi muscles. The electrode locations were as follows: upper trapezius electrode was placed slightly lateral to and halfway between the cervical spine at C-7 and the acromion[16]; the middle trapezius electrode was centered vertically between the medial border of the scapula and the spines of the thoracic vertebrae (T-1 to T-6)[5]; the lower trapezius electrode was placed approximately 5 cm down from the scapular spine; the serratus anterior electrode was placed just below the axillary area, at the level of the inferior tip of the scapula[16]; and the latissimus dorsi electrode was placed three fingerbreadths distal to and along the posterior axillary fold, parallel to the lateral border of the scapula[12].

Measurements were recorded during a series of the push up plus exercise sequences. All movements were completed in a standardized position with the hands placed at shoulder width apart with the subjects' middle fingers under the acromioclavicular joint on the floor.

We asked each participant to maintain four postures. The standard push-up plus (feet on the ground) was carried out utilizing a chair as a stable support, as was the knee push-up plus (knees on the ground). The standard and knee push-up plus were executed utilizing a Swiss ball as an unstable support (Fig. 1).

A. Standard Push up plus on stable Chair support (SP-C).

B. Knee Push up plus on stable Chair support (KP-C).

C. Standard Push up plus on unstable Swiss Ball support (SP-S).

D. Knee Push up plus on unstable Swiss Ball support (KP-S).

The "down position" (scapular retraction) and "up position" (scapular protraction) lasted for 5 seconds in each repetition. Two repetitions were recorded during a 40 second period. An electrical trigger was used to mark the beginning of the first descent and the finish of the last repetition[12].

The standard push up plus started in the push up position. The volunteer rolled the shoulders forward (scapular protraction) and continued to rise up by protracting the scapula, and then lowered his body while approximating

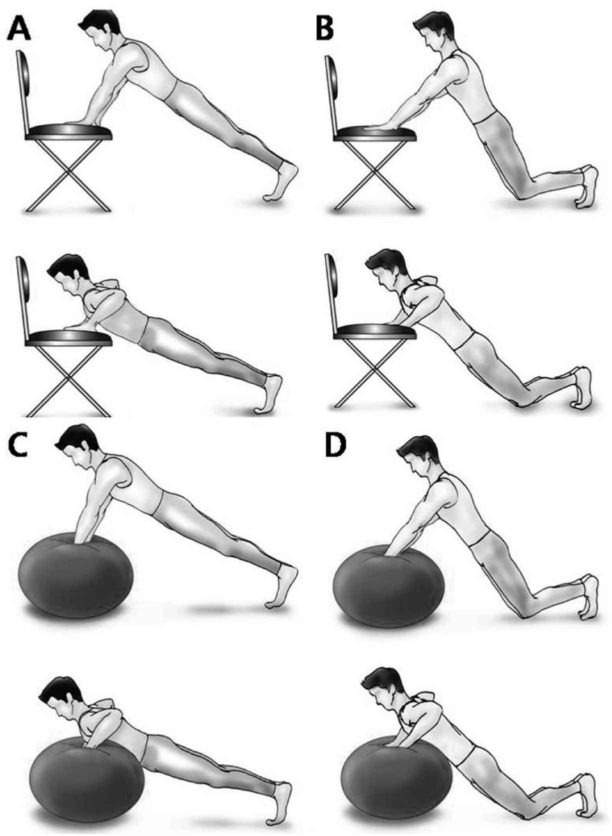

Fig. 1. The figures showed the four types of push-up plus exercise. A, the standard push-up plus on a stable chair support (SP-C). B, knee push-up plus on a stable chair support (KP-C). C, the standard push-up plus on an unstable Swiss ball support (SP-S). D, knee push-up plus on an unstable Swiss ball support (KP-S).

shoulder blades (scapular retraction)[17]. The knee push up plus, a modification of a standard push-up plus, was performed exactly like the standard push up plus except the body weight was supported by the hands and knees, rather than the hands and feet (Fig. 1)[5].

To measure surface EMG (SEMG) of the muscles, an MP150 (BIOPAC System Inc. CA. USA) was used. The surface EMG signal was recorded at a 1000 Hz sampling frequency, and was filtered using a band pass filter between 10 Hz and 500 Hz. Active electrode Ag-AgCl discs (BIOPAC, diameter 2 cm) were adhered to the skin over each target muscle group following the description of Lehman et al.[12, 18, 19]. The ground electrode was attached to the cervical spine at C7. Before application of the surface electrodes, the subjects' skin was shaved if necessary, and wiped with alcohol to reduce skin impedance[20]. The centre-to-centre electrode distance was 2 cm. Electrodes were positioned above the midpoint of the muscle belly, parallel to the direction of the muscle fibers. They were further secured to the skin with adhesive tape together with the preamplifier to reduce motion artefacts[21].

Standard descriptive statistical methods were used to calculate normalized root mean squares (RMS) using percentages of muscle activities of MVIC, and means and standard deviations (SD) of each muscle, during each exercise. Differences among exercises (KP-C, SP-C, KP-S and SP-S) and muscles (upper trapezius, middle trapezius, lower trapezius, serratus anterior and latissimus dorsi) were analyzed using repeated measures ANOVA. The LSD test was performed as a post-hoc test. SPSS 12.0 for Windows was used throughout, and statistical significance was accepted for values of $p<0.05$.

RESULTS

Normalized RMS values for each muscle studied during each exercise are presented in Table 1. The RMS value of the trapezius during push-ups was always greater than those of the other muscles tested.

Table 1 showed the average muscle activity and standard deviations of the two exercise studied on the two different surface bases. The upper trapezius activity was increased on the unstable support during the "down position". When subjects performed the "up position", the muscle activity of the upper trapezius during SP-S was greater than that measured during SP-C. Each exercise showed statistically significant increases in muscle activity on the unstable Swiss ball support compared to the stable support. When SP-C, KP-C and KP-S were compared, the maximum activity level was recorded in SP-C, followed by KP-S and KP-C, although there were no statistically significant differences in muscle activities. The upper trapezius and latissimus dorsi showed significant increases in muscle activities during SP-S and SP-C, compared to KP-C and KP-S. The serratus anterior showed the maximum level of muscle activity in SP-S, followed by KP-S, SP-C and KP-C.

There was a tendency for every muscle activities of the scapular stabilizers to be greater on the unstable support than on the stable support. The middle trapezius and lower trapezius during performance of the Standard push-up plus showed significantly increased activities and the same was true of the lower trapezius during performance of the Knee push up plus. In addition, the activities of the upper trapezius, middle trapezius and latissimus dorsi during the "down position" increased noticeably ($p<0.05$)

The muscle activity of the serratus anterior was greater during the "up position" and the activities of the upper trapezius, middle trapezius and lower trapezius were greater in the "down position" than in the "up position". For the latissimus dorsi, however, there was no statistically significant difference between the "up" and "down" positions. Also, the muscle activities on the unstable support were greater in the "down position" than in the "up position" ($p<0.05$)

Generally, the recorded muscle activities were lower in

Table 1. Muscle activities of the push-up plus on the stable and unstable supports in the "up position" and the "down position" (unit: %MVIC)

Variable	muscle	SP-C Mean (SD)	KP-C Mean (SD)	SP-S Mean (SD)	KP-S Mean (SD)
Up -postion	TU	4.61 (3.333)	4.97 (6.478)	6.91 (7.101)	4.84 (2.873)
	TM▲◆	7.69 (4.841)	7.63 (5.251)	15.68 (7.924)	11.21 (8.987)
	TL▲	5.81 (4.306)	4.43 (2.863)	8.01 (4.845)	6.64 (5.559)
	LD	13.49 (12.123)	6.36 (3.978)	14.36 (9.325)	8.75 (5.788)
	SA	29.84 (10.357)	22.39 (18.919)	39.37 (24.919)	38.58 (23.625)
Down -position	TU+■▲	42.84 (21.354)	25.73 (11.912)	73.26 (16.342)	40.80 (26.119)
	TM▲	38.32 (29.711)	46.29 (20.548)	69.91 (25.024)	60.71 (32.678)
	TL+■	34.59 (16.489)	21.48 (13.900)	39.83 (19.561)	23.55 (12.867)
	LD+▲	7.24 (5.179)	15.55 (10.407)	20.23 (12.611)	15.85 (9.646)
	SA+◆	18.44 (15.052)	9.47 (15.124)	24.69 (22.281)	18.60 (24.485)

▲: SP-C and SP-S showed a statistically significant difference
◆: KP-C and KP-S showed a statistically significant difference
+: SP-C and KP-C showed a statistically significant difference
■: SP-S and KP-S showed a statistically significant difference
TU, upper trapezius; TM, middle trapezius; TL, lower trapezius; LD, latissimus dorsi; SA, serratus anterior

the knee flexion state, however, higher activity levels were measured in the middle trapezius and latissimus dorsi during knee flexion. A statistically significant difference was observed in the upper trapezius, lower trapezius, serratus anterior, and latissimus dorsi in the “down position” on the stable support and similarly the upper trapezius and lower trapezius during “down position” on the unstable support. The activity of the “up position” was lower than that in the “down position”, but the difference was not significant.

DISCUSSION

The push up exercise is important for strengthening muscles around the scapula. A medical ball or Swiss ball has been routinely used in the clinical setting, however, few studies have focused on the scapular stabilizer muscles. This study showed that performance of the knee push-up plus exercise reduced muscle activities compared to the standard push-up plus. However, it was noteworthy that the muscle activities of the middle trapezius and latissimus dorsi were exceptionally high during in the Knee push-up plus stage.

For developing the strength of the serratus anterior muscle, isometric contraction should be maintained in the “up position”, so that the muscle activity of the serratus anterior can be sustained at a high level. Holding the pose in the “down position” can strengthen the muscle activity of the upper trapezius, middle trapezius and lower trapezius.

We compared the two types of exercises in terms of muscle activity measured by surface EMG. The upper trapezius showed greater mean electric activation amplitude during scapular retraction than during scapular protraction, and the serratus anterior showed greater mean electric activation amplitude during scapular protraction than during scapular retraction. The RMS normalized values of the muscles were greater during exercise on the unstable Swiss ball support than on the stable base of support. During scapular retraction, the activation amplitude of the upper trapezius was greater than those of the majority of the muscles studied. During the scapular protraction position, the activation amplitude of the serratus anterior was greater than those of the other muscles studied. Moreover, the anterior action of the serratus anterior has been associated with assisting the centralization of the humeral head in the glenoid fossa[22].

The present contribute to the basic data of the levels of muscular activation during exercises that are common in the clinical practice of shoulder and scapula rehabilitation, and clarify the differences in terms of the type of base support used. Further study is required to identify the levels of muscular activation under different conditions utilizing an unstable base support for patients with sick scapular syndrome and scapular dyskinesia. The exercises used in the present study promoted varying levels of activity within the studied muscles; thus, exercises must be chosen according to patients’ individual needs. For example, a patient with a weak upper trapezius and latissimus dorsi should perform the push-up plus exercise with scapular retraction as this would provide the best effect. In addition, the most effective exercise for the improvement of the serratus anterior would be performance of the push-up plus with a round back.

A limitation of this study is the small number of healthy participants and the lack of a control group. The exercise was performed two times, and there may be concern about the results’ reproducibility; however we found the results were consistent with the findings of a pilot study. Surface EMG to monitor shoulder muscles is less accurate than invasive needle EMG; however, it does not provoke pain.

In summary, we found greater scapular stabilizer muscle activities on the unstable support than on the stable support, suggesting that push-up plus on the knees, especially on a stable support is recommended as an initial program, when a patient or athlete has not fully recovered after an injury or operation.

The results contribute to the basic data of the levels of muscular activation during exercises that are common in the clinical practice of shoulder and scapula rehabilitation, and clarify differences in terms of the types of base support used.

ACKNOWLEDGEMENT

This work was supported by the Global Frontier R&D Program on Human-centered Interaction for Coexistence funded by the National Research Foundation of Korea grant funded by the Korean Government (MSIP) (NRF-M1AXA003-2010-0029748).

REFERENCES

1) Hintermeister RA, Lange GW, Schultheis JM, et al.: Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. Am J Sports Med, 1998, 26: 210–220. [Medline]
2) Dvir Z, Berme N: The shoulder complex in elevation of the arm: a mechanism approach. J Biomech, 1978, 11: 219–225. [Medline] [CrossRef]
3) Watson CJ, Schenkman M: Physical therapy management of isolated serratus anterior muscle paralysis. Phys Ther, 1995, 75: 194–202. [Medline]
4) Kibler WB: The role of the scapula in athletic shoulder function. Am J Sports Med, 1998, 26: 325–337. [Medline]
5) Decker MJ, Hintermeister RA, Faber KJ, et al.: Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med, 1999, 27: 784–791. [Medline]
6) Kleine BU, Schumann NP, Stegeman DF, et al.: Surface EMG mapping of the human trapezius muscle: the topography of monopolar and bipolar surface EMG amplitude and spectrum parameters at varied forces and in fatigue. Clin Neurophysiol, 2000, 111: 686–693. [Medline] [CrossRef]
7) 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]
8) Lehman GJ, Buchan DD, Lundy A, et al.: Variations in muscle activation levels during traditional latissimus dorsi weight training exercises: an experimental study. Dyn Med, 2004, 3: 4. [Medline] [CrossRef]
9) Lukasiewicz AC, McClure P, Michener L, et al.: Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther, 1999, 29: 574–583, discussion 584–586. [Medline]
10) Peat M, Grahame RE: Electromyographic analysis of soft tissue lesions affecting shoulder function. Am J Phys Med, 1977, 56: 223–240. [Medline]
11) Anderson KG, Behm DG: Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res, 2004, 18: 637–640. [Medline]
12) Lehman GJ, MacMillan B, MacIntyre I, et al.: Shoulder muscle EMG activity during push up variations on and off a Swiss ball. Dyn Med, 2006, 5: 7. [Medline] [CrossRef]
13) McLean L, Chislett M, Keith M, et al.: The effect of head position, electrode site, movement and smoothing window in the determination of a reliable maximum voluntary activation of the upper trapezius muscle. J

Electromyogr Kinesiol, 2003, 13: 169–180. [Medline] [CrossRef]
14) Kendal FP, McCreay EK: Muscles, Testing and Function. 3rd ed. Baltimore: Williams and Wilkins, 1983.
15) McGill SM: Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics. J Orthop Res, 1991, 9: 91–103. [Medline] [CrossRef]
16) Cram JR, Kasman GS, Holtz J: Introduction to Surface Electromyography. Gaithersburg: Aspen Publishers, 1998.
17) Jobe FW, Pink M: Classification and treatment of shoulder dysfunction in the overhead athlete. J Orthop Sports Phys Ther, 1993, 18: 427–432. [Medline]
18) Hägg GM: Action potential velocity measurements in the upper trapezius muscle. J Electromyogr Kinesiol, 1993, 3: 231–235. [Medline] [CrossRef]
19) Jensen C, Vasseljen O, Westgaard RH: The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle. Eur J Appl Physiol Occup Physiol, 1993, 67: 266–273. [Medline] [CrossRef]
20) Marshall PW, Murphy BA: Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil, 2005, 86: 242–249. [Medline] [CrossRef]
21) Karamanidis K, Arampatzis A, Bruggemann GP: Reproducibility of electromyography and ground reaction force during various running techniques. Gait Posture, 2004, 19: 115–123. [Medline] [CrossRef]
22) Maffet MW, Jobe FW, Pink MM, et al.: Shoulder muscle firing patterns during the windmill softball pitch. Am J Sports Med, 1997, 25: 369–374. [Medline] [CrossRef]