Effect of remote aftereffects of resistive static contraction of the pelvic depressors on improvement of restricted wrist flexion range of motion in patients with restricted wrist flexion range of motion

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ABSTRACT

The objective of the study was to compare the effects of remote aftereffects of resistive static contraction of the pelvic depressors (RSCPD) with aftereffects of static contraction of upper extremity muscles (SCUE) on improvement of the maximal active range of motion (MAROM) for patients with restricted wrist flexion range of motion (ROM) due to upper limb pain and dysfunction. The participants were 10 outpatients with restricted wrist joints. The mean (SD) age was 53.7 (4.4) years (range, 34–81). The subjects performed two exercise protocols (SCUE and RSCPD) in random order. One-way repeated measures ANOVA showed significant main effects in evaluation of the change in MAROM and IEMG activities for different conditions (after rest, after SCUE, and after RSCPD). The remote aftereffects of RSCPD, but not those of SCUE, caused significant improvement in MAROM for restricted wrist flexion ROM.

KEYWORDS: PNF; Pain; Remote aftereffect; Active range of motion; Resistive static contraction; Pelvic depressors
INTRODUCTION

Deficits in maximal active range of motion (MAROM) may be caused by several factors, including muscle weakness, pain, muscle spasm, and soft-tissue tightness, all of which have been reported following injury and in association with osteoarthritis (Bearne et al. 2002; Povlsen & Rose 2008). After injury, muscles that cross multiple joints or have complex architectures are weaker and at risk for further injury (Garrett 1996). If direct approaches to improve MAROM and strengthen the agonist muscles of restricted joints are difficult because of pain or weakness of agonist or antagonist muscles, indirect therapy may also be useful to improve the restricted joint in an indirect neurorehabilitation procedure (Arai & Shiratani 2012a; Arai et al. 2012b).

Wilson et al. (1995) found that the aftereffect of a static contraction (SC) on the mean afferent spindle discharge rate was 65% higher than the mean precontraction discharge rate. In the cat, monosynaptic excitation by muscle spindle Ia afferents from a given muscle is not distributed exclusively to the α-motoneurons of the muscle (homonymous projections), but also reaches the pools of motoneurons of other muscles (heteronymous projections) acting synergistically at the same joint or at different joints (Marchand-Pauvert et al. 2000). The heteronymous connections described to date in the human upper limb involve wrist-to-elbow muscles (Cavallari & Katz 1989; Mazevet & Pierrot-Deseilligny 1994) and might help provide proximal support for distal movements. The mechanical contributions of these sources of stiffness vary under different functional conditions, such as joint position and voluntary contraction level (Mirbagheri et al. 2001).

Muscle activity is also not restricted to the target muscle, with activity observed in both ipsilateral and contralateral (non-target) muscles during strong unilateral contractions (Post et al. 2008). The ascending effects of resistive exercises on remote muscle activities may depend on the type of exercise (Borroni et al. 2004; Cerri et al. 2003). Compared with the aftereffect
of a weak SC with a neutral shoulder joint position, the aftereffect of an SC of an upper extremity (SCUE), such as a strong SC of the intrinsic hand muscles performed with a diagonal shoulder joint position, significantly influenced improvement in MAROM of wrist flexion in normal volunteers, and this aftereffect correlated with wrist agonist/antagonist surface integrated electromyographic (IEMG) activities (Arai et al. 2012b).

Facilitation of trunk control is also used to influence extremities (Knott & Voss 1969). One proprioceptive neuromuscular facilitation (PNF) activity used during treatment is manual resistance to directed pelvic motion of posterior depression (Trueblood 1989). In particular, a remote aftereffect of resistive static contraction of the pelvic depressors (RSCP) in the mid-range of pelvic motion while lying on the side increases the flexibility of remote body parts, such as the upper shoulder (Arai et al. 2012a). Compared with the static stretch group, the RSCP group showed a significant improvement in AROM of the shoulder joint in patients with rotator cuff tears (Arai et al. 2012a). Application of this technique may be effective for indirect treatment of extremities that cannot be directly exercised because of pain.

The effect of the RSCP technique for patients with restricted wrist flexion ROM due to upper limb pain and dysfunction has not been reported. Thus, the objective of this study was to examine the difference in remote aftereffects of RSCP compared to SCUE for improvement of MAROM for restricted wrist flexion ROM.

**METHODS**

**Participants**

The participants were 10 outpatients (2 males, 8 females) with restricted wrist joints and no history of upper motoneuron diseases who were referred by an orthopedist for improvement of ROM of the upper extremity, including the wrist joints. The patients were
randomly selected from 25 outpatients. The mean age (standard deviation, SD) was 53.7 (4.4) years (range, 34–81 years). The exclusion criteria included any other orthopedic disorders and any neurological disorder within the last year that required medical attention. All patients gave written informed consent.

All patients had pain during movement and restricted wrist motion relative to that of the unaffected side. The MAROM may be restricted by upper limb pain and dysfunction. The time since onset of impairment varied from 9 weeks to 10 years. The patients had primary diagnoses of fractures of the radius and ulna, fracture of the radius, surgical neck fracture of the humerus, rheumatoid arthritis, carpal tunnel syndrome, and tenosynovitis of the flexor-tendon sheath of the index finger. MAROM of wrist flexion was measured on the more affected side (left, 9; right, 1). At the beginning of the study, the patients presented with stiff and mildly swollen wrists. No patient had knowledge of which exercise pattern might be more effective for improving MAROM of the wrist joint.

Experimental design

Each subject learned each SC method sufficiently well before the start of the study to allow performance of the activity alone. Because experienced therapists may have a bias toward certain therapeutic methods that may influence the outcome, the experiments were performed by two well-trained physical therapy students. The two students who performed the assessment had been in our program for 4 weeks and received training in the specific experiments for 2 weeks.

The effects of order were controlled by randomly assigning numbers taken from a table of random numbers for the order of the SC conditions (SCUE, RSCP) for each patient. Prior to data collection, subjects sat for 5 min to relax. After resting, the subject performed each exercise for 2 s (Fig. 1). The forearm attachment was supported during each SC by a
researcher. Each SC condition was separated by a 60-s rest period.

SCUE involved performing strong SCs of the intrinsic hand muscles with a diagonal shoulder joint position (shoulder flexion = 135°, adduction = 45°; Fig. 1(a)). The pinch-force target strengths spanned a range of 70-80% for maximal voluntary contractions (strong pinch), as measured by a pinch meter.

RSCPD for inducing SCs of the lower trunk was applied by the researcher. With elbows locked in extension, the researcher placed hands over the subject’s upper ischial tuberosity while standing behind the subject (Fig. 1(b)). The researcher then applied manual resistance over the upper ischial tuberosity in the direction toward the medial sacral crest. The amount of resistance provided by the researcher depended on the strength of the pelvic depressor and was between 2 and 3 kg. Prior to the study, intrarater reliability was assessed for the RSCPD force by determining the intraclass correlation coefficient (ICC) for 20 s at random points. The RSCPD resistance force was measured using a pinch meter over the ischial tuberosity. The reliability of resistance from 4 trials of RSCPD was determined by performing two-way analysis of variance (ANOVA) to derive an ICC. The ICC of the RSCPD force was 0.95 [95% confidence interval (CI), 0.86–0.99], indicating a high reproducibility of resistance.

Instruments and apparatus

An electrogoniometer (Penny & Giles, Blackwood, Gwent, U.K.) placed laterally across the affected wrist joint was used to measure MAROM of wrist flexion. Two pairs of disposable surface EMG electrodes (blue sensor, type N-10-F; Medicotest, Denmark) with a center separation of 15 mm were attached to the skin surface of the muscle bellies of the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) muscles. All data collection devices were electronically synchronized via a BNC connector to the Noraxon Myosystem 2000 EMG systems (EMG system) (Fig. 2) to facilitate synchronous collection of EMG
signals and goniometer voltage, so that the relationship between the EMG amplitude and MAROM of wrist flexion over a 1-s static phase of flexion could be determined (Fig. 3). The skin was cleaned and shaved, and alcohol was used to remove dirt, oil, and dead skin to lower the impedance to <1 kΩ at the recording site. The electrogoniometer was calibrated with each patient’s wrist resting in an anatomically neutral position. A pinch meter (Yaesu Corp., Tokyo, Japan) was used to measure pinch strength.

**Measurement of MAROM**

After each SC, MAROM for wrist flexion was maintained for >1 s with the arm at the side and neutrally rotated, while the forearm and wrist were held in the neutral position. The forearm attachment was supported by a researcher. Each SC condition was separated by a 60-s rest period.

**Parameters**

The change of MAROM of wrist flexion after SC was calculated by subtracting MAROM before SC from MAROM after SC. This calculation was performed to normalize the change in MAROM to allow an examination of the change in the ROM (Häkkinen et al 2010). The associated surface EMG activities during MAROM for wrist flexion maintained for 1 s (Fig. 3) were normalized by dividing the EMG values by those obtained during maximum voluntary contraction performed before the start of each trial. This normalization allowed the EMG activity for each muscle to be described using a value between 0 and 1.

**Reliability of parameters**

A pilot study was conducted to determine the reliability of measurement of MAROM of wrist flexion and IEMG based on the ICCs for 5 patients. ICC (1,1) for MAROM was 0.96 (P
= 0.000), indicating high reproducibility. ICC (1,1) was 0.86 (P = 0.000) for IEMG of the FCR muscle measured during MAROM of flexion and 0.73 (P = 0.000) for ECR, indicating that the IEMG and MAROM measurements in this study were both reliable.

**Statistical analysis**

SPSS ver. 21.0 for Windows (IBM Corp., Somers, NY) was used to perform all statistical analyses. One-way repeated measures ANOVA, followed by Bonferroni pairwise comparisons, was used to test the significance of variance of changes in MAROM and IEMG activities due to differences in conditions (after rest, SCUE or RSCPD). Relationships between changes in MAROM and IEMG of the FCR and ECR muscles were determined using Pearson correlation analysis. Pearson product moment correlation coefficients were used to evaluate correlations. The level of significance was set at P < 0.05.

**RESULTS**

Means and SDs of change in MAROMs and IEMG for the FCR and ECR muscles are shown in Table 1. One-way repeated measures ANOVA for changes in MAROM showed significant main effects [F (2,18) = 9.17, P = 0.02, η² = 0.95]. A Bonferroni post-hoc test revealed a significant difference only between after rest and after RSCPD conditions (P = 0.004), reflecting a greater change in MAROM after RSCPD (Fig. 3). This was not found in one-way repeated measures ANOVA for IEMG of the FCR [F (2,18) = 1.6, P = 0.23, η² = 0.29] and ECR muscles [F (2,18) = 0.38, P = 0.69, η² = 0.10]. There was no significant correlation between IEMG and changes in CR-MAROM (Table 1). Pearson correlation analysis showed no correlations between improvement of MAROM and IEMG activities.

**DISCUSSION**
This study showed that the remote aftereffect of RSCPD caused a significant improvement in MAROM in this study. The sample size was small, but the effect size was large (\(\eta^2\) value is 0.95). Effect sizes are resistant to sample size influence, and thus provide a truer measure of the magnitude of an effect between variables (Ferguson et al, 2009). However, the hypothesis that facilitation of the agonist for improving MAROM of the wrist joint by RSCPD was not supported because of a non-significant correlation between IEMG activity and changes in MAROM. IEMG may be useful as a measure of voltage associated with recruitment of motor units, which allows estimation of the number of motor units firing and the firing frequency (Schmitz & Westwood 2001). However, IEMG activities failed to explain the significant increases in MAROM of the wrist joint as a remote aftereffect of RSCPD in this study.

Intrinsic stiffness, which arises from muscle fibers and from surrounding connective tissues, or slackness of the intrafusal muscle fibers at a given time is highly dependent on the immediate previous history of movements and contractions (Hagbarth & Nordin 1995). The central nervous system has a prominent role in muscle stiffness (Milner et al 1995) and pain (Tinazzi et al 2000; Zanette et al 2004). Disuse atrophy by immobilization also decreases muscle strength, which may be due to impairments in central neural activation and changes in the functional properties of the central nervous system (Sale 1988). Pain caused by orthopedic diseases or upper limb immobilization also induces extensive neuroplastic reorganization (Tinazzi et al 2000; Zanette et al 2004). Because of the non-significant correlations between IEMG activity and changes in MAROM, deficits in MAROM in this study may reflect peripheral factors, including stiffness and muscle atrophy; as well as central factors, including impairments in central neural activation and/or pain.

The remote aftereffect of RSCPD may influence the muscular recruitment pattern and the role of the central nervous system by changing neuroplastic reorganization and/or modulating
decreases in pain. The remote ascending effects of RSCPD are time-course dependent based on post-hoc analysis (Arai & Shiratani 2012c). This analysis and a third-order polynomial equation revealed that the ascending effects induced by RSCPD on the FCR H-reflex caused large reflexive inhibition during RSCPD, followed by gradual excitation after RSCPD, which may be referred to as a “remote rebound effect”. Thus, RSCPD may be a specific exercise for inducing a remote rebound effect. These reflexive reactions indicate how RSCPD may cause improvement of MAROM in the upper extremities. Temporary profound inhibition occurred during RSCPD in reduction of the FCR H-reflex, which may decrease muscle stiffness and allow more muscle compliance or decrease of pain. In the second phase of the remote rebound effect (Arai & Shiratani 2012c), the gradual facilitation observed in remote upper extremities following RSCPD may reflect increased recruitment of agonist motor units and/or decreased recruitment of antagonist motor units, thereby subsequently improving the upper extremity MAROM. Thus, application of RSCPD may be an effective approach for indirect treatment of extremities that cannot be directly exercised. Inhibition or facilitation of the FCR H-reflex by RSCPD will provide physiological evidence of the remote effect of RSCPD.

Triggering of aftereffects during and after RSCPD may be correlated with activation of load receptors of central pattern generators, which can determine the choice of an appropriate coordinated pattern according to proprioceptive input from muscles, skin, joints and tendon (Dietz 2002; Duysens et al 2000). The RSCPD force magnitude was between 2 and 3 kg in this study. Efficient remote aftereffects to improve MAROM may be dependent on the degree of proprioceptive information generated by the activation of load receptors and the strength of an SC. However, the magnitude of force necessary to facilitate remote aftereffects most efficiently is unknown and further research is needed to identify the optimal magnitude of force. It is also unclear which aftereffect is more effective: the remote aftereffect of a resistive exercise in the mid-range or end-range of pelvic motion of the posterior depression.
Thus, efficient methods to induce remote aftereffects require further investigation.

CONCLUSION

Application of RSCPD may be effective for indirect treatment of extremities. Remote aftereffects of RSCPD may improve MAROM of affected wrist joints in orthopedic patients.
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Fig. 1. Static contractions (SC) of (a) an upper extremity (SCUE) and (b) a resistive SC in the mid-range of pelvic motion of the posterior depression (RSCPD) while lying on the side. *Potential effects of the order in which SCs were performed were controlled by assigning a number from a random table of numbers for the order of the SC conditions (RSCPD and SCUE) for each patient.

Fig. 2. Electromyograph (EMG) and goniometer system. All data collection devices were electronically synchronized via a BNC connector to the Noraxon Myosystem 2000 EMG systems (EMG system).
Fig. 3. Relationship between the EMG amplitude and MAROM of wrist flexion during a 1-s (1000 ms) static phase of flexion.

Table 1. Pearson correlation coefficient between change of MAROM and IEMG activities

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