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Original Article

The influence of various resistance loads on the ratio of activity of the external rotator muscles of the shoulder and the anterior gliding of the humeral head during external rotation exercise

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Abstract. [Purpose] To quantify the ratio of activation of the infraspinatus and posterior deltoid muscles and the anterior gliding motion of the humeral head during external rotation (ER) motions of the shoulder performed in prone position against different external resistance loads. [Subjects] Twenty healthy women between the ages of 20 and 30 years. [Methods] Activity ratio was quantified as the difference in the root mean square of the smoothed electromyography signal (EMG) of the posterior deltoid to the infraspinatus muscle, and anterior gliding pressure of the humeral head using a pressure biofeedback unit (PBU), for three resistance loads: 0, 1 and 2 kg. [Results] There was a significant correlation among all three variables (load, ratio, and pressure). Anterior gliding pressure correlated with the activity ratio, with activity of the posterior deltoid increasing with the magnitude of the resistance load. [Conclusion] There was a positive association between the magnitude of resistance load, activity of the posterior deltoid and anterior gliding pressure of the humeral head. The PBU could be used to facilitate the recruitment of the infraspinatus muscle at higher loads to improve glenohumeral joint stability during ER exercise against higher resistance.
Key words: Glenohumeral stability, Rotator cuff, Pressure biofeedback unit (PBU)

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INTRODUCTION

The strength and coordination of the muscles of the rotator cuff and shoulder girdle are very important for functional shoulder stability[1)]. To ensure the stability and normal movement of the glenohumeral joint, the humeral head must be stabilized in the glenoid cavity by static resistance of the articular capsule and co-contraction of the rotator cuff[2, 3)]. Motion of the humeral head into the coronal plane by activity of the supraspinatus muscle is resisted by contraction of the infraspinatus, subscapularis, and teres minor muscles which produce a downward movement of the humeral head to maintain proper balance stability angle of the joint[4)]. In the transverse plane, the infraspinatus, subscapularis, and teres minor muscles controls the anterior and posterior movement of the humeral head to maintain joint balance[4, 5)]. If the activity of the supraspinatus, infraspinatus, and teres minor muscles is increased, the stability of the glenohumeral joint is also increased. Conversely if the activity of the posterior deltoid and pectoralis major muscles is increased to a greater extent than the activity of the rotator cuff, the stability of the glenohumeral joint is decreased[6)]. Therefore, imbalance in the relative strength and activation of the shoulder girdle and rotator cuff muscles, as well as specific impairment in the function of the rotator cuff as a whole or anyone of its muscle components can lead to an increased movement of the humeral head within the glenoid fossa during functional movements, which can lead to decreased glenohumeral joint stability[7)], shoulder pain, structural damage and loss of function and disability[8, 9)].

Among the rotator cuff muscles, the infraspinatus is the first muscle to be recruited during external rotation of the shoulder and therefore provides an important contribution to maintain shoulder joint stability[10, 11)]. Glenohumeral instability can result when the posterior deltoid strength dominates over the infraspinatus muscle. This imbalance between the posterior deltoid and the infraspinatus muscles can results from changes in neuromuscular coordination,

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with the posterior deltoid contracting without prior activation of the infraspinatus, or due to specific impairments in the strength of the infraspinatus muscle. Thus, patients with symptoms of glenohumeral instability during external rotation motions of the shoulder can improve joint stability by minimizing the work performed by the posterior deltoid and optimizing the function of the infraspinatus and teres minor muscles[12]. Therefore selective strengthening of the infraspinatus muscles and increasing its neuromuscular control are important, both the treatment and prevention of shoulder impingement syndromes and instability[4, 13].

Toward the goal of identifying effective training strategies to optimize the balance between the infraspinatus and posterior deltoid muscles, previous studies have examined the absolute activity of these two muscles for different types of load applications and postures during the performance of external rotation motions of the shoulder[4, 14–17].

However, the relative contribution of the posterior deltoid and infraspinatus muscles to external rotation motions, and the consequent effect of different relative contribution patterns on the movement of the humeral head within the glenoid cavity, have not been comprehensively investigated Therefore, the aim of our study was to quantify the ratio of activation of the infraspinatus and posterior deltoid muscles and the associated anterior gliding motion of the humeral head during external rotation motion of the shoulder, performed in prone position, with different external resistance loads.

SUBJECTS AND METHODS

The methods and procedures for the study were approved by the Bioethics Committee of Kyungsung University, and all participants understood the goal and procedures of the study and voluntarily provided their consent. Participants were 20 healthy, right-hand dominant women, 28.5 ± 4.7 years old.

Muscle activity of the infraspinatus and posterior deltoid was measured during active external rotation of the shoulder using surface, electromyography (EMG) (Noraxon DTS, Hanover, Germany). The EMG electrodes were localized and secured over the belly of the infraspinatus and posterior deltoid muscles, using the guidelines for the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM)[18].

Signals were sampled at 1 KHz, amplified, and bandpass filtered (20–500 Hz), including a notch filter at 60 Hz. The root square mean (RMS) values of the smoothed signals were calculated and used in the analysis.

Anterior gliding motion of the head of the humerus during external rotation motion of the shoulder was measured using a pressure biofeedback unit (PBU) (Chattanooga Group Hixson, TN, USA).

The pressure of the head of the humerus against the PBU was recorded (mmHG). Each measurement was repeated three times and the average value was adopted. To perform the external rotation motion, participants were asked to lie on a bed in prone position, with their head turned toward the right shoulder (i.e., shoulder being evaluated). The shoulder was placed in 90° of abduction, with the elbow in 90° of flexion[19]. Towels were used to support the upper arm parallel to the bed. Straps were secured over participants' upper back, waist, and legs to stabilize the position and prevent compensation of ER by the trunk and legs, to the extent possible. The PBU was placed over the center of the humeral head. The starting pressure on the PBU was set at 40 mmHg. A hand-held dumbbell was used to manipulate the magnitude of the external resistance load to external rotation. Three resistance loads were used: 0 kg (i.e., control condition), 1 kg and 2 kg. The order of resistance loads was randomized across participants. For measurement of muscle activity, participants were instructed to move their shoulder into end-range of external rotation and to maintain this position for 5 s; the middle 3 s of the trial were used for data analysis. Participants practiced the task before data recording, with a 15-min rest provided between the practice and recording session to avoid effects of fatigue on recorded muscle activity. A 3-min rest period was provided between the weighted trials.

All statistical analyzes were performed using the statistical software SPSS, version 21.0. The effects of external resistance load on PBU measures and the ratio of muscle activity of the posterior deltoid to the infraspinatus muscles were evaluated using one-way analysis of variance (ANOVA). Pearson's correlation coefficient was calculated to determine the association between increasing load and change in the ratio of muscle activity and pressure of the anterior glide of the head of the humerus. The level of significance was set, *a priori*, to 0.05.

Table 1. The activity ratio of the posterior deltoid and infraspinatus muscles and the anterior gliding pressure of the humeral head according to the load weight

Load conditions	None	1 kg	2 kg
PD/IS Ratio*	43.5 ± 2.7	50.4 ± 3.4	54.4 ± 4.1
Anterior gliding*	37.1 ± 8.2	48.5 ± 12.1	55.7 ± 11.9

PD: posterior deltoid; IS: infraspinatus; anterior gliding of the humeral head, measured using a PBU, mmHG; mean ± SD; *significant differences ($p < 0.05$)

RESULTS

The changes in the ratio of activity of the posterior deltoid and infraspinatus and the anterior gliding pressure for the three external load magnitudes are reported in Table 1. The ratio of muscle activity and anterior gliding pressure increased as a function of the increasing magnitude of the resistance load ($p < 0.05$). There was a significant correlation ($p < 0.05$) among all three variables (i.e., load, ratio, and pressure). Anterior gliding pressure of the humeral head correlated with the activity ratio ($p < 0.05$) (Table 2).

DISCUSSION

The aim of our study was to investigate the correlation between the change in relative activity of the infraspinatus and posterior deltoid muscles and the anterior gliding pressure of the head of the humerus for three magnitudes

Table 2. Correlation (r-value) among the load weight, the activity ratio of the posterior deltoid and the infraspinatus, and the anterior gliding pressure of the humeral head during external rotation

	Load conditions	PD/IS Ratio	Anterior gliding
Load conditions	1	0.44*	0.80*
PD/IS Ratio		1	0.58*
Anterior gliding			1

PD: posterior deltoid; IS: infraspinatus; anterior gliding of the humeral head, mmHG;
*significant differences ($p < 0.05$)

of external resistance loading to provide accurate exercise methods to avoid shoulder instability during external rotation strength exercises. Anterior gliding pressure and the activity ratio of the posterior deltoid and infraspinatus muscles increased as a function of the resistance load. These results are comparable to Sahrmann's findings of a decrease in shoulder stability with increasing activity of the posterior deltoid muscle during external rotation motions[12]. Bitters et al. proposed that the infraspinatus muscle is selectively activated at low-to-moderate resistance loads which do not exceed 40% of the maximal voluntary isometric contraction (MVIC) of the muscle. When resistance exceeds this 40% cutoff, the posterior deltoid muscle is dominantly recruited, increasing the anterior gliding pressure of the head of the humerus[4]. In our study, the infraspinatus muscle activity was facilitated with use of the 1 kg resistance weight, while activity in the posterior deltoid increased with use of the 2 kg resistance weight. The increase in posterior deltoid activity correlated to increased anterior glide of the humeral head, a proxy measure of decreased functional stability of the glenohumeral joint.

EMG-based feedback has been used to facilitate the recruitment of the infraspinatus muscle during resistance training of shoulder external rotation[20]. As biofeedback is not easily accessible in all clinics, tactile detection of anterior gliding of the humeral head, either by the patient or therapist, could provide an alternative, as anterior gliding pressure correlated with the ratio of the posterior deltoid and the infraspinatus. The PBU feedback could be used to facilitate learning of the selective contraction of the infraspinatus muscle during resistance training exercises of the shoulder, and would be feasible to easily implement in clinical practice. In addition, PBU feedback would be easy to use as part of a home-based program of exercise, improving appropriately timed recruitment of the rotator cuff muscles and, thereby increasing the stability of the shoulder joint and enabling patients to perform more effective types of exercise.

However, the present study was only observed during temporary measured without feedback. Therefore, further studies are needed that fully characterize the functional relationship between ratio of muscle activity and anterior gliding pressure of the humeral head under a range of resistance loads, as well as to determine the specificity of the feedback provided by the PBU on patients' ability to modify the activity ratio.

REFERENCES

1) Howell SM, Galinat BJ: The glenoid-labral socket. A constrained articular surface. Clin Orthop Relat Res, 1989, (243): 122–125. [Medline]
2) Blasier RB, Guldberg RE, Rothman ED: Anterior shoulder stability: contributions of rotator cuff forces and the capsular ligaments in a cadaver model. J Shoulder Elbow Surg, 1992, 1: 140–150. [Medline] [CrossRef]
3) McMahon PJ, Jobe FW, Pink MM, et al.: Comparative electromyographic analysis of shoulder muscles during planar motions: anterior glenohumeral instability versus normal. J Shoulder Elbow Surg, 1996, 5: 118–123. [Medline] [CrossRef]
4) Bitter NL, Clisby EF, Jones MA, et al.: Relative contributions of infraspinatus and deltoid during external rotation in healthy shoulders. J Shoulder Elbow Surg, 2007, 16: 563–568. [Medline] [CrossRef]
5) Burkhart SS: Arthroscopic treatment of massive rotator cuff tears. Clin Orthop Relat Res, 2001, (390): 107–118. [Medline] [CrossRef]
6) Labriola JE, Lee TQ, Debski RE, et al.: Stability and instability of the glenohumeral joint: the role of shoulder muscles. J Shoulder Elbow Surg, 2005, 14: 32S–38S. [Medline] [CrossRef]
7) Wuelker N, Wirth CJ, Plitz W, et al.: A dynamic shoulder model: reliability testing and muscle force study. J Biomech, 1995, 28: 489–499. [Medline] [CrossRef]
8) Murrell GA, Walton JR: Diagnosis of rotator cuff tears. Lancet, 2001, 357: 769–770. [Medline] [CrossRef]
9) Norwood LA, Barrack R, Jacobson KE: Clinical presentation of complete tears of the rotator cuff. J Bone Joint Surg Am, 1989, 71: 499–505. [Medline]
10) Ballantyne BT, O'Hare SJ, Paschall JL, et al.: Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. Phys Ther, 1993, 73: 668–677, discussion 677–682. [Medline]
11) Terry GC, Chopp TM: Functional anatomy of the shoulder. J Athl Train, 2000, 35: 248–255. [Medline]
12) Sahrmann SA: Diagnosis and treatment of movement impairment syndromes. Elsevier Health Sciences, 2002.
13) Malanga GA, Jenp YN, Growney ES, et al.: EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med Sci Sports Exerc, 1996, 28: 661–664. [Medline] [CrossRef]
14) Reinold MM, Wilk KE, Fleisig GS, et al.: Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J Orthop Sports Phys Ther, 2004, 34: 385–394. [Medline] [CrossRef]
15) Ha SM, Kwon OY, Cynn HS, et al.: Selective activation of the infraspinatus muscle. J Athl Train, 2013, 48: 346–352. [Medline] [CrossRef]
16) Kang MH, Oh JS, Jang JH: Differences in muscle activities of the infraspinatus and posterior deltoid during shoulder external rotation in open kinetic chain and closed kinetic chain exercises. J Phys Ther Sci, 2014, 26: 895–897. [Medline] [CrossRef]
17) Jang JH, Oh JS: Changes in shoulder external rotator muscle activity during shoulder external rotation in various arm positions in the sagittal plane. J Phys Ther Sci, 2014, 26: 135–137. [Medline] [CrossRef]
18) Hermes JH: SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles). Roessingh Research and Development, 1999.
19) Magee DJ: Orthopedic physical assessment. Elsevier Health Sciences, 2014.
20) Lim OB, Kim JA, Song SJ, et al.: Effect of selective muscle training using visual EMG biofeedback on infraspinatus and posterior deltoid. J Hum Kinet, 2014, 44: 83–90. [Medline] [CrossRef]