



Original Article

The effect of exercise types for rotator cuff repair patients on activities of shoulder muscles and upper limb disability

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Abstract. [Purpose] This study investigated the effect on activities, shoulder muscle fatigue, upper limb disability of two exercise types performed by patients in the post- immobilization period of rotator cuff repair. [Subjects and Methods] The intervention program was performed by 20 patients from 6 weeks after rotator cuff repair. Ten subjects each were randomly allocated to a group performing open kinetic chain exercise and a group performing closed kinetic chain exercise. Muscle activity and median frequency were measured by using sEMG and the Upper Extremity Function Assessment before and after conducting the intervention and changes in the results were compared. [Results] There was a significant within group increases in the activities of the shoulder muscles, except for the posterior deltoid. The median power frequencies (MFD) of the supraspinatus, infraspinatus and anterior deltoid significantly increased in the open kinetic chain exercise group, but that of the posterior deltoid decreased. There were significant differences in the changes in the upper limb disability scores of the two groups, in the shoulder muscle activities, except for that of the posterior deltoid, in the comparison of the change in the muscle activities of the two groups, and in the MDFs of all shoulder muscles. [Conclusion] The Median power frequencies of all these muscles after closed kinetic chain exercise increased indicating that muscle fatigue decreased. Therefore, research into exercise programs using closed kinetic chain exercises will be needed to establish exercise methods for reducing muscle fatigue.

Key words: Closed kinetic chain exercise, Open kinetic chain exercise, Rotator cuff

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INTRODUCTION

The shoulder joint has the widest range of motion among joints of the body, and has an unstable anatomic structure. Also, it has both stability and mobility¹⁾. Rotator cuff muscles facilitate smooth motions, performing abduction, and rotation, and generates compressive force in the glenohumeral joint²⁾. Mechanical damage of the rotator cuff muscles can be shown by characteristics such as displacement of the shoulder joint, rotation, formation, tendon sprain, tendon movement, fluid outflow, and failure of energy conservation³⁾. It is reported that tendon rupture of the supraspinatus has the highest incidence among rotator cuff muscle injuries⁴⁾. The supraspinatus is recognized as an important muscle because it provides stability and mobility to the shoulder, and it is exposed to potential stresses during doing various sports activities or tasks⁵⁾. Abnormality of kinematic function is accompanied by shoulder pain, atrophy of the muscles around the shoulder and severe

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muscle weakness when such symptoms last^{6,7}). Arthroscopic repair is often conducted as a therapeutic method for the rupture of rotator cuff muscles⁸, and full passive range of motion is regained six weeks after rotator cuff repair during which the involved part should be fixed and active movement should be limited to prevent re-injury⁹. After rotator cuff repair, fixation of the surgical site changes of contractile forces the muscles, reducing the muscle activity on the affected side limb⁸, and fatigue of the surrounding muscles may become more severe due to traction of the tendon and muscle atrophy with time¹⁰. There are limits to performing activities of daily living and keeping maximum contraction of the muscles, and inputs such as proprioception and visual feedback become damaged¹¹. When rotator cuff injury patients perform humeral external rotation, their movement differs from a normal person's external rotation, and special measures are needed for this^{12, 13}). Therefore, this study prescribed open kinetic chain exercise (OKCE) and closed kinetic chain exercise (CKCE) for humeral external rotation, to recover muscle endurance and weak muscle strength, at six weeks after rotator cuff repair. Open kinetic chain exercise is an exercise method in which the proximal part of the joint is fixed and movement of the distal part of the joint occurs. OKCE plays an important role in strengthening muscles of patients with limitation of the range of motion¹⁴). It has the advantages that movements of the joints are independent and it generates more traction power and torque than CKCE¹⁵). Closed kinetic chain exercise is an exercise method in which the distal part of the joint is fixed and movement in only one joint occurs. It provides joint stability by reducing shear force on the joint. Mechanical receptors react to changes in pressure of the articular capsule, sensitively, and OKCE helps to facilitate proprioceptive sense¹⁶). Several studies have discussed the advantages of open kinetic chain exercise and closed kinetic chain exercise. However, studies of the muscle activities after the performance of open kinetic chain exercise have been secondary to general research on exercises used in the period of protection after rotator cuff repair. Therefore, this study investigated the effects of open kinetic chain exercise and closed kinetic chain exercise performed by patients at six weeks after rotator cuff repair. It investigated the effects on muscle fatigue, upper limb disability, and the muscle activities of the supraspinatus, infraspinatus and anterior deltoid and posterior deltoid muscles that surround the shoulder. This study was conducted to provide baseline data for the study of effective exercise methods for rotator cuff repair patients.

SUBJECTS AND METHODS

The study subjects were 20 male patients at 6 weeks after receiving rotator cuff repair for right supraspinatus tendon rupture (grade 2). The subjects were between the ages of 40 and 55, who were treated at M medical institution, located in Jeollanamdo, South Korea, between January 2016 to March 2016. They had no neurological symptoms or musculoskeletal disabilities except for the site of the lesion and abnormality. They had no pain in the right upper limb and hand and no limits on doing exercise, and were able to go to hospital regularly after hospital discharge. All subjects understood the purpose of this study very well and agreed to participate in this study voluntarily. This study was approved by Bioethics Committee of Sehan University Center (IRB) (Approval number: 2015-12).

Ten subjects each were randomly allocated to a group performing open kinetic chain exercise (experimental group I) and a group performing closed kinetic chain exercise (experimental group II). Upper limb disability was evaluated and the muscle activities of the supraspinatus, infraspinatus, anterior deltoid, and the posterior deltoid and median frequency (MDF) of the muscles activities were measured using sEMG at pretest and posttest. The intervention program consisted of 10 exercise performances per set, 3 sets a session, once a day, four times a week and lasted for three weeks. The changes in upper limb disability, muscle activities, and MDFs were compared between pre- and post-test (Table 1).

Muscle activity and MDF were measured using a 4-channel surface EMG MP 100 system (Biopac, USA) to measure muscle activity and muscle fatigue. To minimize skin resistance to the EMG signal, subjects' hair was removed from their skin, and dead skin cells were removed using fine sandpaper. Then, the subjects' skin was rubbed with alcohol-soaked cotton and kept in a clean condition. Two Ag/AgCl surface electrodes were attached to the supraspinatus, infraspinatus, and the anterior and posterior deltoid muscles¹⁷). The values of %RVC and MDF were measured with subjects standing comfortably with the shoulder flexed at 90 degrees, elbow extension, the lower arm in the neutral position, and the hand gripping a dynamometer for ten seconds. The data of the six seconds excluding the first and last two second were used to calculate the mean RMS value without contraction; then, the mean RMS was were evaluated again, in the same manner but with maximum voluntary contraction of the hand gripping the dynamometer, to obtain a value for calculating %RVC. The

Table 1. Characteristic of the subjects

| Items | Experimental group I (n=10) | Experimental group II (n=10) |
|-------------|-----------------------------|------------------------------|
| | Mean ± SD | Mean ± SD |
| Age (years) | 50.4 ± 4.2 | 49.8 ± 3.9 |
| Height (cm) | 168.5 ± 7.3 | 166.5 ± 5.3 |
| Weight (kg) | 68.3 ± 6.5 | 66.5 ± 7.3 |

Shapiro-wilk

average MDF was calculated through power spectrum analysis of the EMG during the maximum voluntary contraction task. Upper limb disability was evaluated using the DASH (Disabilities of the Arm, Shoulder and Hand) questionnaire, which was jointly developed by The American Orthopedic Association and the Institute for Work & Health. It considers the upper limb as a functional unit, and subjectively judge's the condition of the upper limb. The DASH questionnaire is composed of 30 questions evaluating movement ability and higher scores indicate severer disability. This tool has high validity and reliability and Cronbach's α of the DASH questionnaire has been reported as 0.94¹⁸⁾.

All subjects performed stretching of shoulder joint on the affected side before doing exercise. The open kinetic chain exercise group subjects didn't fix the distal part of the arm on a supporting surface. They flexed the shoulder at 90 degrees in the standing position and performed maximum contraction in humeral external rotation. The closed kinetic chain exercise group subjects performed the exercise in the same position, but with the distal part of the arm attached to a pressure biofeedback unit, to prevent compensation, with the initial pressure set to 20 mmHg. After setting the pressure, the subjects fixed the distal part of arm performed the exercise without exceeding 40 mmHg with all the fingers facing outward¹⁹⁾. The exercise was performed without inducing pain. After doing exercise, universal physical therapy, icing and TENS were performed for 15 minutes each.

SPSS 17.0 for Windows was used for data processing. The Shapiro-Wilk's test was used to test the normality of the data of the general characteristics of the subjects. The paired t-test was used to analyze the significance of changes in muscle activity, muscle fatigue and upper limb disability within the groups, and analysis of covariance (ANCOVA) was used to compare the changes in muscle activity, muscle fatigue and upper limb disability between groups. The significance level was chosen as $\alpha=0.05$.

RESULTS

After the intervention, there were significant increases in the muscle activities of the supraspinatus, infraspinatus and anterior deltoid of experimental group I ($p<0.05$, $p<0.01$), and MDF of the supraspinatus, infraspinatus and anterior deltoid increased significantly ($p<0.05$, $p<0.01$) but that of the posterior deltoid decreased significantly ($p<0.05$). There was a significant improvement in the upper limb disability experimental group I ($p<0.05$). There were significant increases in the muscle activities of supraspinatus, infraspinatus and anterior deltoid of experimental group II ($p<0.05$, $p<0.01$, $p<0.001$). MDF of the supraspinatus, infraspinatus and anterior deltoid increased significantly ($p<0.05$, $p<0.001$) and there was a significant improvement in the upper limb disability of experimental group II ($p<0.05$). There were significant differences the changes in the muscle activities of the supraspinatus, infraspinatus and anterior deltoid between the groups ($p<0.05$, $p<0.01$), and there were significant differences in the changes in the MDF of all of the muscles between the groups ($p<0.05$, $p<0.01$) (Table 2).

Table 2. Comparison of Muscle Activities, MDF and Upper Limb Disability scores within and between the groups

| | | Groups | pre-test | post-test | |
|-------------------|------------------|-----------------|--------------|----------------|----|
| %RVC | Supraspinatus | Experi-group I | 96.9 ± 13.3 | 103.3 ± 17.1* | * |
| | | Experi-group II | 98.3 ± 11.8 | 112.5 ± 18.3** | |
| | Infraspinatus | Experi-group I | 115.3 ± 8.3 | 121.3 ± 11.9* | * |
| | | Experi-group II | 109.5 ± 8.7 | 124.3 ± 9.3*** | |
| | Deltoid anterior | Experi-group I | 92.5 ± 10.1 | 104.8 ± 7.7** | * |
| | | Experi-group II | 94.3 ± 9 | 98.2 ± 4.3* | |
| Deltoid posterior | Experi-group I | 100.2 ± 7.3 | 104.8 ± 12.8 | | |
| | Experi-group II | 98.5 ± 6.3 | 100.2 ± 9.5 | | |
| MDF (Hz) | Supraspinatus | Experi-group I | 91.8 ± 3.9 | 95.3 ± 4.2* | * |
| | | Experi-group II | 93.5 ± 6.2 | 101.8 ± 5.8*** | |
| | Infraspinatus | Experi-group I | 94.3 ± 4.8 | 99.1 ± 6.3* | ** |
| | | Experi-group II | 95.3 ± 3.2 | 108 ± 6.9*** | |
| | Deltoid anterior | Experi-group I | 86.3 ± 3.4 | 95.8 ± 4.2** | * |
| | | Experi-group II | 88.4 ± 4.3 | 91.9 ± 3* | |
| Deltoid posterior | Experi-group I | 88.5 ± 6.2* | 82.3 ± 5.2 | * | |
| | Experi-group II | 88.8 ± 3.6 | 90.2 ± 5 | | |
| DASH (score) | Experi-group I | 42.3 ± 4.3 | 36.3 ± 3.9* | | |
| | Experi-group II | 43.3 ± 3.6 | 37.2 ± 4.8* | | |

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

DISCUSSION

During the period of protection after rotator cuff repair, passive exercise is conducted to increase range of motion²⁰. If the protection period continues for a long time, muscle atrophy and muscle fatigue will increase due to muscle weakness. So, after the protection period, proper exercise is a very important factor in the improvement of shoulder function of rotator cuff repair patients⁸). Therefore, this study investigated the changes in the activities of shoulder muscle, fatigue, and upper limb disability of rotator cuff repair patients after open kinetic chain exercise or closed kinetic chain exercise performed at the end of the protection period. Jang¹⁹) studied the effects of open kinetic chain exercise and closed kinetic chain exercise at different shoulder angles on 15 normal persons. The infraspinatus muscle had higher muscle activity than the other muscles in the closed kinetic chain exercise at 45 degrees group. Tucker et al.²¹) studied the effects of open kinetic chain exercise and closed kinetic chain exercise on 15 patients with shoulder impingement syndrome. They measured the muscle activities of the upper trapezius, middle trapezius, lower trapezius and serratus anterior muscles. The activity of the upper trapezius was higher than that of the other muscles in the open kinetic chain exercise group, and the activity of the serratus anterior muscle was lower in this group. However, all of these muscles showed increased muscle activities in the closed kinetic chain exercise group. Thus, according to the literature closed kinetic chain exercise is more effective for patients with diseases related to the shoulder. This study showed that there were significant increases in the muscle activities of the supraspinatus, infraspinatus, and anterior deltoid muscles in the CKCE and OKCE groups, but there was no significant increase in the activity of the posterior deltoid muscle. The intervention method in this study was humeral external rotation at shoulder flexion of 90 degrees significant improvement. This exercise method does not elicit large activation of the posterior deltoid muscle¹⁹), and this would explain the lack of significant improvement seen in this muscle. There were significant increases in the activities of the supraspinatus, infraspinatus and anterior deltoid muscles, but the activity of the anterior deltoid muscle in the open kinetic chain exercise group was higher than in the closed kinetic chain exercise group. This is because the muscle activity would have been higher in OKCE, because the load on the anterior deltoid muscle is greater as the arm in the open kinetic chain exercise is not placed against the wall. Gondin et al.⁸), reported that the activities of muscles around the surgical site decrease due to fixation of about six weeks after rotator cuff repair, and change in the contractile force of the muscles happens. Muscle fatigue increases due to decrease of muscle strength, and the EMG spectrum and amplitude changes result in a shift in MDF²²). After rotator cuff repair, fatigue influences the performance of exercise in rehabilitation. This has an important bearing on the rehabilitation process or clinical course²³). MDF was used as analytic variable in this study.

When muscle fatigue occurs, H⁺ generally accumulates on the muscle fascia due to a decrease in the conduction velocity of the action potential of muscle fibers and an increase in lactic acid. The MDF shifts from high frequency to low frequency due to a decrease in motor neuron excitability, change in the depolarization region, and change in the Na⁺K⁺ ion balance of the muscle fascia²⁴). Kang and Moon²⁵) measured MDF of patients with rotator cuff tear three weeks after rotator cuff repair. It is said that muscle fatigue is indicated by a shift in MDF from high frequency to low frequency in muscles around the shoulder. Nevertheless, Portero et al.²⁶) suggested that MDF moving from a high frequency region to a higher frequency region is closely connected with change in the fast muscle fibers due to training, and MDF is increased by increase of the intramuscular conduction velocity, selective recruitment of fast muscle fibers, and increase in the diameter of muscle fibers resistance to muscle fatigue increases²⁷). Shin²⁸) studied the effects of 12 weeks of muscle strengthening exercise on 10 healthy men. Five subjects performed isometric exercise and 5 subjects performed isotonic exercise. She investigated muscle fatigue after the intervention. MDF increased in both groups and implying that resistance to muscle fatigue is increased by hypertrophy and steady increases in recruitment of fast muscle fibers. In the present study, the MDFs of the supraspinatus, infraspinatus and anterior deltoid muscles increased in both the groups, as well as resistance to muscle fatigue after the intervention in this study. Muscle fatigue, as measured by MDF, improved in the posterior deltoid muscle in the open kinetic chain exercise group, and also improved in the closed kinetic chain exercise group, because of the internal load on the shoulder joint, but the increase was not statistically significant. Therefore, it is possible that there would be a significant increase in MDF, if the intervention period were extended, because the intervention period of 3 weeks was very short in this study. There were significant differences between the groups in the changes in muscle fatigue of all the muscles. Especially, resistance to muscle fatigue increased with increase of MDF. Closed kinetic chain exercise improves the functional ability of the joint through improvement of muscle function and kinetic change²⁹). It has been reported that closed kinetic chain exercise is more effective at improving of muscle endurance because the muscles around the joint cocontract simultaneously¹⁶). The results of the present study suggest that closed kinetic chain exercise is more effective at decreasing muscle fatigue than open kinetic chain exercise in patients with shoulder joint disease. It has been reported that the shoulder function of patients is closely connected with muscle strength, and increase of muscle strength improves the function of shoulder³⁰). Previous studies of muscle strengths exercise for rotator cuff repair patients have reported improvements in upper limb disability after conducting various exercise methods, such as a preoperative exercise program³¹), accelerated rehabilitation exercise³²), and scapular stabilization exercise³³). In the present study both the CKCE and OKCE groups showed significant decreases in upper limb disability and increase in upper limb functional activity of the rotator cuff repair patients, but no significant differences were found between the groups. After surgery, pain decreases and active movement of the shoulder joint is possible. Therefore, it is possible that the absence of significant differences was due to the fact that patients' activities of daily living couldn't

be controlled. Future research should investigate the effects of exercise performed at various angles of the shoulder joint, since it is possible that a significant difference in the function of the upper limb might be found between the CKCE and OKCE groups. In the present study, both types of exercise were effective at increasing the activities of the muscles around the shoulder as well as muscle endurance to fatigue increased, as evidenced by an increase in MDF in all the muscles, after conducting closed kinetic chain exercise. Therefore, closed kinetic chain exercise as intervention for muscle fatigue due to muscle atrophy should be used more than open kinetic chain exercise. On the basis of the present result, further studies of exercise programs using closed kinetic chain exercise will be needed to find exercise methods which decrease muscle fatigue after rotator cuff repair.

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