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Comparative Study of Infraspinatus and Posterior Deltoid Muscle Activation According to Angle of External Rotation of Glenohumeral Joint

Background: Based on the understanding of the muscle activation relationship between the infraspinatus and posterior deltoid muscles to according to the angle of motion during external rotation on glenohumeral joint, effective shoulder joint strengthening exercise for the prevention and rehabilitation of shoulder injury due to muscle strength imbalance can be performed by achieving the ideal muscle activity ratio during exercise.
Objectives: To compare and analyze the muscle activation changes and activity ratio of the infraspinatus and posterior deltoid muscles according to the glenohumeral external rotation angle.
Design: Quasi-randomized trial.
Methods: The study included 48 healthy male and female adults who provided informed consent for participation in the study. All the subjects performed isometric glenohumeral external rotation by setting the angle of motion to 30°, 45°, and 60° using a 5 kg resistance weight pulley. On surface electromyography, the differences in muscle activation and activity ratio between the infraspinatus and posterior deltoid muscles were investigated.
Results: A significant difference in muscle activation was found in the comparison between the infraspinatus and posterior deltoid muscles according to the glenohumeral external rotation angle ($P<.05$). The muscle activation levels of the infraspinatus and posterior deltoid muscles were highest at the external rotation angles of 30° and 60°, respectively. The muscle activity ratio between the infraspinatus and posterior deltoid muscles also showed a significant difference ($P<.05$) and was highest at the shoulder external rotation angle of 30°.
Conclusion: The findings of this study suggest that muscle activity is the highest at the shoulder external rotation angle of 30° in healthy individuals.

Keywords: *Angle of motion; Muscle activity ratio; Muscle activation; Isometric contraction*

Dongseok Yang, PT, MS[a], Wonho Choi, Prof., PT, PhD[b]

[a]Department of Physical Therapy, Daegu Hospital of Korea, Daegu, Republic of Korea;
[b]Department of Physical Therapy, Gachon University of Korea, Inchon, Republic of Korea

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Address for correspondence
Wonho Choi, PT, PhD
Department of Physical Therapy, Gachon University of Korea, 191 Hambakmoero, Yeonsu-ku, Inchon, Republic of Korea
Tel: 82-32-820-4423
E-mail: whchoi@gachon.ac.kr

INTRODUCTION

In modern society, 1 in 3 adults who enjoy sports activities experience shoulder pain during their lifetimes due to an injury of the shoulder joint, which performs key functions in daily life.[1] The rotator cuff muscles provide dynamic stabilization to the glenohumeral joint, which has the largest range of motion among all body parts and the primary role of stabilizing the glenohumeral joint by compressing the humeral head against the glenoid.[2] Of the rotator cuff muscles, the infraspinatus (IS) muscle performs glenohumeral external rotation and is known to contribute significantly to the stabilization rather than to the generation of the large torque required to perform external rotation in terms of kinematics.[3] Imbalance between the IS and posterior deltoid (PD) muscles of the rotator cuff during glenohumeral external rotation causes abnormal scapulohumeral rhythm and problems with the scapular movements.[4,5] The IS and PD muscles are anatomically positioned in the direction of the same muscle fiber, contributing to glenohumeral external rotation.[6,7] For strengthening the muscles involved in glenohumeral external rotation, identifying which between the IS and PD muscles has a higher activation level during external rotation is important. In patients with shoulder disease or functional impairment such as rotator cuff pathologies, instability, and impingement syndrome, the muscle activation level of the PD is relatively higher than that of the IS during external rotation.[8] The IS and PD muscles contribute to the glenohumeral external rotation, with the action of the IS maintaining the stability of the joint by simply performing the external rotation of the humeral head in the vicinity of the rotation axis of the shoulder. By contrast, the PD muscle performs both the extension and external rotations and, at higher activation levels, moves the humeral head upward owing to muscle strength imbalance, causing impingement syndrome.[3,9–11] From a biomechanical point of view, when an angle of a joint is generated in motion, the lengths of the lever arm and muscle are changed, and these changes alter muscle contraction.[12] Alterations in muscle length caused by joint angle changes can induce changes in the force generated in muscles.[13] In conclusion, for patients with poor dynamic shoulder joint stability, performing exercises that cause excessively higher muscle activation of the PD than that of the IS during external rotation is not recommended.[14]

Therefore, on the basis of the assumption of a close correlation between the changes in the joint angles and muscle activation during glenohumeral external rotation in healthy adults, this study aimed to determine the optimal joint angle during glenohumeral external rotation and to investigate the difference in the muscle activity ratio between the IS and PD. With the findings of this study, we aim to propose an effective exercise method for patients with shoulder injuries such as rotator cuff muscle imbalance and impingement syndrome.

SUBJECTS AND METHODS

Subjects

The study experiment was conducted for 10 weeks, from January to March 2018, after approval by the institutional review board of Gachon University (1044396–201804–HR–100–01). The subjects were 48 healthy male and female adults residing in D city. Before the experiment, all the subjects fully understood the contents of the study and signed the consent form. The inclusion criteria for the study were as follows: patient who had no musculoskeletal disorders in the past year and no congenital anomalies, orthopedic disorders, or deformities; those who did not currently have pain in the neck, back, or shoulder; those who had no joint contracture or limited range of motion; and those who were right–hand dominant. Patients whose upper limb tension and crank test results were positive were excluded from the study (Table 1).

Intervention methods

The study was designed as a randomized controlled trial. In the study, 48 healthy male and female adults were randomly assigned into three groups by using the random number table of the Microsoft Excel 2010 Program. The joint angles during glenohumeral external rotation were set to 30°, 45°, and 60° on a flat mirror, and the error range was reduced using a baseline inclinometer (AcuAngle Inc, USA). As for the starting position, the subject assumed a side–down position with the elbow in 90° flexion and the glenohumeral joint in 0° adduction.[14] An isometric exercise was performed using a weight pulley, and the subject's resistance was set to 5–kg. Under the guidance of the investigator, a surface electromyography was measured by performing the corresponding action for each group.

Measurement methods

To measure the muscle activation levels of the IS and PD according to the 30°, 45°, and 60° joint angles during shoulder external rotation, Biopac Student Lab 3.7.3 (MP35, Biopac Systems Inc, USA), a surface electromyography (EMG) system, was used. For normalization, the maximal isometric strength was measured with the maximal voluntary isometric contraction (MVIC) in the manual muscle testing position in accordance with the method used by Ekstrom et al. and Kendall.[7,15] During maximal isometric contraction, data were obtained for 5 seconds, and the mean EMG signal value for 3 seconds, excluding the respective 1 second at the beginning and end, was used as the maximum voluntary isometric contraction rate (%MVIC). All motions were measured three times. When the EMG sensors were attached, muscle contraction was induced to locate the EMG signal in the thickest part, and attachment of the EMG sensors to the tendon and muscle edges was avoided. The EMG sensors were attached parallel to the longitudinal direction of the muscle fibers. All the EMG electrodes were attached by a single investigator for all the subjects after identifying the approximate locations by checking the voluntary contraction. For the IS muscle, the electrodes were attached 4 cm below the spine of the scapula on the lateral side, and for the PD muscle, these were attached approximately 2 cm below the lateral side near the spine of the scapula. Each exercise posture was maintained for 5 seconds, and the examination posture was set with a joint angle measurement system so that all the subjects can perform the exact motions. The investigator gave oral instructions. To minimize muscle fatigue, which may affect the results of this study, a 2-minute rest time was allowed between each motion performance.[16] The mean value of three trials was used in the data analysis.

Statistical Analyses

SPSS version 18.0 was used for data processing in this study, and the measured values of all the variables were calculated as the mean and standard deviation. For all the subjects, normal distribution was confirmed using the Shapiro-Wilk normality test. A chi-square test and one-way analysis of variance (ANOVA) were performed to compare the general characteristics of the subjects and to test the homogeneity between the groups. To analyze the differences in the muscle activation and muscle activity ratio between the IS and PD muscles according to the joint angle during glenohumeral external rotation, normality was confirmed using the Shapiro-Wilk test, and one-way ANOVA was performed. Then, a post hoc Scheffe test was performed. All statistical analyses were performed with the significance level set at $P<.05$.

RESULTS

General characteristics of the subjects

This study was conducted in 48 healthy male and female adults (n=30 and n=18, respectively), and those who were left-hand dominant were excluded from the study. The characteristics of the study participants were as follows (Table 1).

Changes in muscle activation between the IS and PD muscles according to the glenohumeral external rotation angle

As a result of analyzing the muscle activation of the IS according to the glenohumeral external rotation angle, we found a significant difference in mean (±SD) muscle activation level in the order of 68.26±20.88, 84.79±19.81, and 85.46±20.68 for the 60°, 45°, and 30° angles of motion, respectively ($P<.05$).

As a result of the post hoc test, the muscle activation of the IS according to the glenohumeral external rotation angle was significantly higher at the joint angle of 30° and 45° than at 60° ($P<.001$), but no significant difference was found between the 30° and 45° joint angles.

The analysis of the muscle activation of the PD muscle according to the glenohumeral external rotation angle revealed significant differences in the mean (±SD) muscle activation level in the order of 53.72±16.69, 62.87±12.24, and 70.94±11.38 for the 30°, 45°, and 60° angles of motion, respectively ($P<.05$).

The post hoc test revealed that the muscle activation of the PD according to the glenohumeral external rotation angle showed significant differences between 30° and 45°, between 30° and 60°, and between 45° and 60°($P<.001$) (Table 2).

Changes in muscle activity ratio between the IS and PD muscles according to the glenohumeral external rotation angle

The analysis of the muscle activity ratio between the

Table 1. General characteristics of the subjects

(n=48)

Group		30° (n=16)	45° (n=16)	60° (n=16)	P
Sex	Male	10 (62.5%)	11 (68.8%)	9 (56.3)	.280[a]
	Female	6 (37.5%)	5 (31.2%)	7 (43.7)	.540[b]
Age (years)		30.5 ± 2.7	30.4 ± 5.0	29.5 ± 5.4	.832[b]
Height (cm)		165.4 ± 7.9	167.7 ± 7.2	165.8 ± 8.0	.674[b]
Weight (kg)		61.8 ± 9.5	63.5 ± 8.9	62.8 ± 8.8	.530[b]
BMI (kg/m²)		22.63 ± 2.43	23.09 ± 2.60	22.89 ± 2.04	

The values are presented as mean ± SD
[a]Chi-square test, bOne-way analysis of variance

Table 2 Comparison of muscle activation levels between the IS and PD muscles

Variable	Shoulder external rotation angle			F	*P*	Post hoc (Scheffe)
	30° (n=16)[a]	45° (n=16)[b]	60° (n=16)[c]			
IS (%MVIC)	85.46 ± 20.68	84.79 ± 19.81	68.26 ± 20.88	14.18	.000***	a 〉c, b 〉c
PD (%MVIC)	53.72 ± 16.69	62.87 ± 12.24	70.94 ± 11.38	13.60	.000***	c 〉b 〉a

The values are presented as mean ± SD

*P〈.05, ***P〈.001

IS: Infraspinatus, PD: Posterior deltoid, MVIC: Maximal voluntary isometric contraction

Table 3. Analysis of muscle activity ratio between the IS and PD muscles

Variable	Shoulder external rotation angle			F	*P*	Post hoc (Scheffe)
	30° (n=16)[a]	45° (n=16)[b]	60° (n=16)[c]			
IS/PD ratio	1.57 ± .36	1.53 ± .53	.96 ± .63	5.55	.030*	a 〉c, b 〉c

The values are presented as mean ± SD

*P〈.05, IS: Infraspinatus, PD: Posterior deltoid

IS and PD muscles according to the glenohumeral external rotation angle revealed significant differences in mean (±SD) muscle activity ratio in the order of 1.57±.36, 1.35±.53, and .96±.63 for the 30°, 45°, and 60° angles of motion (*P*〈.05).

As a result of the post hoc test, for the IS, the muscle activity ratio according to the glenohumeral external rotation angle was significantly higher at the joint angle of 30° and 45° than at 60° (*P*〈.05), and no significant difference was found between the 30° and 45° joint angles (Table 3).

DISCUSSION

The purpose of this study was to investigate the change in muscle activation between IS and PD according to glenohumeral external rotation angle. On the basis of the previous studies, the glenohumeral joint angles were set to 30°, 45°, and 60° in the adduction position, and a resistance of 5-kg was applied.

In this study, during glenohumeral external rotation, in case of the IS, the highest muscle activation level was observed at the 30° joint angle. Pelyonen et al. reported high muscle activation values of the IS, measured using a variable resistance machine, at the shoulder external rotation angles of 30° and 45° in the 90° abduction posture of the shoulder joint.[17] Bobbert and Harlaar reported the highest muscle activation value at the angle of 45° in the MVIC of the muscles.[18] In a study by Reinold et al. an experiment was conducted at a posture that can perform MVIC of the IS, and the highest muscle activity ratio was reported at 30°, half of the maximum joint angle of 60°.[14] In this study, the muscle activation level of the IS was measured by changing only the external rotation angle in the adduction position with a resistance size of 5-kg. Therefore, the results of the previous studies showed muscle activation values according to the abduction angle, which is different from the method used in this study. As for the PD muscle, the highest muscle activation level was measured at the 60° joint angle. In a study by Reinold et al. the PD muscle had the highest muscle activation level of 88% when external rotation was performed with horizontal abduction of the shoulder at 100° in prone position.[14] During shoulder external rotation, the muscle activation level increased as the joint angle increased. Kisner and Colby reported that during shoulder external rotation, with the dynamic stabilizing function of the shoulder complex, the IS and teres minor act as agonists, and PD acts as a synergist from an angle of 30°.[19] Therefore, the PD muscle produces coordinated activities and provides mobility through complex combination of actions.

Comprehensively, this study and previous studies show that the PD muscle activity increases as the glenohumeral external rotation angle increases. Also, in this study the IS/PD activation ratio was significantly higher when compared with the 60° glenohumeral external rotation at 30° and 45° glenohumeral external rotation. Clisby et al. reported the change in the joint angle determines the muscle length and amount of force, and muscle strength can vary depending on the joint angle on muscle contraction and extension.[8] For this reason, it is thought that this study also showed changes in muscle activity. The IS is an external rotator of the glenohumeral joint,[7] but it is also an important stabilizing muscle.[3] In contrast, the mechanical properties of the PD compared with the IS support them having a primary torque-producing role rather than a stabilizing role.[20] During rotator cuff retraining programs for the shoulder, external rotation exercises are commonly used with the intention of improving the stabilizing ability of the IS and teres minor and assist in restoring balance of the force couples.[3] The PD a shoulder external rotator active during exercise.[7] This activation of the deltoid with its potential to create humeral head translation is likely to be negative affect to a rehabilitation.[3] Sahrmann reported that imbalance between the PD and IS muscles cause the humeral head to induce an anterior dislocation of the should joint due to the change in the neuromuscular coordination during PD contraction without prior activation of the IS for specific motions.[6] Therefore, PD contraction should be minimized in patients with shoulder joint instability during the external rotation of the shoulder.[21] Thus, for efficient rotator cuff rehabilitation, it is necessary to consider an glenohumeral external rotation angle between 30° and 45° to increase the muscle activity of the IS and lower the muscle activity of the PD when performing glenohumeral external rotation.

As a result, significant changes in joint angle were identified in the IS and PD muscles during shoulder external rotation. Therefore, to promote the muscle activity of the IS without excessive muscle activity of the PD muscle during shoulder external rotation, the findings of this study will provide a basis for obtaining clinically useful information in the future. Additionally, in this study the intensity of resistance was applied to all subjects at 5-kg. In a future study, it is necessary to find an effective exercise intensity by applying various resistance sizes.

The limitations of this study were as follows: 1) the study subjects were all of young age, so the interpretation of the study results cannot be generalized to the general population; 2) manual resistance could not be applied objectively during the measurement of MVIC; 3) because the study was conducted with healthy adults without shoulder pain, trial discontinuation due to pain and fatigue showed individual differences, and the study results cannot be applied to patients with shoulder pain; and 4) as the study was conducted in the side-down position, the compensatory movement of the muscles of the opposite side could not be restricted.

CONCLUSION

In this study, the glenohumeral external rotation angle was comparatively analyzed. The IS muscle showed the highest muscle activation level at the joint angles of 30° and 45°, whereas the PD muscle showed the lowest muscle activation at the joint angle of 30°. Furthermore, the muscle activity ratio analysis between the IS and PD muscles revealed the highest values at the joint angle of 30°. From the findings of this study, which was conducted in healthy adults, we propose that further studies on muscle activities should be conducted by broadening the types of subjects to include those with rotator cuff disease, athletes, and various age groups.

REFERENCES

1. Luime JJ, Koes BW, Hendriksen IJ, et al. Prevalence and incidence of shoulder pain in the general population:asystem aticreview. *Sc and J Rheumatol*. 2004;33(2):73-81.
2. Warner JJ, Micheli JJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med*. 1990;18(4):366-375.
3. Bitter NL, Clisby EF, Jones MA, et al. Relative contributions of IS and deltoid during external rotation in healthy shoulders. *J Shoulder Elbow Surg*. 2007;16(5):563-568.
4. Steenbrink F, Meskers CG, Nelissen RG, et al. The relation between increased deltoid activation and adductor muscle activation due to glenohumeral cufftears. *J Biomech*. 2010;43(11):2049-2054.
5. Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil*. 2003;84(7):1000-1005.
6. Sahrmann SA. *Diagnosis and treatment of movemen timpairment syndromes*. New York: Mosby; 2002.
7. Kendall FP, McCreary EK, Provance PG, et al. *Muscles: Testing and function with posture and*

pain. 5th ed. Baltimore: Williams & Wilkins; 2005.

8. Elizabeth F. Clisby EF. Relative contributions of the IS and deltoid during external rotation in patients with symtomatic subacromial impingement. *J Shoulder Elbow Surg*. 2008;17(1S).
9. Clisby EF, Bitter NL, Sandow MJ, et al. Relative contributions of the IS and deltoid during external rotation in patients with symptomatic subacromial impingement. *J Shoulder Elbow Surg*. 2008;17(1):87S–92S.
10. David G, Magarey ME, Jones MA, et al. EMG and strength correlates ofselected shoulder muscles during rotations of the glenohumeral joint. *Clin Biomech*. 2000;15(2):95–102.
11. Morris AD, Kemp GJ, Frostick SP. Shoulder electromyography in multi directional instability. *J Shoulder Elbow Surg*. 2004;13(1):24–29
12. An KN, Kaufman KR, Chao EYS. Physiological considerations of muscle force through the elbow joint. *J Biomechanics*. 1989;22:1249–1256.
13. Kapandji IA. *The physiology of the joints*. 5th ed. Edinburgh: Churchill Living stone; 1983.
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 Othop Sports Phys Ther*. 2004;34(7):385–394.
15. Ekstrom RA, Donatelli RA, Soderberg G. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. *J Orthop Sports Phys Ther*. 2003;33(5):247–258.
16. Smith J, Kotajarvi BR, Padgett DJ, et al. Effect of scapular protraction and retraction on isometric shoulder elevation strength. *Arch Phys Med Rehabil Mar*. 2002;83(3):367–370.
17. Heikki Pelyonen, Jari Arokoski, Mauri Kallinen, Teemu Pullinen. Muscle loading and activation of the shoulder joint during humeral external rotation by pulley and variable resistance. *J Electromyogr Kinesiol*. 2012;22:424–430.
18. Bobbert MF, Harlaar J. Evaluation of moment-angle curves in isokinetic knee extension. *Med Sci Sports Exerc*. 1993;25:251–259.
19. Kisner C, Colby LA. *Therapeutic Exercise; Foundations and Techniques*. 6th ed. Philadelphia: FA Davis; 2012.
20. Jones D, Round J, de Hann A. *Skeletal muscles from molecules to movement. A textbook of muscle physiology for sport, exercise, physiotherapy and medicine*. Edinburgh, UK: Churchill Livingstone; 2004.
21. McMahon PJ, Mathiyakom W. Electromyographic analysis of deltoid and rotator cuff function under varying loadsand speeds. *J Shoulder Elbow Surg*. 2000;9(1):47–58.