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Original Article

Effect of Resistance Training Maintaining the Joint Angle-torque Profile Using a Haptic-based Machine on Shoulder Internal and External Rotation

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Abstract. [Purpose] The aim of this study was to present an individualized resistance training method to enable exercise while maintaining an exercise load that is set according to an individual's joint angle-torque using a haptic-based resistance training machine. [Methods] Five participants (machine group) performed individualized shoulder internal and external rotation training with a haptic resistance training machine, while another five participants performed general dumbbell-based shoulder internal and external rotation training for eight weeks. Internal and external rotation powers of subjects were measured using an isokinetic machine before and after training. [Results] The average powers of both shoulder internal and external rotation has been improved after training (25.72%, 13.62%). The improvement in power of external rotation in the machine group was significantly higher than that in the control group. [Conclusion] This study proposes a haptic-based individualized rotator cuff muscle training method. The training protocol maintaining the joint angle-torque profile showed better improvement of shoulder internal/external rotation than dumbbell training.
Key words: Rotator cuff, Haptic machine

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INTRODUCTION

Rotator cuff diseases are some of the most common musculoskeletal diseases among adults, occurring frequently in both the young and the old[1)]. There are various causes and symptoms of rotator cuff diseases, and it is important to implement treatments appropriate for each case. As one ages and the rotator cuff weakens or tears, it becomes harder to prevent rotator cuff diseases from occurring[2)]. However, various studies have proposed methods to prevent these symptoms through rotator cuff muscle training exercises[3–6)].

The patterns of maximum torque and muscle activity for a given joint angle and velocity are different for each person. Existing resistance training machines assume the general hill type muscle model to produce a cam shape that keeps muscle activation consistent during the exercise process and appropriate for these patterns. However, there is a limit to maintaining the muscle activity using a cam shape[7)]. West et al. and Carignan et al. proposed a training machine that enables exercise that satisfies the individual user's patterns of joint torque and muscle activation using a haptic device[8, 9)]. When a haptic device is used, the individual user's patterns can be measured and registered using a force sensor, and the exercise load can be adjusted to maintain the muscle activity at a steady level throughout the exercise process. In fields such as rehabilitation, in which exercise customized to the individual user is especially effective, various uses of exercise machines using haptic devices have been attempted[10)].

Because it is hard to effectively train the target muscles in a proper posture using dumbbells unless the user is experienced in performing resistance training with them, training using machines is advantageous for beginners. Shoulder joint rotator cuff training exercise is necessary for athletes who actively use their rotator cuffs, such as professional golfers, but it is also necessary for the middle-aged and older populations who suffer from diseases such as frozen shoulder or who want to prevent such diseases. It is difficult

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for this population to maintain a correct posture during rotator cuff exercises using dumbbells or cables without some help of an assistant. However, except for expensive isokinetic machines, resistance training machines for rotator cuff exercise that are not easily accessible at general fitness centers. Even the rotator cuff training exercises suggested by past studies include many routines that use dumbbells or a resistance band or cable[3]. The present study proposed an individualized resistance training method to enable exercise while maintaining a workload that is set according to an individual's joint angle-torque using a haptic-based resistance training machine.

SUBJECTS AND METHODS

This study was used to develop a haptic-based resistance training machine that enables exercise using a 2-D arbitrary path and then used the machine for rotator cuff muscle training. Figure 1 shows the haptic-based resistance training machine and controlling software[11]. Haptic-based resistance training machines enable exercise and measurement of 2-D force using two electric motors and a force sensor, and can apply resistance in an arbitrary 2-D direction. This makes it possible to measure and record an individual user's exercise trajectory and force profile, and to apply a dynamic exercise load according to a predefined exercise trajectory (PDET) and location appropriate for each user by position-based impedance control[11]. By using this haptic-based resistance training machine, the user can exercise with a subject-specific dynamic exercise load.

The experiment was conducted on ten subjects to verify the effects of exercise using the haptic-based resistance training machine for rotator cuff muscle training. The recruited subjects were Korean males in their twenties who had no history of shoulder injury and who had no professional experience in weight training in the year before the experiment (24.9±1.7 ages, 174.4±4.6 cm, 67.3±8.5 kg). Before the start of the experiment, the subjects were given a full explanation of the purpose and experimental procedure, and signed Institutional Review Board consent forms to comply with the ethical standards of the Declaration of Helsinki (1975, revised 1983). They were not allowed any exercise that could affect the rotator cuff during the training period (e.g., tennis, baseball, golf). Subjects were placed in two groups at random. The machine group consisted of five subjects who performed rotator cuff training exercises using the haptic-based resistance training machine developed in this study, and the control group consisted of five subjects who performed standard rotator cuff training exercises using dumbbells.

Before starting training, each subject's 1 repetition maximums (1 RMs) of internal rotation and external rotation were measured. For both groups, 1 RM was measured using dumbbells. In the case of the control group, 20 RM, which was calculated based on 1 RM, was set as the load for the training[12, 13]. In the case of the machine group, an individual's exercise trajectory and force-velocity-angle curve were determined in an isokinetic manner using the haptic device, and was then applied to the haptic-based training machine

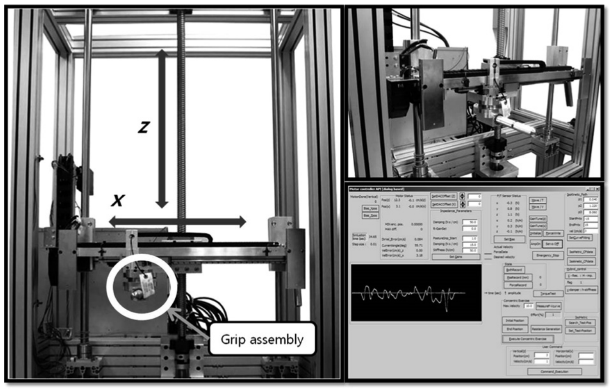

Fig. 1. Haptic-based resistance training machine and the controlling and measurement software

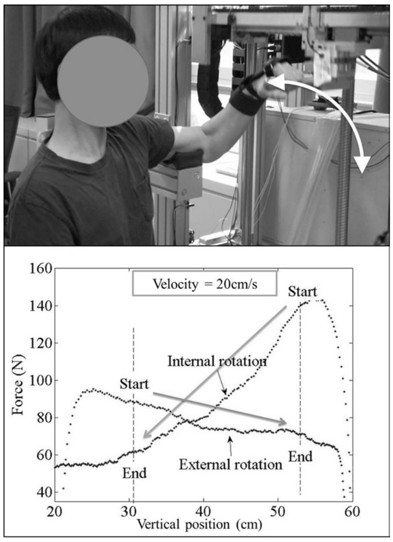

Fig. 2. External/internal rotation exercise using a haptic-based resistance training machine (upper) and force profiles of external/internal rotation measured by a haptic-based resistance training machine (lower)

to set the load pattern for training. The training load pattern for each subject was set to 20 RM by scaling down the angle-force profile.

Training was conducted over an eight-week period, and each exercise session lasted about one hour and was performed twice per week. The machine group anchored their upper arm to the support of the haptic device while sitting in a chair, as shown in Fig. 2, and executed internal and external rotation motions. A pair of internal rotation and external rotation motions was counted as one repetition, and five sets of twenty repetitions were executed. The control group executed internal and external rotation motions using dumbbells while lying on their sides, as shown in Fig. 3. Five sets of twenty repetitions each of internal and external

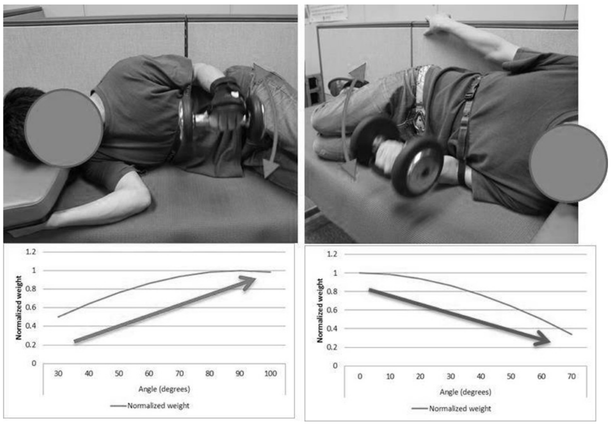

Fig. 3. External (left)/ internal (right) rotation exercise using dumbbells (upper) and force profiles with respect to shoulder rotation angle (lower)

Table 1. Summary of the progress in average power of external rotation

External rotation			
Average power (watts)			
	Pre	Post	Progress %
Sub1	16.4	19.4	18.29
Sub2	14.3	17.8	24.48
Sub3	16.7	19	13.77
Sub4	15.2	22.8	50.00
Sub5	15.4	18.8	22.08
Sub6*	18.4	20.2	9.78
Sub7*	12.2	14.3	17.21
Sub8*	13.7	15.1	10.22
Sub9*	12.3	12.8	4.07
Sub10*	19.3	19.8	2.59
Progress of average power of machine group % (SD)			25.72 (14.16)
Progress of average power of control group % (SD)			8.77 (5.80)

* Control group

Table 2. Summary of progress in average power of internal rotation of internal rotation

Internal rotation			
Average power (watts)			
	Pre	Post	Progress %
Sub1	31.2	35.2	12.82
Sub2	25.9	26.5	2.32
Sub3	28.9	32.9	13.84
Sub4	29.8	40.5	35.91
Sub5	34	35.1	3.24
Sub6*	38.2	40.2	5.24
Sub7*	27.6	28.7	3.99
Sub8*	25.9	30.3	16.99
Sub9*	22.8	25.1	10.09
Sub10*	34.4	35.4	2.91
Progress of average power of machine group % (SD)			13.62 (13.53)
Progress of average power of control group % (SD)			7.84 (5.80)

* Control group

rotations were executed.

To evaluate the exercise performance of the shoulder joint rotator cuff before and after training, the average powers of the shoulder internal and external rotation motions were measured with a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA) on a scapular plane[14–18]. The one-way ANOVA test was used to compare average power progresses between the two groups.

RESULTS

The average powers of shoulder internal and external rotation were increased after eight weeks training for both groups. Tables 1 and 2 show the results of training. In the machine group, the mean average power of external rotation increased 25.7% and mean average power of internal rotation increased 13.6%. In the control group, the mean average power of external rotation increased 8.77%, while that of internal rotation increased 7.84% In the case of external rotation, there were significant differences in mean average power progress between the two groups ($p<0.05$), while that of internal rotation did not show any significant difference.

DISCUSSION

Comparison of the average power before and after training indicates that shoulder external rotation training using the haptic-based resistance training machine has a larger impact than conventional training using dumbbells In the case of internal rotation, however, haptic-based training and dumbbell-based training show similar progresses on average power. The differences in average power progress of external rotation between the groups are due to the difference in the joint angle-torque profiles when engaged in exercise using dumbbells as opposed to exercise using haptic-based resistance training. Each subject's joint angle-torque profile was measured as shown in Fig. 2, and the resistance of the haptic device was determined based on this measurement. In contrast, in the case of the control group, the exercise load was determined by the weight of the dumbbell and the influence of gravity for each joint angle as shown in Fig. 3. In the case of internal rotation, there was no substantial difference in the impact of the training sessions because the joint angle-force profiles for the machine group and control group showed similar tendencies. However, in the case of external rotation, the profiles exhibited opposite tendencies, as shown in Fig. 3, and this was consistent with the finding that the machine group showed a greater improvement in exercise performance by maintaining consistent muscle activation throughout the exercise. Many previous studies mentioned the effectiveness of a training load considering the joint angle-torque relationship in elbow or knee joint exercises[7, 11, 19].

There were some limitations of this study. The number of subjects was limited, because we had only one haptic device and only one subject could use the device at a time. To clarify the effects of haptic resistance training, studies with more subjects using haptic devices will be needed in the future. This study focuses on the effect of resistance training in the beginners; however, the results cannot be applied to older people who need to train rotator cuff muscles, because the subjects who participated in this study were young, with the mean age being only 24.9.

This study proposes a rotator cuff muscle training exercise using a haptic-based resistance training machine. In the case of existing rotator cuff training exercises using dumbbells, cables, or rubber bands, it is difficult for beginners or older subjects to effectively train the target muscles because it is difficult to assume the appropriate postures without assistance. In the case of the haptic-based resistance training, every subject could effectively train in a stable posture without assistance, as the machine guides the exercise trajectory and direction of the force. Furthermore, the impact of exercise can be expected to be the same as, or greater than, that of the standard rotator cuff training exercise because the muscle activation levels are kept relatively consistent during the exercise process.

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REFERENCES

1) Yamaguchi K, Ditsios K, Middleton WD, et al.: The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am, 2006, 88: 1699–1704. [Medline] [CrossRef]
2) Milgrom C, Schaffler M, Gilbert S, et al.: Rotator-cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J Bone Joint Surg Br, 1995, 77: 296–298. [Medline]
3) Kuhn JE: Exercise in the treatment of rotator cuff impingement: a systematic review and a synthesized evidence-based rehabilitation protocol. J Shoulder Elbow Surg, 2009, 18: 138–160. [Medline] [CrossRef]
4) Reinold MM, Wilk KE, Fleisig GS, et al.: Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J Orthop Sports Phys Ther, 2004, 34: 385–394. [Medline] [CrossRef]
5) Jung J, Cho K, Yu J: Effects of scapular stabilizing exercise in patients with partial-thickness rotator cuff tear. J Phys Ther Sci, 2012, 24: 1173–1175. [CrossRef]
6) Kim K, Kim HD, Han JT: Effects of the shoulder horn and lightweight dumbbell training on shoulder external rotators. J Phys Ther Sci, 2008, 20: 239–242. [CrossRef]
7) Folland J, Morris B: Variable-cam resistance training machines: do they match the angle - torque relationship in humans? J Sports Sci, 2008, 26: 163–169. [Medline] [CrossRef]
8) West AA, Smith JD, McLeod CS: Development and initial evaluation of a smart resistance training system. Proc IMechE Part P, 2009, 223: 31–47.
9) Carignan RC, Jonathan T: A haptic control interface for a motorized exercise machine. IRCA 2008, Pasadena, CA, USA, 2008: 2055–2060.
10) Patton JL, Kovic M, Mussa-Ivaldi FA: Custom-designed haptic training for restoring reaching ability to individuals with poststroke hemiparesis. J Rehabil Res Dev, 2006, 43: 643–656. [Medline] [CrossRef]
11) Park JW, Kim KN, Hong DH: Haptic-based resistance training machine and its application to biceps exercises. Int J Prec Eng Manuf, 2011, 12: 21–30. [CrossRef]
12) Brzycki M: A practical approach to strength training. McGraw-Hill, 1998.
13) LeSure DA, McCormick JH, Mayhew JL, et al: The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. J Strength Cond Res, 1997, 4: 211–213.
14) Walmsley RP, Szybbo C: A comparative study of the torque generated by the shoulder internal and external rotator muscles in different positions and at varying speeds. J Orthop Sports Phys Ther, 1987, 9: 217–222. [Medline] [CrossRef]
15) Smith K, Padgett DJ, Kotajarvi BR, et al.: Isokinetic and isometric shoulder rotation strength in the protracted position: a reliability study. Isokinet Exerc Sci, 2001, 9: 119–127.
16) Kuhlman JR, Iannotti JP, Kelly MJ, et al.: Isokinetic and isometric measurement of strength of external rotation and abduction of the shoulder. J Bone Joint Surg Am, 1992, 74: 1320–1333. [Medline]
17) Chandler TJ, Kibler WB, Stracener EC, et al.: Shoulder strength, power, and endurance in college tennis players. Am J Sports Med, 1992, 20: 455–458. [Medline] [CrossRef]
18) Ferri A, Scaglioni G, Pousson M, et al.: Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. Acta Physiol Scand, 2003, 177: 69–78. [Medline] [CrossRef]
19) Dalleau G, Baron B, Bonazzi B, et al.: The influence of variable resistance moment arm on knee extensor performance. J Sports Sci, 2010, 28: 657–665. [Medline] [CrossRef]