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ORIGINAL ARTICLE

Scapular kinematic and shoulder muscle activity alterations after serratus anterior muscle fatigue

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Background: Although the serratus anterior muscle has an important role in scapular movement, no study to date has investigated the effect of serratus anterior fatigue on scapular kinematics and shoulder muscle activity. The purpose of this study was to clarify the effect of serratus anterior fatigue on scapular movement and shoulder muscle activity.

Methods: The study participants were 16 healthy men. Electrical muscle stimulation was used to fatigue the serratus anterior muscle. Shoulder muscle strength and endurance, scapular movement, and muscle activity were measured before and after the fatigue task. The muscle activity of the serratus anterior, upper and lower trapezius, anterior and middle deltoid, and infraspinatus muscles was recorded, and the median power frequency of these muscles was calculated to examine the degree of muscle fatigue.

Results: The muscle endurance and median power frequency of the serratus anterior muscle decreased after the fatigue tasks, whereas the muscle activities of the serratus anterior, upper trapezius, and infraspinatus muscles increased. External rotation of the scapula at the shoulder elevated position increased after the fatigue task.

Conclusion: Selective serratus anterior fatigue due to electric muscle stimulation decreased the serratus anterior endurance at the flexed shoulder position. Furthermore, the muscle activities of the serratus anterior, upper trapezius, and infraspinatus increased and the scapular external rotation was greater after serratus anterior fatigue. These results suggest that the rotator cuff and scapular muscle compensated to avoid the increase in internal rotation of the scapula caused by the dysfunction of the serratus anterior muscle.

Level of evidence: Basic Science Study; Kinesiology

Keywords: Shoulder; scapula; fatigue; serratus anterior muscle; biomechanics; rehabilitation

The Kyoto University Graduate School and the Faculty of Medicine Ethics Committee approved the study design (R0327). The study conformed to the principles of the Declaration of Helsinki.

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The shoulder complex consists of the scapula, humerus, and clavicle, and the scapula upwardly and externally rotates and posteriorly tilts during shoulder elevation.[28,31] This coordinated movement is controlled by the neuromuscular function and capsular ligaments.[23] Dysfunction of the control

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system alters the scapular movement and might cause a shoulder disorder. Previous studies reported that the scapular movement during shoulder elevation changed in people with subacromial impingement syndrome,[27,29] rotator cuff tear,[37] or shoulder instability.[37,41]

Shoulder muscle activity plays an important role in controlling scapular movement, and the dysfunction of these muscles might be a factor that changes scapular movement. Previous studies found decreased activity of the serratus anterior muscle[27] and increased activity of the upper trapezius muscle[9,27] in subacromial impingement syndrome. Furthermore, the serratus anterior and the upper and lower trapezius muscles work as a force couple for upward rotation of the scapula. Decreased activity of the serratus anterior muscle relative to the upper trapezius muscle associated with the change in scapulohumeral rhythm and a decrease in scapular upward rotation during shoulder elevation were found in people with impingement syndrome.[19,36] These findings in previous studies suggested that the change in muscle activity of the serratus anterior was related to the change in scapular movement. In addition, the consensus statement from the scapular summit also proposed that the serratus anterior is one of the causes of scapular dyskinesis[22] and is one of the target muscles for its rehabilitation.[11] However, the cause-consequence relationship between the dysfunction of the serratus anterior muscle and abnormal scapular movement is unknown.

Some studies investigated the effect of muscle dysfunction caused by acute muscle fatigue on the scapular movement to clarify the relationship between shoulder muscle activity and scapular movement.[7,14,33] A previous study of serratus anterior fatigue and scapular movement examined the effect of a push-up plus task on muscle activity and scapular movement and found an increase in scapular internal rotation and a decrease in posterior tilt during scapular plane elevation. However, electromyography (EMG) data showed fatigue of the serratus anterior and upper and lower trapezius and infraspinatus muscles.[5] Therefore, the relationship between selective fatigue of the serratus anterior and changes in scapular kinematics is unknown, whereas the effect of selective muscle fatigue on scapular kinematics should be elucidated to further develop our knowledge of the shoulder complex.

Many previous studies evaluated 3-dimensional scapular motion during only shoulder elevation. However, it is possible that muscle endurance at the shoulder elevated position is important for evaluating shoulder function because some shoulder functional tests apply muscle endurance at the shoulder elevated position, which is impaired in people with shoulder disease.[8,39]

The purpose of this study was to investigate the effect of selective fatigue of the serratus anterior on muscle activity and scapular movement. We hypothesized that scapular upward rotation would be increased at the shoulder elevated position after the fatigue task due to the compensatory increase in muscle activity of the upper trapezius.

Materials and methods

Participants

This study was a controlled experimental study. The study participants were 16 men (mean age, 25.6 ± 3.4 years; mean height, 172.4 ± 5.4 cm; mean weight, 66 ± 7.2 kg) who were students from our institution. At the time of recruitment, the participants confirmed that they did not meet the exclusion criteria, which included present or history of orthopedic or nervous system disease in the upper limb, athletes, or persons who perform any extensive exercise, and female gender. Before the experiment, no participants were excluded. The aim and procedure of this study was explained to all participants, each of whom provided informed consent.

The sample size was calculated based on a 2-way analysis of variance (ANOVA) with repeated measures (effect size = 0.25, α error = 0.05, power = 0.8) using G*Power 3.1 software (Heinrich Hein University, Düsseldorf, Germany) before the participants were recruited and showed that a group size of 10 subjects was required for this analysis to enable the detection of statistical significance. Therefore, 16 healthy men were recruited.

Experimental procedures

The dominant and nondominant upper limb was identified as the control and fatigue limb, respectively. The participants performed maximal isometric shoulder flexion at 90° and then kept their arm at shoulder flexion at 90° to measure the shoulder muscle strength and endurance, respectively. Scapular kinematics and EMG measurements were collected during the muscle endurance test. The participants underwent the fatigue task for 25 minutes. Muscle strength and endurance, scapular movement, and muscle activity were measured again after the fatigue task.

Fatigue task

The fatigue task consisted of electric muscle stimulation of the serratus anterior muscle using a musculoskeletal electric stimulator (EU-910, Ito Co. Ltd., Tokyo, Japan) to induce selective muscle fatigue. Participants sat on a stool, and the skin was shaved and cleaned to reduce skin resistance. Bipolar electrodes (2 cm × 2 cm) were attached to the skin over the lower parts of the serratus anterior with tape at level of the sixth rib on the midaxillary line along the leading edge of the latissimus dorsi muscle. The motor point of the lower parts of the serratus anterior muscle was interposed between these electrodes to activate this muscle as much as possible. A high-voltage pulsed current with a 50-μs pulse width and 100-Hz frequency was used in this study. During the initial 5 minutes of muscle stimulation, the intensity was gradually increased to the maximum level that each subject could tolerate and then sustained for the following 20 minutes. The average voltage intensity was about 30 V. Fatigue induced by electrical muscle stimulation was applied in previous studies, and acute loss of muscle strength after electrical muscle