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Original Article

Differences in Muscle Activities of the Infraspinatus and Posterior Deltoid during Shoulder External Rotation in Open Kinetic Chain and Closed Kinetic Chain Exercises

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Abstract. [Purpose] This study investigated the changes in electromyographic (EMG) activities of the infraspinatus and posterior deltoid muscles during shoulder external rotation under open kinetic chain (OKC) and closed kinetic chain (CKC) exercise conditions. [Subjects] In total, 15 healthy males participated in this study. [Methods] Subjects performed shoulder external rotations under CKC and OKC conditions while standing with and without weight support provided by a height-adjustable table. Pressure biofeedback was used to ensure a constant amount of weight support. The activities of the infraspinatus and posterior deltoid muscles during shoulder external rotation were measured using a wireless surface EMG system. The paired t-test was used to compare the EMG activities of the infraspinatus and the posterior deltoid muscles and the ratio of the infraspinatus to the posterior deltoid during shoulder external rotation under OKC and CKC conditions. [Results] The EMG activity of the infraspinatus and the ratio of the infraspinatus to the posterior deltoid activities were significantly increased, whereas the posterior deltoid activity was significantly decreased under the CKC condition compared to the OKC condition. [Conclusion] Clinicians should consider the CKC shoulder external rotation exercise when they wish to selectively strengthen the infraspinatus.

Key words: Infraspinatus, Posterior deltoid, Selective muscle strengthening

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INTRODUCTION

Selective strengthening of the shoulder muscles, particularly the rotator cuff muscles, has been emphasized as improving shoulder stability and preventing shoulder injuries in clinical and sports-related settings[1, 2)]. Among the rotator cuff muscles (which include the subscapularis, teres minor, supraspinatus, and infraspinatus), the infraspinatus functions as a stabilizer muscle as well as a prime mover during shoulder external rotation-related activities[1, 3)]. However, during shoulder external rotation, the posterior deltoid is activated together with the infraspinatus[4–6)]. Because hyperactivation of the posterior deltoid often induces anterior translation of the humeral head and consequently increases the instability of the glenohumeral joint[7)], many researchers have focused on the selective activation of the infraspinatus when designing strengthening exercises for the infraspinatus[5, 6)].

Closed kinetic chain (CKC) or open kinetic chain (OKC) shoulder exercises are frequently performed to strengthen the shoulder muscles[5, 6, 8–10)]. Compared to OKC exercises, CKC exercises have greater proximal joint stability, enhanced joint compression and reduced shear force[8–10)]. Moreover, clinicians prefer CKC exercises to OKC exercises in the early stages of rehabilitation because axial loading through CKC exercises helps to restore proprioception[9, 10)].

Despite the benefits of CKC exercises, most exercises for infraspinatus strengthening have been performed the OKC exercises[4–6)]. Reinold et al.[4)] found that shoulder external rotation in the side-lying position elicits the greatest electromyographic (EMG) activity in the infraspinatus. Findings by Kim et al.[6)] show that shoulder external rotation while sitting maximizes the contribution of the infraspinatus, compared to the shoulder abduction with external rotation in the prone position, shoulder external rotation with abduction while sitting, and shoulder external rotation while side-lying.

Considering their clinical efficacy, it is important to know whether CKC exercises can selectively elicit infraspinatus muscle activity better than OKC exercises. However,

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no previous study has yet examined differences in infraspinatus and posterior deltoid muscle activities under CKC and OKC conditions. Therefore, the aim of the present study was to examine changes in EMG activities in the infraspinatus and posterior deltoid, as well as the ratio of the infraspinatus to posterior deltoid activity, during external rotation exercises under CKC and OKC conditions. The findings of this study will provide clinicians with useful information for designing infraspinatus strengthening exercises.

SUBJECTS AND METHODS

For this study, 15 healthy males (mean age: 24.33 ± 1.54 years, mean height: 175.00 ± 5.12 cm, and mean weight: 69.00 ± 6.93 kg) were recruited from a local university in Gimhae, South Korea. None of the subjects had a history of shoulder impingement, rotator cuff tear or other shoulder injuries. Subjects who experienced shoulder or neck pain in the last 6 months were excluded from this study. All the subjects provided their written informed consent prior to participation in this study, which was approved by the Inje University Ethics Committee for Human Investigations.

A surface EMG system (Delsys Inc., Boston, MA, USA) with a sampling rate of 2,000 Hz and a bandwidth of 20–450 Hz was used to record the muscle activities of the infraspinatus and posterior deltoid muscles on the dominant side during shoulder external rotation. The raw data of EMG activities of the infraspinatus and posterior deltoid were converted into the root mean square (RMS) and processed for analysis. Prior to attachment of the electrodes, the skin area at the placement sites of the electrodes was shaved and cleaned by rubbing with alcohol. The placements of the electrodes for the infraspinatus and posterior deltoid on the dominant side were determined as recommended by Criswell[11]. The muscle activity was normalized using the maximum value of voluntary isometric contraction (MVIC). For the MVIC of the infraspinatus, subjects in the prone position maintained the end-range of external rotation of the shoulder against manual resistance from an examiner, while the examiner stabilized the humerus of the subject in the glenoid cavity; the resistance was applied to the wrist joint. To test the posterior deltoid, subjects in the prone position performed horizontal abduction of the shoulder with slight external rotation while manual resistance was applied to the distal part of the humerus[12]. The MVIC of each muscle was measured for 5 sec and repeated three times. The mean value of the middle 3 sec was used for normalization.

All subjects performed external rotation of the shoulder on the dominant side under the OKC and CKC conditions. Under the OKC condition, subjects in the standing position arranged their forearm supination and shoulder internal rotation so that the medial and lateral epicondyles of the humerus were parallel in the sagittal plane. Subjects were asked to perform a shoulder external rotation and maintain the end-range of this external rotation for 5 sec. For the CKC condition, the starting position of the upper limb was the same as that in the OKC condition; however, the tested upper limb was supported on a height-adjustable table[13]. To provide constant weight support for the subjects, a pressure biofeedback unit (Chattanooga Group, Hixson, TN, USA) was placed between the palm surface and the table, and inflated to 20 mmHg. The height of the table was adjusted so that the extended elbow and wrist could be maintained without shoulder elevation or depression. Subjects were instructed to press the pressure biofeedback unit until it read 40 mmHg, and then perform shoulder external rotation while the wrist and palm were fixed on the pressure biofeedback unit. The subjects maintained external rotation of the shoulder at the end-range for 5 sec. The mean value of the middle 3 sec of EMG activity of each muscle while the subject maintained the end-range of shoulder external rotation under both conditions was normalized as a percentage of the MVIC for data analysis. The data were analyzed with PASW Statistics Ver. 18.0 (SPSS, Inc., Chicago, IL, USA). Significant differences in EMG activities of the infraspinatus and the posterior deltoid, and the ratio of the infraspinatus to the posterior deltoid were assessed using the paired t-test with the level of significance chosen as 0.05.

RESULTS

The infraspinatus muscle activity was significantly greater under the CKC condition than under the OKC condition ($p = 0.001$), while the EMG activity of the posterior deltoid was significantly decreased under the CKC compared to the OKC condition ($p = 0.002$). A significantly higher ratio was observed in the infraspinatus to posterior deltoid ratio under the CKC condition than that under the OKC condition ($p < 0.001$; Table 1).

DISCUSSION

Current shoulder external rotation exercises have focused on minimizing the contribution of the posterior deltoid to shoulder external rotation for selective strengthening

Table 1. Electromyographic (EMG) activity of the infraspinatus and posterior deltoid during shoulder external rotation under open kinetic chain (OKC) and closed kinetic chain (CKC) conditions

Muscle	Mean ± SD (%MVIC)	
	OKC	CKC
Infraspinatus	20.26 ± 8.88	28.22 ± 9.28*
Posterior deltoid	5.55 ± 3.51	3.22 ± 1.67*
Infraspinatus / posterior deltoid	4.30 ± 1.84	10.47 ± 5.44*

MVIC, maximum voluntary isometric contraction. *$p < 0.05$

of the rotator cuff muscles, especially the infraspinatus[5, 6]. The present study found that CKC shoulder external rotation exercise is more effective at selectively strengthening the infraspinatus than OKC shoulder external rotation exercise.

In this study, the infraspinatus muscle activity was significantly increased with less activity of the posterior deltoid during shoulder external rotation exercise under the CKC condition compared to the OKC condition ($p < 0.05$). It has been stated that excessive activation of the deltoid muscles or decreased infraspinatus activity might potentially increase the translation of the humeral head[7, 14]. Conversely, it is possible that translation of the instantaneous center of rotation of the humeral head facilitates the activation of the posterior deltoid with lesser infraspinatus activity during shoulder external rotation exercises. From this point of view, increased translation of the instantaneous center of rotation of the humeral head may be associated with muscle imbalance between the rotator cuff (e.g., infraspinatus) and the scapulohumeral (e.g., posterior deltoid) muscles. When performing shoulder external rotation exercise under the OKC condition, it is difficult to maintain the instantaneous center of rotation of the humeral head during exercise because shoulder abduction or extension movements often accompany shoulder external rotation under the OKC condition. Bitter et al.[5] suggested that unnecessary shoulder abduction movements during shoulder external rotation may lead to overactivation of the deltoid muscle and translation of the humeral head. Under the CKC condition, however, the humerus may be rotated externally with minimal compensatory movement, e.g. shoulder abduction, or extension due to the fixation of the distal part of the upper limb. We suggest that reduced compensatory movements in CKC shoulder external rotation may lead to decreased translation of the humeral head, which consequently elicits muscle activity of the infraspinatus while decreasing the posterior deltoid muscle activity.

The ratio of the infraspinatus to the posterior deltoid activity was significantly greater under the CKC condition than under the OKC condition ($p < 0.001$). For selective strengthening of the infraspinatus, it is important to identify the contribution of the infraspinatus with respect to the posterior deltoid to shoulder external rotation[6]. The ratio of the infraspinatus to the posterior deltoid activity might illuminate the contribution of the infraspinatus to shoulder external rotation without excessive posterior deltoid activity. Our present findings suggest that the CKC exercise condition is more appropriate for maximizing the contribution of the infraspinatus during shoulder external rotation exercises.

The present study had several limitations. First, all subjects were healthy males; therefore, future studies should evaluate the differences in EMG activities of the infraspinatus and posterior deltoid during OKC and CKC shoulder external rotation exercises using patients with shoulder pain. Second, the humeral head translation during shoulder external rotation under OKC and CKC conditions was not identified. Future studies should investigate the path of the instantaneous center of rotation of the humeral head during shoulder external rotation under OKC and CKC conditions.

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