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Original Article

The effect of rotator cuff physical exercise combined with electrically stimulated antagonist on shoulder rotator cuff strength

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A B S T R A C T

Background: An elastic band (EB) is generally used with a low load for rotator cuff physical exercise, but the resulting increase in muscle strength is insufficient. We assessed the efficacy on external rotator muscle strength of the shoulder joint; of a hybrid training system (HTS) that resists the motion of a volitionally contracting agonist muscle using the force generated by its electrically stimulated antagonist vs. general rotator cuff exercise with EB.
Methods: Twenty healthy men with no shoulder joint disorders were randomized to 6 weeks of tri-weekly 10-min rotator cuff exercise with HTS or EB in a clinical research laboratory. Isokinetic concentric external rotator muscle strength at angular velocities of 60°/s and 180°/s (CON60, CON180, respectively) and isokinetic eccentric external rotator muscle strength at an angular velocity of 60°/s (ECC60) were measured as rotator cuff function before and after 6 weeks of intervention.
Results: There were no significant intergroup differences in baseline characteristics. There were statistically significant differences ($p = 0.0358$, $p = 0.0213$, respectively) in the increase in CON180 (mean ± SD) and ECC60 between the HTS group (Δ6.0 ± 6.0Nm, $p = 0.015$; Δ7.5 ± 4.7Nm $p = 0.0007$, respectively) and the EB group (Δ0.3 ± 5.2Nm, $p = 0.8589$; Δ1.8 ± 5.3 Nm $p = 0.3133$, respectively). There was a trend toward CON60 increasing in the HTS group (Δ4.7 ± 6.5Nm, $p = 0.0494$) which was greater than in the control group (Δ-0.9 ± 6.3Nm, $p = 0.6637$) (inter-group, $p = 0.0677$).
Conclusions: The results of this study support the conclusion that HTS is more effective for increasing external rotator muscle strength more effectively than EB. HTS would be useful for rotator cuff physical exercise.

1. Introduction

Shoulder pain is very common and one of the most prevalent musculoskeletal disorders presenting to primary care [1]. Moreover, chronic shoulder pain is all too common, and the pain persists in approximately 46.7% of cases one year later [2]. About two-thirds of the patients with shoulder pain are diagnosed as rotator cuff disorder [3]. Conservative medical treatment is commonly recommended, and rehabilitation such as rotator cuff physical exercise is very important [4].

It is necessary to control muscle contractions of the outer muscle when we perform physical exercise of the rotator cuff which is the inner muscle of the shoulder joint so that a shearing force does not occur between the humeral head and scapula glenoid fossa. When exercise load is increased, outer muscles are activated although the activation of inner muscles decreases inversely. Therefore it is recommended that the physical exercise for rotator cuff be implemented with a low exercise load, so an elastic band (EB) is often used [5]. Moreover, there are studies showing the usefulness of eccentric training. The reason is because eccentric training can disperse more of the load to the tendon than

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concentric training can [6]. Eccentric exercise has the effect of increasing the tendon cross-sectional area and results in hormonal changes that benefit the nervous, endocrine and musculoskeletal systems [7,8]. Many studies have shown that eccentric training is useful for the treatment of Achilles' tendon and patellar tendon disorders, but there are few studies addressing rotator cuff disorder [9]. However, the effect of eccentric training is said to be no different from the effect of concentric training [10]. Furthermore, a more effective eccentric exercise method is required [11].

Neuromuscular electrical stimulation (NMES) is widely used to increase muscle strength and improve physical function even at a low-moderate exercise intensity [12]. Furthermore, the combined application of electrical stimulation and volitional contractions is said to be more effective than either method alone [13]. As one of these combination techniques, a hybrid training system (HTS) that resists the motion of a volitionally contracting agonist muscle using the force generated by its electrically stimulated antagonist has been developed [14]. It has been shown that HTS can increase both muscle strength and mass [14–17]. It is considered to be a characteristic of HTS that electrically stimulated eccentric muscle contractions result in increased muscle strength and mass in spite of relatively low exercise intensity [15–17]. In addition, it was shown that the force from antagonist muscles is useful as a source of resistance for the agonists [18]. Therefore, it is supposed that HTS is useful for rotator cuff physical exercise when we apply HTS to both internal and external rotation of the shoulder joint.

The purpose of this study is to compare the effects of conventional physical exercise using an elastic band and HTS on muscle strength in the rotator cuff.

2. Materials and methods

This research has been approved by the IRB of the authors' affiliated institutions.

2.1. Subjects

Following an IRB-approved consent process, we acquired written informed consent from 20 healthy men with no abnormality in the shoulder joints (age, 27.4 ± 6.6 (SD) yr; height, 173.3 ± 8.3 cm; and weight, 69.6 ± 15.4 kg) who had reviewed the goals of this study and agreed to participate. Subjects were required to have normal musculoskeletal examinations and histories. Subjects were then randomly allocated into two groups: HTS group (n = 10), and Elastic Band group (EB, n = 10).

2.2. Exercise

Subjects carried out a tri-weekly training program for 6 weeks (Monday, Wednesday, Friday). They performed 8 sets of 10 reciprocal 1-s internal shoulder rotations and 1-s external shoulder rotations in a sitting position with the shoulder in neutral abduction and the elbow flexed at 90°.

2.2.1. HTS group

Exercises were performed with the subject's pectoralis major muscle electrically stimulated as they volitionally rotated their shoulder outward. The reverse occurred (i.e., the infraspinatus was stimulated) as they volitionally rotated their shoulder inward. Shoulder joint range of motion was restricted to an arc that extended from 30° internal rotation to 60° external rotation (Fig. 1). Subjects changed the direction of their muscle contractions in response to a tone emitted by the electrical stimulator. The subjects in the HTS group performed 8 sets of 10 reciprocal internal and external shoulder rotations with their arms (Fig. 2). Sets were separated by 1-min rest intervals and each exercise session required 9 min and 40 s to complete.

2.2.2. EB group

Exercises were performed in the traditional method using an elastic band (Thera-Band® yellow [thin], Hygenic Corp, Akron, USA) [5,19,20]. The subjects in the EB group performed 3 sets of 30 reciprocally resisted internal and external shoulder rotation exercises with repetitions. Each subject performed the rotations from about 60°, with the end of the elastic band attached to the wall at elbow level and the elbow flexed to 90°. The distance between the subjects and the wall was 30cm and they extended the band to 60cm–75cm. The resistance force (torque) at that time was estimated to be 2.26Nm - 2.60Nm [20], which was equivalent to <30% maximum voluntary contraction (MVC) (very light intensity).

Sets were separated by 1-min rest intervals and each exercise session required 10 min to complete.

2.2.3. Equipment

The HTS apparatus consisted of an electrical stimulator, surface electrodes, and a joint motion sensor that triggered stimulation of the antagonist once it sensed the initiation of a volitional contraction. Low impedance gel-coated electrodes (Sekisui Plastics Co., Tokyo, Japan) were placed over the motor points of the pectoralis major muscle and the infraspinatus.

2.2.4. Waveform

Stimulation parameters were based on a standard Russian waveform in which a 5000 Hz carrier frequency was modulated at 40 Hz (2.4 ms on, 22.6 ms off) to deliver a rectangular biphasic wave pulse.

2.2.5. Intensity

HTS exercise intensity would be about 25–30% MVC using 80% maximal tolerable intensity [16,17]. The repetition maximum (RM) is generally used for the exercise load. 20RM or more produces the greatest gains in muscle endurance, and this intensity is expressed as “very light” [21] which is equivalent to <30%MVC. In this study, the subjects were able to perform more than 50 RM of shoulder external rotation exercises with HTS at the trial stage of the HTS exercise method. Thus, we set the exercise intensity of the shoulder external rotation by HTS to “very light”.

2.3. Evaluation

As one of the important causes of shoulder pain, external rotation muscular strength is known to relatively decrease as compared with internal rotation muscular strength. Therefore, evaluation of external rotation muscular strength is important in the physical therapy of the shoulder [8]. The peak torque of the external shoulder rotator was measured using an isokinetic dynamometer (CYBEX770-NORM,Ronkonkoma,NY,USA), subjects performed concentric and eccentric maximal tests in a seated position with the arm in the scapula plane (45° of abduction, 30° of flexion). In all tests, the elbow was flexed at 90°, the machine axis was aligned with the longitudinal axis of the humerus and coincident with the center of the glenohumeral joint (Fig. 3). Interrater reliability was calculated with the use of intraclass correlation coefficients (ICC). ICC were calculated with JMP Version 14.0 statistical software (SAS Institute Inc., Cary, NC, USA). Test-retest (ICC 0.928–0.959 for Class 1) reliability of our study was determined to be excellent.

60°/sec (CON60) and 180°/sec (CON180) were the speeds chosen for this study as these are able to detect the risk factor of shoulder lesions [22] and at larger than 180°/sec evaluation is said to be difficult even in the case of pro athletes [23]. Moreover, we did the

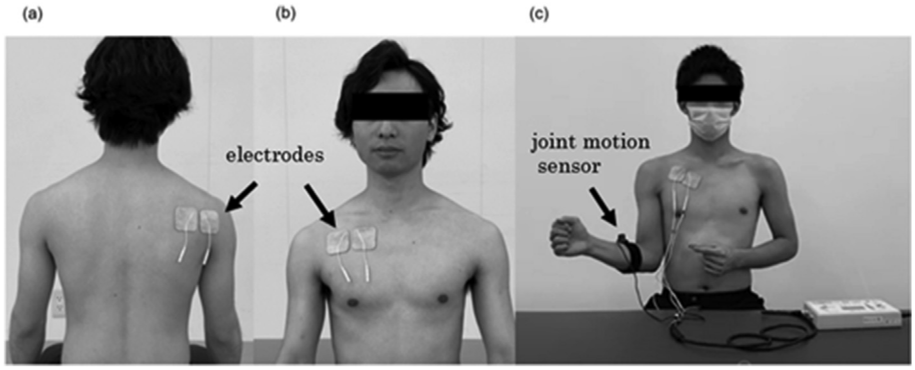

Fig. 1. Hybrid training system. (a) Infraspinatus muscle was electrically stimulated. (b) Pectoralis major muscle was electrically stimulated. (c) Performing exercise with the hybrid training system. Shoulder joint range of motion was restricted to an arc that extended from 30° internal rotation to 60° external rotation. Subjects changed the direction of their muscle contractions in accordance with a tone emitted by the electrical stimulator. Electrodes and a joint motion sensor were indicated by Arrows (→).

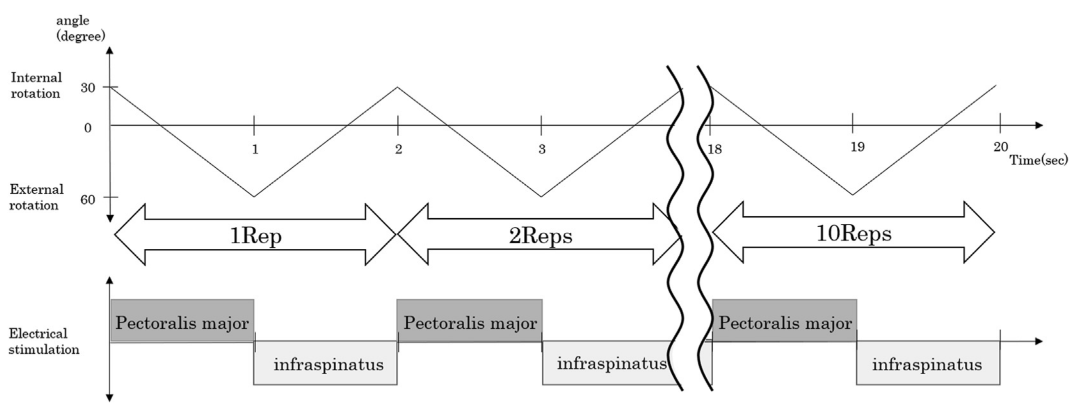

Fig. 2. Procedure of the HTS exercises (1 set consists of 10 reps for a total of 8 sets, 1time/day, 3 day/week, for 6 weeks). Exercises were performed with the subject's pectoralis major muscle electrically stimulated as they volitionally rotated their shoulder outward. The reverse occurred (i.e., the infraspinatus was stimulated) as they volitionally rotated their shoulder inward. The angular velocity of these exercises is 90°/sec. Rep, repetition.

Fig. 3. Measurement of the muscle strength. The peak torque of the external shoulder rotator was measured using an isokinetic dynamometer, in a seated position with the arm in the scapula plane (45° of abduction, 30° of flexion).

eccentric mode with measurement for 60°/sec (ECC60) only, because the exercise load on the muscle was greater than for the concentric mode and a high speed was not recommended [24]. For concentric torque evaluation, five consecutive maximum contractions were executed in the concentric–concentric mode. Movements were performed at an angular velocity of 60°/sec and 180°/sec and a range of motion between 30° internal shoulder rotation and 40° external rotation. For eccentric torque evaluation, five consecutive maximal contractions were executed in the eccentric–eccentric mode. Movements were performed at an angular velocity of 60°/sec and a range of motion between 30° internal shoulder rotation and 40° external rotation. We evaluated the muscle strength before exercise intervention and after the 6-week exercise intervention program.

2.4. Statistical analysis

All variables are presented as means ± standard deviation (SD). Baseline demographics of each intervention group were compared using 2-sample t-tests for continuous variables (e.g. age, muscle strength). We compared the changes from the pre-intervention results within each group using a paired t-test. The Welch's t-test was used to compare changes in measurement values between groups. All the statistical analyses were performed using JMP Version 14.0 statistical software (SAS Institute Inc., Cary, NC, USA) and p values < 0.05 were considered to be statistically significant.

3. Results

There were no dropouts and no adverse events. There were no significant differences in subject's characteristics and baseline anthropometric measurements between groups (Table 1). All

Table 1
Baseline characteristics. (Mean ± SD).

	HTS (n = 10)	EB (n = 10)	P-value
Age (years)	27.8 ± 2.9	27.1 ± 2.7	0.4235
Height (cm)	173.4 ± 4.6	174.8 ± 3.1	0.8495
BMI (kg/m^2)	23.2 ± 2.9	23.2 ± 1.9	0.8498
Peak Torque (Nm)			
CON 60°/sec	24.0 ± 4.9	23.7 ± 5.9	0.7528
CON 180°/sec	15.0 ± 4.2	15.9 ± 7.5	1.0000
ECC 60°/sec	28.8 ± 6.5	30.6 ± 7.2	0.7589

HTS: Hybrid training system, EB: Elastic band, BMI: Body mass index, CON: concentric, ECC: eccentric. P-values are for comparison of groups by 2-sample t-test.

measured values at baseline and follow-up assessment in each group are shown in Table 2. ECC60 in the HTS group significantly increased from 28.8 ± 6.5 Nm pre-training to 36.3 ± 4.1 Nm post-training (p = 0.0007). However, ECC60 in the EB group did not significantly change (p = 0.3133). Furthermore, ECC60 in the HTS group significantly increased more than in the EB group (p = 0.0213). CON60 in the HTS group significantly increased from 24.0 ± 4.9 Nm pre-training to 28.7 ± 3.9 Nm post-training (p = 0.0494). However, CON60 in the EB group did not significantly change (p = 0.6637). Moreover, there was a trend towards a significant difference in increased CON60 between the HTS group and the EB group (p = 0.0677). CON180 in the HTS group significantly increased from 15.0 ± 4.2 Nm pre-training to 21.0 ± 3.2 Nm post-training (p = 0.0150). However, CON180 in the EB group did not significantly change (p = 0.8589). Furthermore, CON180 in the HTS group significantly increased more than in the EB group (p = 0.0358).

4. Discussion

Results of this study showed that HTS resulted in greater increased muscle strength of the shoulder joint rotator cuff than EB did. These results support the possibility that HTS is superior to resistance training with EB for improving rotator cuff function. Furthermore, this study provides evidence supporting the usefulness of HTS as the preferred training method for the inner muscle of the shoulder.

4.1. Rotator cuff physical resistance exercise with EB

In this study, rotator cuff physical resistance exercise with low load EB did not increase isokinetic muscle strength of external rotation. Sugimoto et al. reported that 8 weeks of progressive strength training for young adults with no previous shoulder injury using EB with the shoulder in neutral abduction did not increase the shoulder's isokinetic concentric or eccentric internal or external rotation strength although it did increase isometric muscle strength [25]. Moreover, Treiber et al. reported that rotator cuff physical exercise with both EB and dumbbells (2 pounds) with low load and 90° shoulder abduction (3 × 10 reps, 1time/day, 3 day/week, for 3 weeks) did not increase muscle strength of external rotation in tennis players [26]. Low load with concentric exercise is generally used for rotator cuff physical exercise [5,19], but the muscle strengthening effect is insufficient according to many previous reports [27] and this is confirmed in this study. We were unable to make a suggestion as to why muscle strength didn't improve using EB as neurological mechanisms were not investigated in this study.

4.2. Selective electrically enhanced eccentric exercise of inner muscle

HTS would have a distinct advantage as an electrically enhanced eccentric exercise. Generally, 60°/sec in the isokinetic muscular strength is said to be a standard muscle output to generate sufficient compressive force in a low speed test, and 180°/sec is a standard speed for muscular strength at the high function speed for work efficiency and stamina in a medium–high speed test. For shoulder lateral rotation, this is thought to be an index of the deltoid for outer muscle-based exercise at the low speed and an index of the infraspinatus for inner muscle-centered exercise at the medium–high speed. We can speculate that we were able to strengthen the rotator cuff effectively using HTS on the infraspinatus muscle, which is an inner muscle because HTS increased approximately 50% of external rotation muscular strength at 180°/sec (at the medium–high speed). This may be the result of the infraspinatus muscle being trained by electrically stimulated eccentric contractions selectively with HTS.

HTS would have another advantage as NMES, regarding selective electrically eccentric exercise. Previous reports, regarding eccentric training of shoulder musculature for the management of shoulder pain, refer to the shoulder abductors [11]. None of these reports of exercise protocols have targeted only the external rotators. Exercise protocols consisting of shoulder abduction may exacerbate an existing abnormal deltoid to rotator cuff muscle imbalance, accentuating one of the causes of shoulder pain [11]. Thus, HTS may have benefits for improving shoulder function by the selective electrically induced eccentric exercise of the inner muscle without the patient's volitional movement. In this way, HTS might be a more useful eccentric exercise method to improve rotator cuff function than EB which has been the main conventional training. In a future study, it is necessary to evaluate the effect of HTS on clinical shoulder disorders.

4.3. Benefit of combined electrical stimulation and volitional contractions

Reinold et al. reported a benefit of combining isometric training with NMES as shoulder external rotation strength was increased about 22% after shoulder rotator cuff repair [28]. HTS caused an increase of about 20% of CON60, about 26% of ECC60 and about 40% of CON180 of external rotation strength of the shoulder joint in this study. HTS utilized electrically stimulated eccentric muscle

Table 2
External rotation strength (Mean ± SD) changes in outcome measures from baseline to 6-week follow-up.

	HTS	EB	P-value Comparing Groups
Peak Torque (Nm)			
ECC 60°/sec	Δ7.5 ± 4.7 (P = 0.0007)[a]	Δ1.8 ± 5.3 (P = 0.3133)[a]	0.0213[b]
CON 60°/sec	Δ4.7 ± 6.5 (P = 0.0494)[a]	Δ-0.9 ± 6.3 (P = 0.6637)[a]	0.0677[b]
CON 180°/sec	Δ6.0 ± 6.0 (P = 0.0150)[a]	Δ0.3 ± 5.2 (P = 0.8589)[a]	0.0358[b]

HTS: Hybrid training system, EB: Elastic band, CON: concentric, ECC: eccentric.
[a]P-values between baseline and follow-up were calculated by the paired t-test.
[b]P-values the changes of measurement values between groups were calculated by the Welch's t-test.

contractions which produce an eccentric contraction that is about 50% stronger than its concentric counterpart [29]. In addition, there is a further advantage in combining electrical stimulation and volitional contractions. HTS could add an exercise load on the subscapularis muscle which is the strongest internal rotation muscle. This is achieved by the volitional concentric muscle contractions against the electrically stimulated eccentric muscle contractions of the external rotation muscle (infraspinatus muscle) although NMES using the surface electrode does not easily cause the deep muscle to contract. Moreover, electrically stimulated contractions of musculus pectoralis major which is the second strongest internal rotation muscle would be appropriate resistance to the antagonist of the shoulder's external rotation muscle because the internal rotation muscle is approximately 1.5 times stronger than the external rotation muscle [30]. In other words, HTS might provide appropriate resistance to sufficiently activate the inner muscle while minimizing outer muscle activity performed as internal and external rotation exercise in the shoulder joint.

4.4. Limitations

There are several potential limitations in this study. Primarily, the sample size would be insufficient even if this was an exploratory study. A future study with a bigger sample size is necessary. Next, the intervention period might be too short, although the 6-week training intervention may be sufficient to cause neural adaptation. In addition, it is necessary to evaluate the muscles morphologically. Besides, a study of clinical patients in consideration of age or gender will be necessary in the future because the subjects of this study were limited to healthy men.

5. Conclusion

The results of this study support a conclusion that HTS, which utilizes a combination of electrically eccentric contractions with voluntary concentric contractions, is more effective for increasing external rotator muscle strength than EB.

Author disclosures

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Declaration of competing interest

There is no conflict of interest.

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