Electromyographic Analysis of Rehabilitation for Rotator Cuff Repair

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Electromyographic Analysis of Rehabilitation for Rotator Cuff Repair

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<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

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Background: The rotator cuff tear is one of common musculoskeletal diseases in old age and the rotator cuff repair is considered as proper treatment for patients showing no improvement with nonsurgical treatment. Although there was debate about the time to start the range of motion exercise, it is important to prevent shoulder stiffness for patients got rotator cuff repair. Self-assisted shoulder and elbow exercises are common home-based rehabilitation, but have been also considered dangerous to the repaired tendon. We assessed differences in the activities of the rotator cuff and parascapular muscles during self-assisted forward flexion (FF) and external rotation (ER) of the shoulder and elbow flexion-extension exercises (EFE) with electromyography (EMG).

Methods: In total, 15 healthy subjects participated in this prospective study. A self-assisted FF exercise was performed, using a table (FFT), a pulley and rope (FFP), and a cane (FFC), while the self-assisted ER exercise was performed with a cane (ERC) and a wall (ERW). Activation amplitudes of the upper subscapularis, supraspinatus, and infraspinatus were evaluated using fine wires. Bipolar surface electrodes were used to record EMG activities from eight parascapular muscles: anterior, middle, and posterior deltoid, upper trapezius, pectoralis major, latissimus dorsi, serratus anterior, and biceps brachii. The EFE exercise and its modification by holding the upper arm with the contralateral hand (EFEH) were also performed. The peak and mean values of muscle activity were normalized to the maximal voluntary isometric contraction (MVIC).

Results: In the FFC exercise, peak activities of cuff muscles were above 10% (11-24%), while when using a rope and pulley, only the activity of the supraspinatus was above 10% (17%). The FFT showed peak EMG activities below 10% of MVIC in all rotator cuff muscles (1-10%). Regarding the tools used, the supraspinatus and infraspinatus showed lower peak EMG activities when using a table compared with a cane ($P < 0.01$ in both the supraspinatus and infraspinatus) and a pulley and rope ($P < 0.05$ in both the supraspinatus and infraspinatus). Forward flexion of < 90° decreased peak supraspinatus activation versus 170° (P = 0.047). In the ER exercise using the cane and wall, activities of the upper subscapularis were both over 10% (15-27%). However, there was no difference between the tools, used such as the cane and wall, in peak EMG activities in the rotator cuff (P > 0.05 in the supraspinatus, infraspinatus, and upper subscapularis). The EFE exercise showed activities above 10% in the upper subscapularis and supraspinatus (13-18%), The EFEH exercise resulted in lower peak EMG activity in the supraspinatus than the EFE (P = 0.018).

Mean EMG activities in the rotator cuff muscles showed differences between the tools used during the FF, ER, and EFE with similar peak EMG activities. No parascapular muscles showed a peak % MVIC of more than 10% in the FF exercises, except the anterior and middle deltoid and the serratus anterior, which showed 16.1%, 13.3%, and 16.5%, respectively, during the FFC.

Conclusions: The table sliding exercise may cause less stress in the rotator cuff tendon in self-assisted forward flexion compared with the cane or the pulley and rope. Decreasing the range of motion below 90° in forward flexion activated the supraspinatus less. Two methods, the wall and cane, resulted in different activation of parascapular muscles during the external rotation movement of the shoulder. Moreover, movement of the elbow can be performed with the contralateral hand holding the upper arm to activate the rotator cuff and upper trapezius to a lesser extent.

Key words: Electromyography, rotator cuff, rehabilitation, forward flexion, external rotation

Electromyographic Analysis of
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I. INTRODUCTION

The rotator cuff tear is one of common diseases with the prevalence of about 54% of patients aged > 60 years.[1] The rotator cuff repair is considered as proper treatment for patients showing no improvement with nonsurgical treatment.[2] A rotator cuff surgery is intended to provide tendon fixation to hold the tendon in the original anatomical area at the proximal humerus until biological healing occurs.[3,4]

Among the many factors affecting the prognosis of the repaired tendon, postoperative rehabilitation programs are considered important.[5,6] The purpose of an immediate postoperative rehabilitation program is to prevent the development of stiffness in the shoulder, elbow and hand without stressing the repaired tendon.[7] Cummins et al. stated that the major cause for revision surgery is pulling a suture through the tendon,[8] and other researchers reported that 16% of failed rotator cuff repairs were related to incorrect postoperative rehabilitation.[9]

There has been much debate about immediate postoperative rehabilitation programs; the appropriate time to start passive motion of the shoulder is part of this debate.[10,11] Some recommend no passive motion until 6 weeks, while others permit it immediately after the operation.[12] The time of strengthening is also disputed. The surgeon decides the time to begin strengthening exercises according to the quality of the tendon substance and the size of the tear, with little scientific support for this decision.[13]

We evaluated the electromyographic activities of the rotator cuff such as subscapularis, supraspinatus and infraspinatus and parascapular muscles such as deltoid, biceps, trapezius, latissimus dorsi, serratus anterior, and pectoralis major during rehabilitation, using various methods; i.e., a table, a pulley and rope, and a wall and a cane. The more the rotator cuff muscles are activated, the more tension is developed in the repaired tendon. Thus, a rehabilitation method that activates the rotator cuff less could be selected to prevent overstress in the repaired tendons.[14]

Electromyography (EMG) has been used to detect muscle activity in the shoulder during rehabilitation, since few studies have been published.[15,16] An overhead reaching movement with a shoulder immobilized with a brace resulted in 23% maximal voluntary isometric contraction (MVIC) in the supraspinatus and 38% MVIC in the upper subscapularis.[17] The pendulum exercise is usually performed immediately after surgery; however, Long et al. presented 13% MVIC in the supraspinatus and 22% MVIC in the infraspinatus when this exercise was performed by tracing concentric circles 51 cm in diameter, indicating the possibility of high stress levels in the repaired cuff tendons.[18]

The following hypotheses were established: 1) self-assisted forward flexion of the shoulder by sliding on a table may activate the rotator cuff and parascapular muscles less than a cane or pulley and rope; 2) self-assisted forward flexion of < 90° may decrease activation of the rotator cuff and parascapular muscles compared with 170°; 3) self-assisted external rotation of the shoulder using a wall may activate the rotator cuff and parascapular muscles similar to when using a cane; 4) elbow flexion–extension exercises may decrease the activity of the rotator cuff and parascapular muscles when it is done with the contralateral hand holding the upper arm.

II. MATERIALS AND METHODS

1. Participants

In total, 16 healthy male subjects participated in the study, but one dropped out because of excessive pain during insertion of the intramuscular needle. All were right hand dominant and no subject had previously experienced musculoskeletal disorders of the right upper limb.

Average age, height, and weight were 24.7 (range, 21-30) years, 175.1 (range, 165-184) cm, and 71.3 (range, 55-106) kg, respectively.

All experimental procedures were approved by the University Hospital Institutional Review Board. Written informed consent was obtained from all subjects.

2. EMG recording

To evaluate the muscle activity of the rotator cuff and parascapular muscles in each rehabilitation procedure, EMG signals were recorded from 11 muscles using a combination of surface and intramuscular fine-wire electrodes. EMG signals from the supraspinatus, infraspinatus, and upper subscapularis were recorded using intramuscular fine wires. Bipolar surface electrodes were used to record EMG activities from eight parascapular muscles: anterior, middle, and posterior deltoid, upper trapezius, pectoralis major, latissimus dorsi, serratus anterior, and biceps brachii. A disposable, self-adhesive, and pre-gelled bipolar Ag/AgCl electrode was used with an inter-electrode distance of 20 mm. Prior to attaching the electrode, the skin overlaying the muscles of the right upper extremity was cleaned with alcohol gauze to minimize impedance; electrode positions were then marked on the skin using a waterproof pen.[19] A Telemyo 2400T DTS telemetry system (Noraxon, AZ, USA) was used to collect EMG signals. The signals were amplified with a gain of 500, noise <1 μV, and a common mode rejection ratio of 100. They were sampled at 1500 Hz and filtered with a bandwidth of 10-500 Hz. All signals were acquired with a laptop computer with a 16-bit analog-to-digital converter.

A 139-μm stainless-steel wire coated with Teflon (A-M Systems, WA, USA) threaded through 25-gauge hypodermic needles was used as the guide for the intramuscular wire electrode. The Teflon coat was removed from the end of the wire, which was hooked so that it remained securely in the muscle belly during shoulder motion. The intramuscular wire electrodes were inserted into the target muscles aseptically using established techniques.[20] For the upper subscapularis, a medial approach was used for insertion of the wire electrode.[21] For this approach, the spine and medial border of the scapula were marked and the midpoint of the scapular spine was identified. From a point 2 cm medial to the medial border of the scapular spine, the needle was inserted and directed toward the midpoint of the spine. To connect the fine-wire electrodes to the telemetry system, a DTS fine-wire lead set (Noraxon) was used. Accurate placement of wire electrodes was evaluated by manual muscle testing of the rotator cuff muscles. To confirm the proper electrode placement, the subject was asked to perform submaximal isometric contractions in specific positions that were expected to generate high EMG activity. For example, if the EMG activity is lower in MVIC position for subscapularis than those for serratus anterior or other parascapular muscles, the wire electrode may not be inserted into subscapularis muscle (Table 1) (Fig. 1).

Table 1. Electrode for three rotator cuff and eight parascapular muscles placement and maximum voluntary isometric contraction (MVIC) testing.

Muscle	Electrode placement	MVIC testing
Supraspinatus	Supraspinous fossa, just above the middle of the spine of the scapula.	With the elbow bent at a right angle, the arm was placed in abduction at the shoulder level.
Infraspinatus	Infraspinous fossa, two fingerbreadths below the medial portion of the spine of the scapula.	External rotation of the shoulder, with the elbow held at a right angle.
Upper subscapularis	Midpoint between medial and lateral end of scapular spine (Entry site: 3 cm below the medial border of the scapular spine).	Extension and adduction of the humerus in the medial rotation, with the hand resting on the posterior iliac crest.
Anterior deltoid	One finger width distal and anterior to the acromion	Shoulder abduction in slight flexion, with the humerus in slight lateral rotation
Middle deltoid	The acromion to the lateral epicondyle of the elbow, which should correspond to the greatest bulge	Shoulder abduction without rotation
Posterior deltoid	About two finger widths posterior of the acromion	Shoulder abduction in slight extension, with the humerus in slight medial rotation
Upper trapezius	50% on the line from the acromion to the spine of vertebra C7	Elevation of the acromial end of the clavicle and scapula
Pectoralis major	Anterior axillary fold	The elbow extended and with the shoulder in flexion and slight medial rotation

Latissimus dorsi	Three finger widths distal to posterior axillary fold	Adduction and extension of the arm in the medially rotated position
Serratus anterior	The level of the inferior tip of the scapula, and just medial of the latissimus dorsi	The upward rotation action of the serratus in the abducted position
Biceps brachii	The line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit	Elbow flexion slightly less than or at a right angle, with the forearm in supination

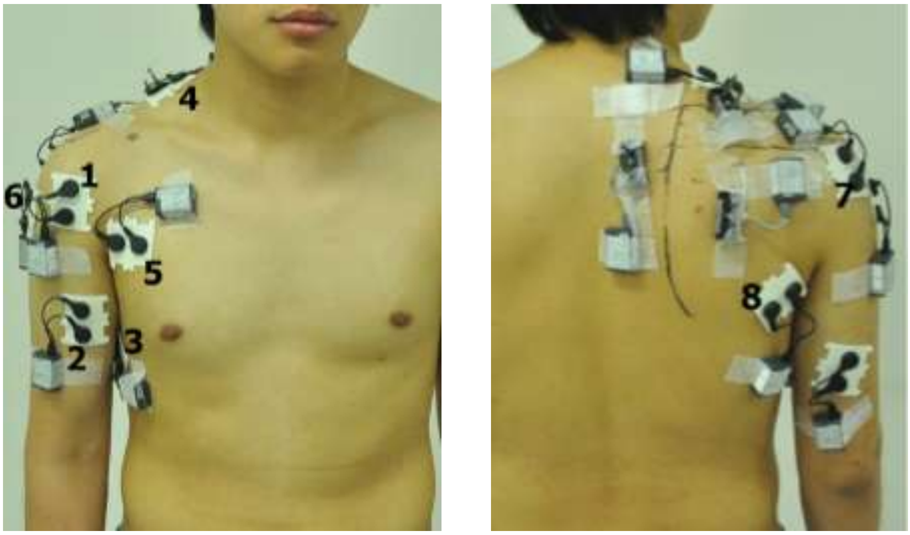


Figure 1. Photographs showing the bipolar surface electrodes placement for 8 parascapular muscles (1:anterior deltoid, 2:biceps brachii, 3:serratus anterior, 4:upper trapezius, 5:pectoralis major, 6:middle deltoid, 7:posterior deltoid, 8:latissimus dorsi). A Telemyo 2400T DTS telemetry system (gray cuboidal shape) used to collect EMG signals were connected with the paired surface electrodes.

3. Procedures

Subjects were instructed thoroughly regarding the procedures in advance. The subjects performed MVIC testing for normalization. MVIC testing was performed three times for 5 seconds following the guidelines by Kendall et al.[22] The subjects received verbal encouragement and visual feedback of the EMG amplitude to produce maximal force with each muscle. At least 2 min of recovery was allowed between MVIC testing to avoid localized muscle fatigue.

Each subject performed three exercises: self-assisted forward flexion of the shoulder (FF), self-assisted external rotation of the shoulder (ER), and elbow flexion and extension (EFE). The FF exercises were repeated using three different methods: a table (FFT), a cane (FFC), and a pulley and rope (FFP). The subject performed the SFFT exercise by sitting beside a table and placing the right hand on a paper located on the table. He continued touching the paper with the right hand and passively sliding it forward by flexing his trunk until his shoulder angle reached at least 170° (Fig. 2A).[23] For the FFC exercise, the subject gripped the head of a cane with his right hand and the bottom of the cane with his left hand in a standing position. He passively elevated the right arm until the shoulder angle reached at least 170° by pushing the cane upward with the left arm (Fig. 2B). For the FFP exercise, a pulley was fixed on the wall above the head of the subject. The subject held the two handles, one with each hand, and pulled down the left handle to passively flex the right shoulder up to 170° flexion. To evaluate the effect of flexion degree, the FFP exercise was repeated in a modified manner (FFP < 90), where the right hand was up to 90° flexion of the shoulder (Fig. 2C).

The ER exercises were carried out using two different methods; a wall (ERW) and a cane (ERC). For the SERW exercise, the subject stood by the corner of a wall with the right elbow at 90° and grasped the corner with the right hand. He twisted his body to the left until his shoulder was rotated externally to the end range (Fig. 2D). For the ERC exercise, the subject gripped the head of a cane with his right hand and the bottom of the cane with the left hand. He passively rotated the right arm externally by pushing the cane to the right side with the left hand (Fig. 2E).

The subjects performed the active elbow exercise using two different methods. The EFE exercise was performed by flexing and extending the right elbow actively in a standing position. This was done without shoulder motion (Fig. 2F). The EFEH exercise was also performed with the left hand firmly holding the upper arm (Fig. 2G). All exercises described above were repeated five times consecutively maintaining a constant speed based on the auditory signal from a metronome.

4. Data analysis

The first and fifth repetitions for each exercise were eliminated from the analysis. The peak EMG values for repetitions 2, 3 and 4 were averaged for each muscle.

The second, third and fourth repetitions were extracted from the five repetitions by visually inspecting the motion captured with a digital camcorder to define each exercise. The EMG signals averaged from three repetitions were converted by full-wave rectification and filtered through a second-order Butterworth filter with a cutoff frequency of 3 Hz.[19,24] The average of three peak values obtained from the MVIC testing was used for the normalization of each muscle; Fischer et al. recommended this normalization method to maximize intra-subject reproducibility.[25] The peak and mean values of normalized EMG activities were calculated for each muscle for each exercise. The peak value % MVIC is helpful in estimating the risk of re-tear of the rotator cuff in each exercise, while the mean value % MVIC shows the general pattern of muscle activity in each exercise.

5. Statistical analysis

The non-parametric Mann–Whitney U-test was used to compare rehabilitation exercises for the peak values of normalized EMG activities because the data were not normally distributed. A p value of < 0.05 was considered to indicate statistical significance, determined using the SPSS software (ver. 12.0.1; SPSS, Inc., Chicago, IL, USA).

Figure 2. Photographs of rehabilitation exercises.

A. Self-assisted forward flexion of the shoulder by sliding on a table.

B. Self-assisted forward flexion of the shoulder using a cane.

C. Self-assisted forward flexion of the shoulder using a pulley and rope.

D. Self-assisted external rotation of the shoulder using a wall.

E. Self-assisted external rotation of the shoulder using a cane.

F. Elbow flexion and extension without shoulder motion.

G. Elbow flexion and extension holding the upper arm with the contralateral hand.

III. RESULTS

1. Rotator cuff muscles: supraspinatus, infraspinatus, and upper subscapularis

A. Self-assisted forward flexion exercises of the shoulder

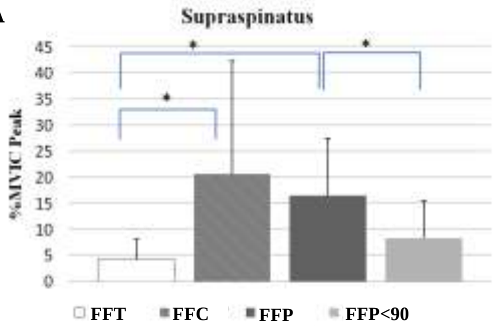
Relative to the peak value of % MVIC, EMG activity above 10% MVIC was noted in the supraspinatus (21%), infraspinatus (11%), and upper subscapularis (24%) during the FFC and in the supraspinatus (17%) during the FFP. The FFT showed peak EMG activities below 10% MVIC in all rotator cuff muscles (1-10%).

Rotator cuff muscles showed various peak EMG activities according to the tool used. In the supraspinatus, the FFT resulted in significantly lower activities than did the FFP and the FFC (P = 0.028 and < 0.01, respectively). In the infraspinatus, the FFT also showed significantly lower peak EMG activities than the FFP and the FFC (P = 0.036 and < 0.01, respectively). The upper subscapularis showed no significant difference in peak EMG activities, irrespective of the tool used.

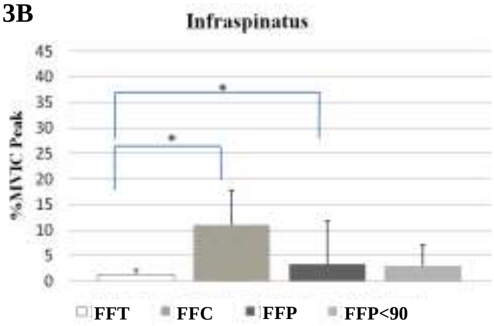
The FFP <90 exercise showed 8% MVIC as the peak EMG activity, lower than that of the FFP in the supraspinatus (P = 0.047) (Fig. 3 A-C).

In terms of the mean value of % MVIC, the EMG activities during the FF exercise varied according to the tool used. In the supraspinatus, the FFT resulted in significantly lower mean EMG activities than did FFP or FFC (P = 0.028 and < 0.005, respectively). In the infraspinatus, the FFT also showed significantly lower mean EMG activities than the FFC (P = 0.008). The upper subscapularis showed lower mean EMG activities in FFT than FFC (P = 0.028; Fig. 3 D-F).

3A



3B



3C

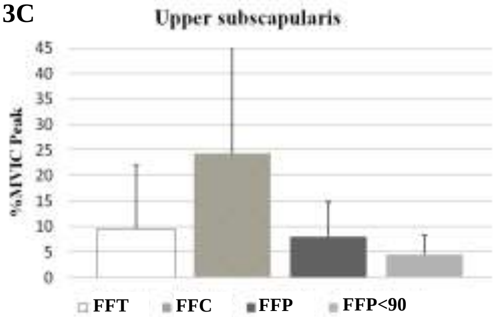


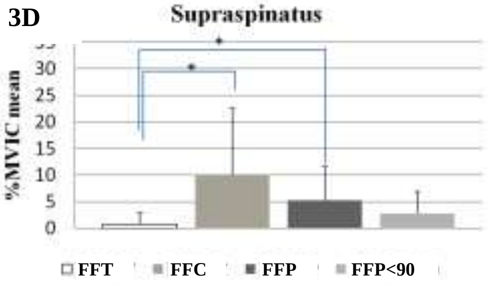
Figure 3. Electromyographic activities of rotator cuff muscles for self-assisted forward flexion of the shoulder (*; $p < 0.05$. Data are expressed as medians + standard deviation).

(A) Peak % MVIC value in the supraspinatus.

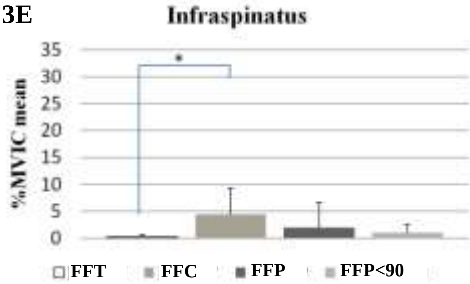
(B) Peak % MVIC value in the infraspinatus.

(C) Peak % MVIC value in the upper subscapularis.

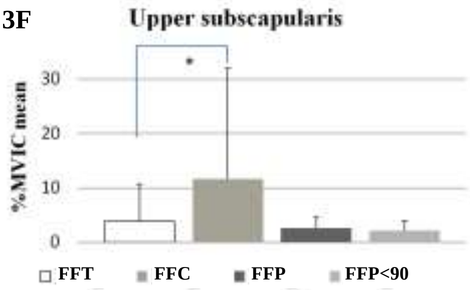
3D



3E



3F



(D) Mean % MVIC value in the supraspinatus.

(E) Mean % MVIC value in the infraspinatus.

(F) Mean % MVIC value in the upper subscapularis

B. Self-assisted external rotation exercises of the shoulder

Relative to the peak value % MVIC, EMG activity above 10% MVIC was noted in the infraspinatus (18%) and upper subscapularis (15%) during the ERC and in the upper subscapularis (27%) during the ERW. The supraspinatus was inactive during the ERC and ERW (< 5%). However, there was no significant difference in peak EMG activities in the rotator cuff muscles between ERW and ERC (Fig. 4A-C).

In terms of the mean value % MVIC, the supraspinatus, infraspinatus, and upper subscapularis showed EMG activities < 8.7% MVIC. These rotator cuff muscles showed no difference in mean % MVIC between ERC and ERW (P = 0.859, 0.139, and 0.463, respectively; Fig. 4D-F).

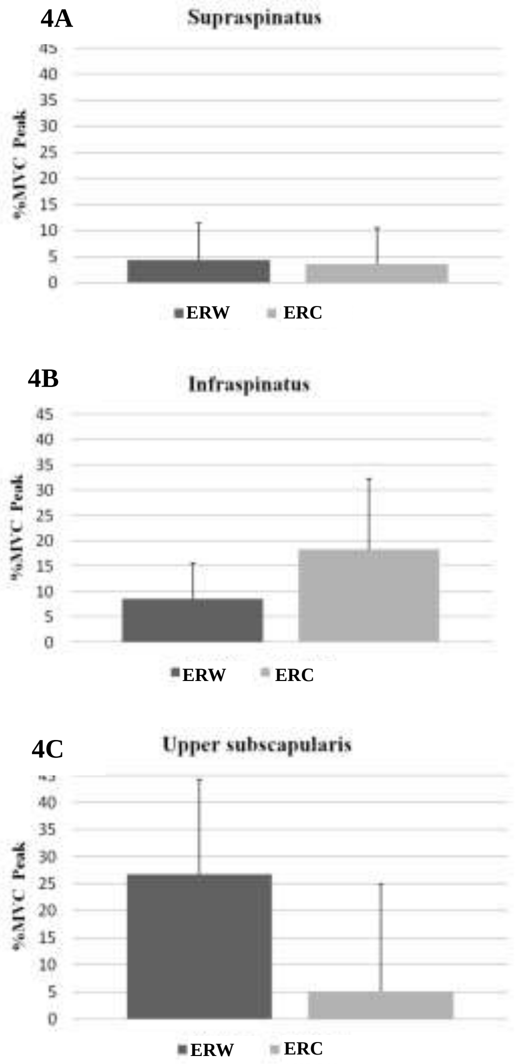


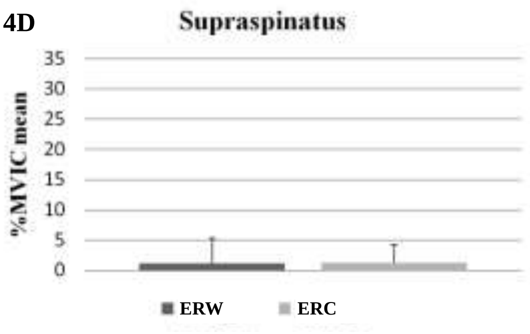
Figure 4. Electromyographic activities of rotator cuff muscles during self-assisted external rotation of the shoulder (*; $p < 0.05$. Data are expressed as medians + standard deviation).

(A) Peak % MVIC value in the supraspinatus.

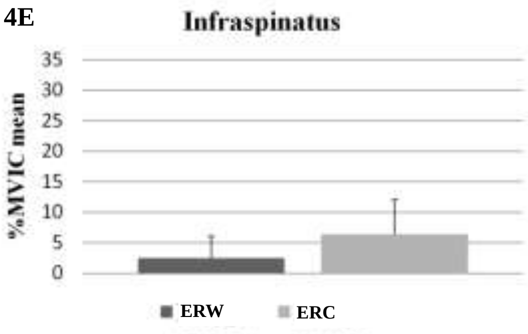
(B) Peak % MVIC value in the infraspinatus.

(C) Peak % MVIC value in the upper subscapularis.

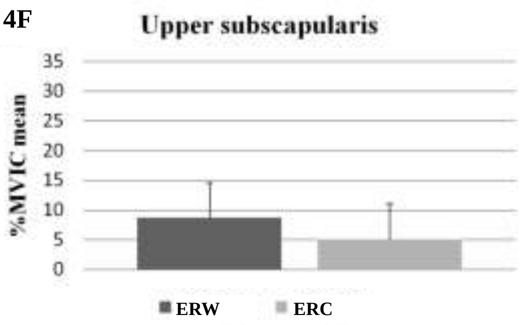
4D



4E



4F



(D) Mean % MVIC value in the supraspinatus.

(E) Mean % MVIC value in the infraspinatus.

(F) Mean % MVIC value in the upper subscapularis.

C. Elbow flexion extension exercises

Relative to the peak value of % MVIC, EMG activity above 10% MVIC was noted in the supraspinatus (13%) and upper subscapularis (18%). The supraspinatus showed lower peak EMG activities in the EFEH (10%) than in the EFE (*P* = 0.018; Fig. 5A-C).

In terms of the mean value of % MVIC, the EMG activity was less than 10% MVIC in the supraspinatus, infraspinatus, and upper subscapularis. The supraspinatus showed lower mean EMG activities in the EFEH than in the EFE (*P* = 0.043; Fig. 5D-F).

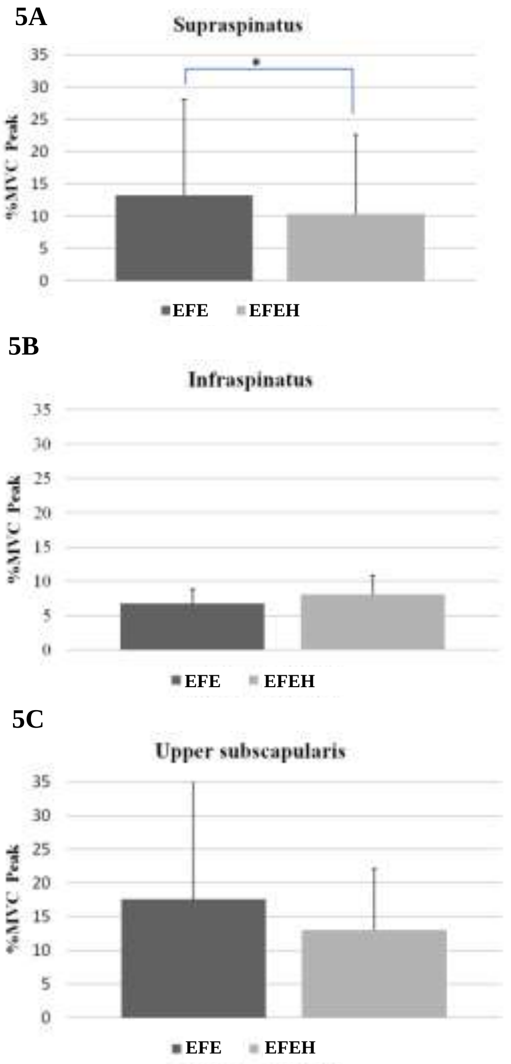


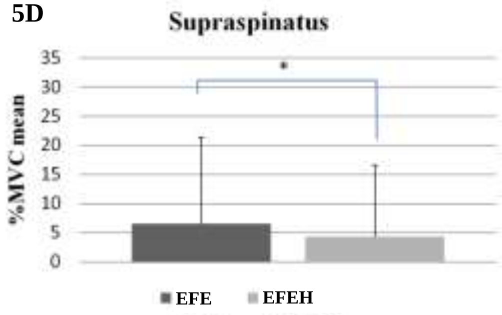
Figure 5. Electromyographic activities of rotator cuff muscles during elbow flexion and extension (*; $p < 0.05$. Data are expressed as medians + standard deviation).

(A) Peak % MVIC value in the supraspinatus.

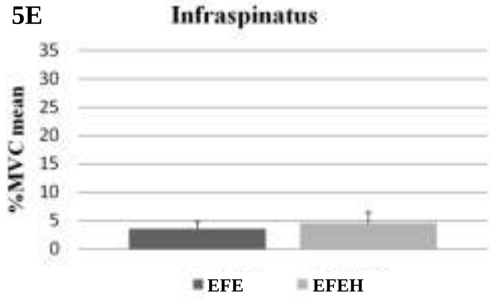
(B) Peak % MVIC value in the infraspinatus.

(C) Peak % MVIC value in the upper subscapularis.

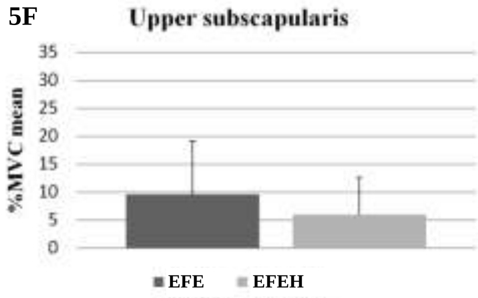
5D



5E



5F



(D) Mean % MVIC value in the supraspinatus.

(E) Mean % MVIC value in the infraspinatus.

(F) Mean % MVIC value in the upper subscapularis.

2. Parascapular muscles other than the rotator cuff

A. Peak value % MVIC

During the FF exercise, most parascapular muscles showed peak % MVIC less than 10% in the FFC, FFT, and FFP. However, the anterior and middle deltoid and the serratus anterior had peak % MVIC higher than 10% during the FFC (16.1%, 13.3%, and 16.5%, respectively). The middle and posterior deltoid, and the serratus anterior, showed lower peak % MVIC in the FFT than in the FFC (*P* = 0.001, 0.005, and 0.005, respectively) and the FFP (*P* = 0.015, 0.041, and 0.031, respectively). The upper trapezius and the biceps brachii had lower peak % MVIC in the FFT than in the FFC (*P* = 0.005 and 0.001, respectively).

During the ER exercise, all parascapular muscles showed peak % MVIC less than 10% in the ERW and the ERC. The anterior deltoid, middle deltoid, the upper trapezius, the serratus anterior and the biceps brachii had lower peak % MVIC in the ERC than in the ERW (*P* = 0.001, 0.012, 0.017, 0.003, and 0.011, respectively).

During the elbow exercise, most parascapular muscles, except the biceps brachii, showed peak % MVIC less than 10% in the EFE and the EFEH. The biceps brachii had 11.2% as a peak % MVIC in the EFE, significantly higher than in the EFEH (*P* = 0.033). The upper trapezius also showed higher peak %

MVIC in the EFE than in the EFEH (*P* = 0.008; Table 2A).

B. Mean value % MVIC

During the FF exercise, no parascapular muscle showed a mean % MVIC higher than 8.6%. The middle and posterior deltoid, and the serratus anterior, showed lower mean % MVIC in the FFT than in the FFC (all *P* = 0.001) and the FFP (*P* = 0.031, 0.024, and 0.015, respectively).

The ER and the EFE exercises also showed mean % MVIC lower than 4.0% in all parascapular muscles. The anterior and middle deltoid, the upper trapezius, the pectoral major, the serratus anterior, and the biceps brachii showed lower mean % MVIC in the ERC than in the ERW (*P* = 0.001, 0.007, 0.017, 0.035, 0.003, and 0.025, respectively; Table 2B).

Table 2. Electromyographic activities of eight parascapular muscles, but not the three rotator cuffs, during rehabilitation.

A. Peak % MVIC.

	AD	MD	PD	UT	PM	LD	SA	BB
FFT	2.6 (14.1)	2.8 (4.7)	0.9 (1.2)	2.2 (6.8)	1.4 (44.9)	4.0 (4.7)	7.3 (5.7)	1.3 (1.1)
FFC	16.1 (10.7)	13.3 (7.4)	3.3 (1.8)	8.2 (10.9)	1.4 (4.0)	4.3 (31.8)	16.5 (11.7)	5.8 (2.4)
FFP	9.2 (10.5)	7.6 (11.0)	1.5 (2.0)	4.1 (9.5)	0.7 (12.4)	4.0 (4.3)	9.8 (11.1)	2.1 (3.5)
ERW	7.7 (4.9)	1.2 (0.8)	1.0 (1.3)	1.6 (2.7)	4.9 (3.9)	5.2 (22.0)	2.2 (5.9)	2.3 (1.8)
ERC	0.6 (1.3)	0.8 (0.6)	0.8 (0.6)	0.9 (1.5)	2.8 (5.8)	2.0 (2.9)	1.3 (0.9)	1.5 (0.9)
EFE	5.9 (4.4)	1.7 (1.6)	0.7 (0.7)	1.6 (2.6)	1.3 (1.6)	1.5 (1.3)	3.8 (2.1)	11.2 (8.2)
EFEH	5.3 (4.7)	1.3 (1.0)	0.5 (0.4)	1.0 (1.0)	1.7 (1.2)	0.9 (0.6)	2.9 (2.3)	7.9 (6.9)

B. Mean % MVIC.

	AD	MD	PD	UT	PM	LD	SA	BB
FFT	1.2 (2.9)	1.1 (1.5)	0.3 (0.3)	1.2 (1.5)	0.6 (2.0)	1.1 (1.0)	2.5 (1.9)	0.6 (0.3)
FFC	8.1 (5.7)	5.5 (3.8)	1.3 (0.9)	4.9 (6.2)	0.7 (0.6)	1.1 (2.3)	8.6 (5.2)	2.4 (1.2)
FFP	3.8 (4.0)	2.2 (2.6)	0.5 (0.7)	1.6 (4.7)	0.4 (1.5)	0.9 (1.4)	3.5 (3.4)	0.6 (1.0)
ERW	2.3 (1.7)	0.6 (0.4)	0.4 (0.4)	0.8 (1.1)	2.3 (1.8)	1.3 (2.2)	1.0 (2.2)	1.5 (1.0)
ERC	0.4 (0.5)	0.5 (0.3)	0.4 (0.3)	0.5 (0.9)	1.3 (1.2)	1.0 (1.1)	0.7 (0.6)	1.0 (0.6)
EFE	2.6 (2.2)	0.8 (0.7)	0.3 (0.3)	0.8 (0.8)	0.6 (0.7)	0.6 (0.4)	1.7 (1.2)	3.6 (2.3)
EFEH	3.1 (2.7)	0.7 (0.5)	0.3 (0.3)	0.7 (0.3)	0.9 (0.7)	0.5 (0.2)	1.4 (1.0)	2.8 (2.9)

AD = anterior deltoid, MD = middle deltoid, PD = posterior deltoid,

UT = upper trapezius, PM = pectoralis major, LD = latissimus dorsi,

SA = serratus anterior, BB = biceps brachii.

Data are expressed as medians (standard deviation).

IV. DISCUSSION

This study is aimed to evaluate the muscle activity in shoulder during the exercise of rehabilitation for the rotator cuff repair. The EMG signals in the rotator cuff and parascapular muscles were compared during self-assisted shoulder and elbow exercises using several different methods.

Consensus regarding when shoulder joint should begin range of motion exercises following rotator cuff repair are lacking. Recommendations include immobilization or alternatively, passive movement for the first postoperative 3 weeks.[26] Most early postoperative regimens recommend passive movement of the shoulder to minimize activation of the repaired cuff.[11] However, the muscles covering a joint may be activated to stabilize the joint even during assisted exercise; rotator cuff muscles play an important role in dynamic glenohumeral stability in middle- and end-range of motion.[27]

In the FF exercises, EMG activities of rotator cuff muscles were significantly affected by the kinds of method used. The exercise using a table showed less activation of the supraspinatus and infraspinatus compared with the pulley and rope. This may be due to sliding on the table during forward flexion, which is similar to a closed-chain exercise. One study showed lower EMG activity when using the table compared with the pulley and rope in patients who underwent a subacromial decompression or distal clavicle resection.[15] Burkhart et al. recommended the self-assisted forward flexion using a table during acute-phase rehabilitation after cuff repair.[23] A plastic cane is known to be useful for self-assisted rehabilitation because it enables multidirectional exercising of the shoulder, such as forward flexion, abduction, and external and internal rotation. However, the cane may also cause more stress in the repaired supraspinatus or infraspinatus tendon compared with table sliding.

A modified exercise program that limits the FF exercise to 90° for 3 weeks following cuff repair resulted in a lower retear rate than did unlimited FF exercise.[28] The FF exercise to 90° resulted in less activity in the supraspinatus than did the FF exercise to 170°, suggesting that the supraspinatus is highly activated at >90° compared with at <90°. The FF exercise to 90° may therefore result in relatively less stress to the repaired supraspinatus tendon.

In a biomechanical study, the external rotation movement of the shoulder following cuff repair induced gap formation in the anterior supraspinatus.[29] However, several protocols include external rotation exercise on the second postoperative day.[2] A self-assisted external rotation results in activation of supraspinatus and infraspinatus more than a therapist-assisted exercise.[15] Therefore, we assessed self-assisted method using the cane or the wall showed lower EMG peaks. Contrary to the expectation that the unstable cane might show a higher EMG peak than the stable wall, there was no difference in EMG peaks between them.

The clinician may typically delay the time to begin ROM exercise of the shoulder according to tear size while not delaying the time to start active motion of the elbow according to tear size.[28] Elbow movement activated the rotator cuff muscles by up to 17.6%, although the shoulder remained stationary, indicating that the rotator cuff muscle was activated considerably by elbow movement, which cause EMG activity higher than those in the FFT, FFP, and ERC with shoulder motion.[16,30-33] Besides the elbow, the hand movement activates the muscles in the shoulder. The trapezius, posterior deltoid, and infraspinatus were increased by 2% MVIC during the gripping.[34] Based on our findings, holding the upper arm with the contralateral hand may be preferred as an elbow exercise so as to not overactivate the supraspinatus. This may be due to which the shoulder has a tendency to be extended during elbow flexion and the rotator cuff muscles activate not to move the shoulder because the anterior deltoid showed the highest EMG activity in the parascapular muscles. Clinicians may wish to delay the time for active motion of the elbow if they are concerned about overstress at the repaired supraspinatus tendons with severe degeneration. However, the duration of the delay needs further study.

The parascapular muscles, such as the deltoid, upper trapezius, and serratus anterior, showed EMG activity during the FF, ER, and EFE exercise similar to the rotator cuff muscle in the present study. The EMG activities of these muscles varied according to the tool used. The table sliding had lower peak % MVIC in the middle and posterior deltoid and serratus anterior during the FF than the cane and the pulley and rope. Although the wall showed higher activities in the ER than the cane in the anterior deltoid, middle deltoid, upper trapezius, serratus anterior and biceps brachii, their activities were weak as less than 10% MVIC. The biceps brachii and upper trapezius had lower peak % MVIC in the EFEH than in the EFE, which might help to select the rehabilitation program for patients got the biceps tenodesis.

This study had a number of limitations. First, many factors affect the healing of the repaired tendon other than overactivity of the rotator cuff muscles, including compressive pressure around the tendon.[35] Additionally, the possibility of discrepancies between muscle activity and true tensile load at repair sites exists because the EMG does not reflect the tension of the tendon without muscle contraction. However, the more a muscle is activated the more tension develops in the repaired tendon. Second, the participants were not patients who had undergone rotator cuff repair but normal subjects. Patients' pain during the acute rehabilitation phase may affect EMG signals and add bias independent of muscle contraction and for this reason, many researchers prefer to use healthy subjects rather than symptomatic patients in EMG-based studies.[15,17,18,36] Additionally, ethical issues may exist when performing the MVIC as the normalization technique for patients during the acute rehabilitation phase. Third, while we consider EMG activity in each exercise > 10% to be 'active,'[33] this needs more study. Some consider a muscle showing less than 10% MVIC to be *in*active, while one study reported that muscle activity under 20% MVIC was considered low and less stressful than activity over 20% MVIC, without any support for the cut-off.[31,32] According to the degree of tendon degeneration or cuff muscle atrophy, the degree of activity may be adjustable in terms of EMG activity. Forth, the activities of all rotator cuff muscles were measured except teres minor. The incidence of tear in the teres minor is not common even in large sized tear,[37] and many researches evaluating the rotator cuff activity usually skipped this muscle.[14,38,39]

V. CONCLUSIONS

In this study, the EMG activities of rotator cuff and parascapular muscles were investigated during rehabilitation, such as the FF, ER, and EFE exercises. The effects of the tools used for rehabilitation were also examined.

1. In the FF exercise, the table sliding exercise showed significantly lower peak and mean EMG activities in the rotator cuff than the cane and pulley and rope exercises. The deltoid, upper trapezius and serratus anterior in the parascapular muscles showed significantly lower peak and mean EMG activities using the table sliding than the cane.
2. In the FF exercise, decreasing the range of motion below 90° in forward flexion resulted in less activation of the supraspinatus.
3. In the ER exercise, there was no significant difference in the peak or mean EMG activities of rotator cuff muscles between the wall and cane exercises. However, the deltoid, upper trapezius, and serratus anterior in the parascapular muscles showed higher peak EMG activities using the wall than the cane.
4. The EFE exercise resulted in peak EMG activities higher than 10% in the supraspinatus and upper subscapularis, with no shoulder motion. Holding the upper arm with the contralateral hand decreased the peak and mean EMG activities in the supraspinatus significantly. The biceps brachii and upper

trapezius also exhibited lower peak EMG activity in the EFEH than EFE.

In conclusion, the table sliding exercise may cause less stress in the rotator cuff tendon in self-assisted forward flexion compared with the cane or the pulley and rope. Decreasing the range of motion below 90° in forward flexion activated the supraspinatus less. Two methods, the wall and cane, resulted in differing activation of parascapular muscles during the external rotation movement of the shoulder. Moreover, movement of the elbow can be performed with the contralateral hand holding the upper arm to activate the rotator cuff and upper trapezius to a lesser extent.

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ABSTRACT (IN KOREAN)

회전근개 파열을 위한 재활 운동들의 근전도 분석

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배경: 회전근개 파열은 고령에서 흔한 근골격계 질환으로 비수술적 치료에 호전되지 않는 경우, 회전근개 봉합술이 실시되곤 한다. 관절 운동을 시작하는 시기에 대한 이견들이 있기는 하지만, 봉합술을 시행받은 환자에게 어깨 강직이 나타나지 않도록 예방하는 것은 중요하다. 자기 보조 어깨 운동과 능동적 팔꿈치 운동은 어깨 힘줄 파열 봉합술 이후에 실시되는 흔한 재활 치료 방법이다. 하지만, 이 같은 운동들이 봉합된 어깨 힘줄의 재손상을 야기할 수도 있다고 여겨진다. 우리는 자기 보조 어깨 전방굴곡 운동, 자기 보조 어깨 외회전 운동 및 능동적 팔꿈치 굴곡 및 신전 운동 과정에서 회전근개 및 견갑골 주변 근육의 활성도가 각 운동에서 사용되는 도구들에 따른 변화를 알아보고자 하였다.

방법: 총 15명의 건강한 피험자를 대상으로 전향적 실험실 연구를

계획하였다. 자기 보조 어깨 전방 굴곡 운동은 테이블, 도르래와 줄, 그리고 운동용 지팡이를 가지고 시행되었다. 반면, 자기 보조 어깨 외회전 운동은 운동용 지팡이와 벽을 사용해 이루어졌다. 근전도 측정을 위해 극상건, 극하건, 그리고 상부 견갑하건은 근육내 미세 근전도 센서로서, 견갑골 주변 근육인 전방, 중앙, 및 후방 삼각근, 상부 승모근, 대흉근, 광배근, 전거근 및 이두박근 등은 이극 표면 근전도 센서를 사용하였다.

능동적 팔꿈치 굴곡 및 신전 운동은 고식적 방법 이외에 반대편 손으로 상완부를 고정하는 변형된 방법 두 가지로 실시되었다. 최대 및 평균 근전도 활성도 수치는 최대 수의적 등척성 수축도에 대한 백분율로 표준화 시켰다.

결과: 자기 보조 어깨 전방굴곡 운동에 있어서, 운동용 지팡이는 세 회전근개 모두에서 최대 근전도 활성도가 10% 이상을 보인 반면 (11-24%) 도르래와 줄을 이용한 경우 극상건에서만 관찰되었다 (17%). 테이블을 이용한 경우 회전근개는 모두 10% 미만의 최대 근전도 활성을 보였다 (1-10%). 사용된 도구간 비교를 할 경우, 극상건과 극하건은 테이블을 이용한 경우 다른 도구들, 운동용 지팡이와 도르래와 줄을 사용한 경우보다 의미있게 낮은 최대 근전도 활성을 보였다. 어깨 전방 굴곡 시

굴곡 각도를 90도 이하로 낮추는 방식은 고식적인 170도 굴곡 방법에 비해 의미있게 극상건의 최대 근전도 활성을 감소시켰다 (P = 0.047). 자기 보조 어깨 외회전 운동은 상부 견갑하건의 최대 근전도 활성도를 10% 이상 증가시켰다 (15-27%). 그러나 사용된 도구인 운동용 지팡이와 벽 간에 의미있는 최대 근전도 활성도 차이는 없었다.

능동적 팔꿈치 운동 시 상부 견갑하근과 극상근은 10% 이상의 최대 근전도 활성을 보였다 (13-18%). 반대편 손으로 상완부를 고정하고 팔꿈치 운동을 시행할 경우, 극상근의 최대 활성도는 의미있게 감소되었다 (P = 0.018).

자기 보조 어깨 운동 및 능동적 팔꿈치 운동 시, 사용된 도구들에 따라 회전근개의 평균 근전도 활성도는 최대 활성도와 비슷한 변화를 보였다.

운동용 지팡이를 이용한 자기 보조 어깨 전방 굴곡 시 각각 16.1% 와 16.5%의 최대 근전도 활성을 보인 전방 삼각근, 중앙 삼각근, 전거근을 제외하곤 모든 견갑골 주변 근육들은 수동적 어깨 전방 굴곡 및 외회전 운동시 10% 미만의 낮은 최대 근전도 활성을 나타냈다. .

결론: 이상의 결과를 종합해 볼 때, 테이블을 이용한 자기 보조

어깨 전방 굴곡 운동은 운동용 지팡이나 도르래와 줄을 이용한 방식에 비해 회전근개에 보다 적은 스트레스를 야기할 것이다. 전방 굴곡 운동시 90도 미만으로 각도를 제한하는 것은 극상건의 활성도를 감소시킨다. 일부 견갑골주변 근육의 활성도는 자기 보조 어깨 외회전을 위한 두 가지 방법 - 운동용 지팡이와 벽- 간에 차이가 나타났다. 또한 능동적 팔꿈치 굴곡 및 신전 운동을 함에 있어서 반대편 손으로 상완부를 고정하는 변형된 방식은 회전근개 및 상부 승모근의 활성도를 감소시킬 수 있었다.

핵심되는 말: 근전도, 회전근개, 재활, 전방 굴곡, 외회전