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A Trial to Evaluate Experimentally Induced Delayed Onset Muscle Soreness and Its Modulation by Vibration

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Abstract: Clinical muscular pain such as stiff neck and lumbago is often treated with massage, stretch, and vibration; however, the effectiveness of these procedures and their action mechanisms remain unclear. We consider it important to quantitatively evaluate the effectiveness of these procedures using experimentally induced muscular pain. Exercise-induced pain has been used as a model of muscular pain. In the present experiment, we used this model to evaluate the effect of vibration, which is used in physical therapy. Muscle soreness was induced by exercise of the upper arm using a weight belt, and changes in the muscle were evaluated using limb circumference, joint angle, strength of muscle soreness, dimensions of muscle and blood flow before and after exercise and vibration. The present exercise protocol induced delayed onset muscle soreness 1 day after exercise. Vibration given immediately and 2 days after exercise widened the limited range of motion, decreased muscle soreness in full flexion and extension positions, increased blood flow in the deep tissues involving muscle and another connective tissues, increased the thickness of subcutaneous tissues, and tended to decrease the thickness of flexors. However, in contrast to our clinical experience, these effects did not last long after vibration. The reason for this might be that the kind of pain was different.

Key words: delayed onset muscle soreness, vibration, human, muscle evaluation

The mechanisms of clinical muscular pain such as stiff neck and lumbago remain insufficiently understood, although this kind of pain is often a chief complaint of patients visiting clinics or hospitals. The affected muscles often have trigger points with locally contracted muscle fibers. Massage and stretch are often used by physical therapists to stretch and relax the shortened or stiff muscle and to relieve pain. However, the effectiveness of these procedures and their action mechanisms are unclear. We consider it important to quantitatively evaluate the effectiveness of these techniques using experimentally induced muscular pain. One such model that has been used in humans and animals is exercise-induced pain. Delayed onset muscle soreness (DOMS) usually occurs 24 to 48 hours after unaccustomed exercise (Smith 1991), especially after eccentric exercise. Such exercise damages the muscle and another connective tissue, and has been shown subsequently to cause inflammatory responses (Armstrong, Warren et al. 1991). However, Nosaka and Clarkson (1996) claimed that the inflammatory responses such as muscle swelling and soreness after exercise were different from those accompanying infection or tissue injury, because none of the plasma levels of inflammatory markers showed significant changes after exercise. Although there is some controversy regarding the mechanism for development of DOMS, as described above, it can be consistently produced; thus, we consider it useful for evaluating the effect of physical therapy. In this experiment we attempted to develop a DOMS model using a weight belt, which is easy to handle and can be used anywhere, and evaluated muscle condition from many aspects. Next, we evaluated the effect of vibration stimulation, which has recently been used for treatment of muscular pain, on changes in the affected muscle. Vibration stimulation was used instead of massage because vibration at low frequency has some common features with massage, and is considered to be more easily quantified than massage done with the hands.

Material and methods

Subject and experimental protocol

The subjects were 24 healthy volunteers (12 males and 12 females), with ages ranging from 19 to 23 years (mean 20.8 years). Each subject gave informed consent. They were ran-

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domly assigned to one of three groups, with the sex ratio kept the same in each group: control group (exercise only), vibration immediately after exercise (early-V group), and vibration 2 days after exercise (late-V group). The subjects lay supine, and a load was placed on the wrist of their non-dominant arm. The weight was adjusted according to the subject's sex (2 kg for women and 3 kg for men). With the weight wrapped around their non-dominant arm, the subjects were instructed to lower the arm from a position of 60 degree to 20 degree elbow flexion over 5 sec, and then to return it to the initial 60 degree flexion position over another 5 sec. This exercise was continued until exhaustion (the subject could no longer perform the movements), and 3 sets with the same load were done with a 5 min rest period between sets. Starting from the 2nd set, when a subject was unable to flex the elbow joint by him- or herself, the experimenter manually assisted the subject in bringing the arm to the flexed position.

Measurement

All subjects underwent the following measurements to evaluate changes in the muscle condition: circumference of the upper arm, range of motion (ROM; arm angles in both directions at elbow joint), muscle perception (soreness and dull sensation), blood flow in deep tissues, and ultrasound images of the muscle. These were measured before and immediately after the exercise, and 2 and 7 days after the exercise. They were also measured after vibration in the two vibration groups. All parameters except muscle perception were measured three times at each time point and data thus obtained were averaged. The circumference of the upper arm was measured at a point approximately one-third of the upper arm length distal from the epicondyle of the humerus, which was marked with a felt-tipped pen. ROM at the elbow joint was measured using a goniometer in flexion and extension. Soreness and dull sensation in the muscle were assessed using a numerical rating scale (NRS) where 0 is no pain or dull sensation and 10 is the strongest pain or dull sensation when the subjects' forearms with the weight (0.5 kg for women and 1 kg for men) were moved actively or passively to the full flexion and full extension positions. Blood flow in the deep tissues was evaluated based on the total hemoglobin (Hb) contents using near infrared spectroscopy (PSA-IIIN, Biomedical Science, Japan). Transverse ultrasound images of elbow flexors were obtained cautiously so as not to compress the tissues (SSA-340A, Toshiba, Japan). Distances from the surface of the humerus and from the skin to the outer surface of flexors were measured on the ultrasound image, and they were denoted as muscle and skin thickness, respectively.

Each measurement was evaluated by a different examiner. All subjects were asked to retrospectively draw a curve presenting the change in pain sensation (NRS) with each day for 1 week after exercise.

Vibration

Eight subjects received vibration at 30 Hz with amplitude of 8.0 mm shortly after all measurements were carried out following exercise (early-V group). Another 8 subjects received vibration after all measurements 2 days after exercise (late-V group). The vibrator (tip diameter 1.8 cm) was pressed on the belly and tendon of the biceps brachii muscle for 20 min in total with a strength that induced no apparent pain.

Data analysis

Data are expressed as mean ± SEM. One way analysis of variance (ANOVA) with repeated measures followed by Bonferroni's post hoc test was used to detect differences in the measures at different time points. The Kraskal-Wallis test was used for comparison among the three groups. Paired t-test was used for the effects of vibration to NRS in each group because NRS was 0 before exercise. Statistical significance was set at $p<0.05$.

The experiment was approved by the committee of Human Research, Research Institute of Environmental Medicine, Nagoya University.

Results

All subjects developed DOMS when examined 2 days after the exercise. Unexpectedly, the retrospective report of NRS with each day revealed that the highest soreness (NRS between 7.5 and 8.8) was experienced 1 day after the exercise, and NRS became lower 1 day later, between 5.4 and 5.5. Recovery from soreness was observed between 3 and 7 days after the exercise, and there were no significant differences in the magnitude of soreness and this time course among the three groups.

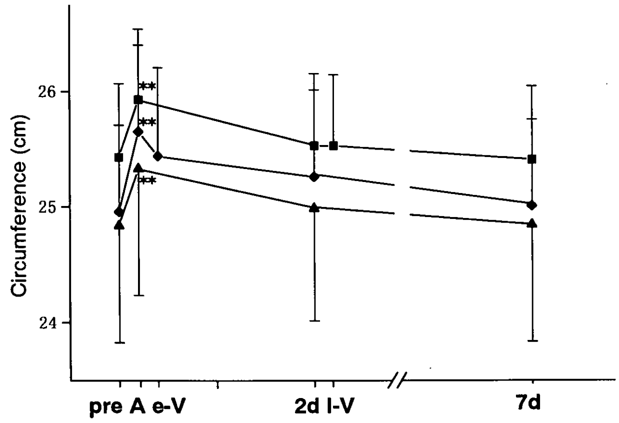

Fig. 1 Change in the circumference of the non-dominant arm. Ordinate: circumference in cm, Abscissa: time. pre: before exercise; **A**: immediately after exercise; **e-V**: immediately after vibration; **l-V**: after vibration 2 days after exercise; and **2d** and **7d**: 2 and 7 days after exercise. Rhombuses: early-V group; squares: late-V group; and triangles: control group. Values are shown as mean±SE. (** $p<0.01$, compared with the values before exercise, Bonferroni's multiple comparison test).

Circumference of the upper arm significantly increased in the two vibration groups after the exercise, but it returned to its original size 7 days after the exercise (Fig. 1). Vibration given either immediately or 2 days after the exercise had no effect on the arm circumference. The control group also showed a small increase in arm circumference, but it was not significant.

The elbow joint angle at maximum flexion decreased significantly after the exercise in all groups (Fig. 2). This angle before the exercise was 150.6 ± 1.8 degrees in the early-V group, 151.9 ± 0.9 degrees in the late-V group, and 150.8 ± 2.0 degrees in the control. After the exercise, it decreased to 74.4 ± 12.5, 83.8 ± 10.7, and 120.8 ± 6.9 degrees, respectively. **The elbow joint angle in maximum extension**, in contrast, tended to decrease immediately after the exercise but a significant decrease was observed only in the late-V group 2 days after the exercise. The vibration after exercise significantly increased these angles (ROM) (p<0.01). Two days after the exercise ROM was almost restored by vibration in the late-V group.

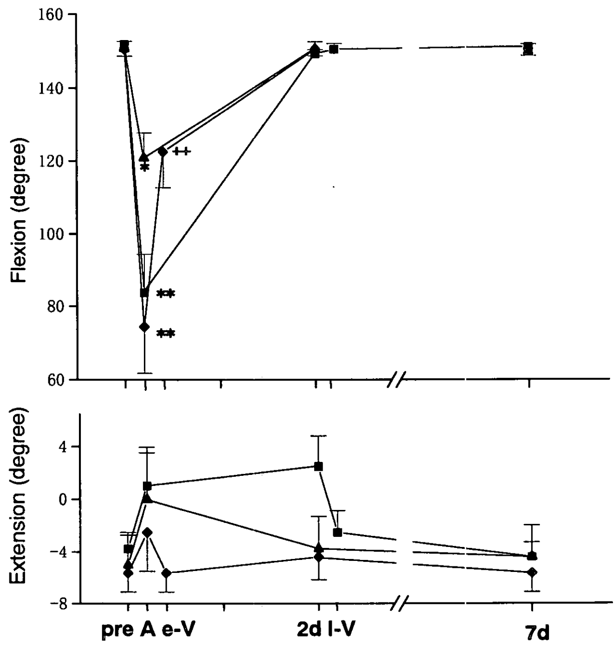

Fig. 2 Changes in the range of motion at elbow joint.
Upper panel shows the elbow angle in flexion and lower panel in extension. The presentation of abscissa is the same as in Fig. 1. The flexion range significantly decreased after exercise in all group (* p<0.05, ** p<0.01). The flexion range significantly increased after vibration in the early-V group (++ p<0.01).

Muscle soreness expressed in NRS in active movement, passive full flexion, and full extension peaked 2 days after the exercise (Fig. 3). Increased values of NRS in passive full flexion and extension were significantly decreased by vibration in the late-V group (p<0.05).

NRS of **dull sensation** in active movement and passive full flexion significantly increased after exercise in all groups. NRS of dull sensation in active movement was significantly decreased by vibration in the early-V group (p<0.05).

Blood flow in the deep tissues tended to decrease after the exercise in all groups, and it significantly increased after vibration in the early-V group (p<0.01).

Exercise did not affect the thickness of subcutaneous tissues that was measured using **ultrasound images**, whereas the thickness was significantly increased after vibration in both the early-V and late-V groups (Fig. 4, p<0.01 and p<0.05, respectively). In contrast, the thickness of flexor muscles of the upper arm became significantly thicker after exercise in all groups (p<0.01), and the thickness reduced again by the same amount 7 days after the exercise in all groups. In the early-V and late-V groups the thickness of flexors tended to reduce after vibration.

Subjects often complained of or reported pain when the exercised muscles were pressed with the vibrator or palpated with the fingers of the examiner. These complaints were less about 10 min after vibration started.

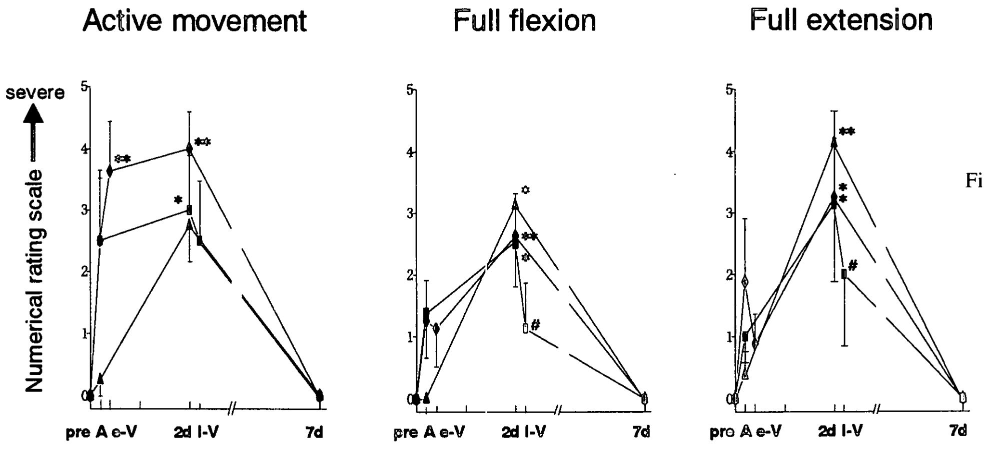

Fig. 3 Change in the soreness sensation of exercised muscle at three conditions. Ordinate: scale of 0 = no pain to 10 = intolerable pain. The presentation of abscissa is the same as in Fig. 1. Peak muscle pain was 2 days after exercise in all groups (* p<0.05, ** p<0.01). Peak muscle pain in full flexion and extension significantly decreased after vibration in the late-V group (# p<0.05, paired-t test).

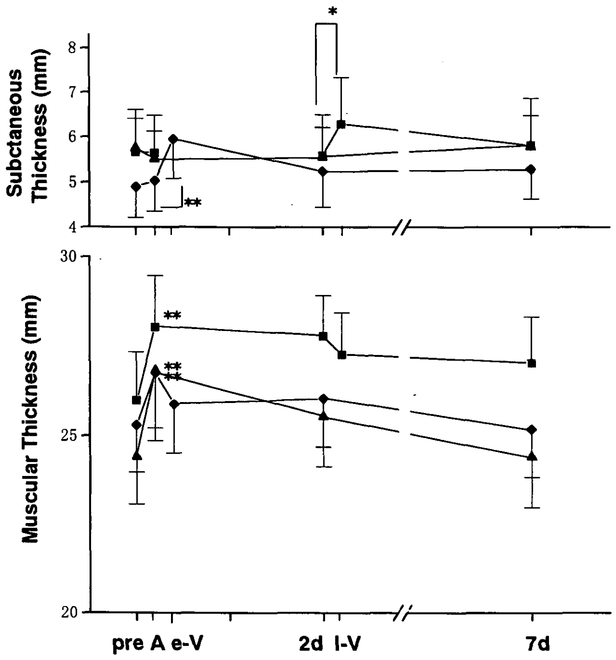

Fig. 4 Changes in the thickness of subcutaneous tissues and flexors. Upper panel: thickness of the subcutaneous tissues. Lower panel: thickness of the flexors. The thickness of flexors increased in all groups after exercise ($p<0.01$). The thickness of subcutaneous tissues was significantly increased after vibration in early-V and late-V groups (* $p<0.05$, ** $p<0.01$).

Discussion

The present study showed that DOMS was induced with the protocol used. Subjects' retrospective reports on soreness revealed that the peak soreness was experienced one day after exercise. Although soreness was not the strongest 2 days after the exercise, the circumference of the upper arm was larger, the extended elbow joint angle was limited and flexors were thicker. Also unexpected was the finding that, although all subjects of both sexes were randomly assigned to one of three groups, ROM was more strongly limited in both the early-V and late-V groups than in the control group, and soreness was also more intensive in these two groups. Subjects who regularly played sport were included in all groups, but they were not always less susceptible to DOMS. To obtain more conclusive results the number of subjects must be increased.

The circumference of the upper arm did not change after vibration in either the early-V or late-V group. This might be because the thickness of flexors decreased while the thickness of subcutaneous tissues increased after vibration.

It is clear that vibration improved ROM. The mechanism underlying the decrease in ROM has not been fully elucidated, but shortening of the connective tissue due to swelling and/or a spontaneous contraction of muscle fibers have been postulated (Clarkson, Nosaka et al. 1992). It has been demonstrated that a decrease of the maximally extended elbow joint angle is also related to increased muscle stiffness (Jones, Newham et al. 1987). It is known that vibration of muscle or tendon activates motoneurons through the tonic vibration reflex, simultaneously inhibiting the phasic myotatic reflexes that involve the motoneurons of the same pool. The Hoffman reflex is reported to be decreased with low frequency vibration (Desmedt and Godaux 1978). The decrease of muscle tone from vibration might have resulted in wider ROM.

Pain in active movement did not change after vibration in either of the vibration groups, but pain in the passively full-flexed and extended positions was reduced after vibration. Muscle tension generated during the active contraction with a weight is larger than that produced by passive movement. The vibration used in this study might have reduced the tension left in the previously exercised muscle, and thus have reduced the total muscular tension during passive flexion/extension below the pain threshold. However, if the tension was not strongly reduced, the total muscular tension during active contraction might have fallen below the pain threshold. For the moment it is not clear whether this is the case, but it would be reasonable to think that the difference in the total tension generated in the muscle during passive/active movement might be related with the difference in the effectiveness of vibration.

The thickness of subcutaneous tissues was significantly increased after vibration; in contrast, the thickness of the flexors tended to decrease after vibration, although this decrease was not significant. This result suggests that muscle swelling was reduced and subcutaneous edema was induced by vibration. Chleboun et al. (1998) reported that muscle stiffness increased immediately after exercise. This stiffness and hyperemia of the muscle are most likely related to muscle swelling. Since muscle tone is considered to be decreased by vibration (Desmedt and Godaux 1978), muscle stiffness and the thickness of flexors would also be decreased. On the other hand the mechanism of the thickening of subcutaneous tissues after vibration is not clearly understood. It might be caused by hyperemia because total Hb contained in the deep tissues increased during and after vibration. Again, the mechanism of this hyperemia is not clear.

In summary, vibration at 30 Hz widened ROM, decreased muscle soreness in full flexion and extension, increased the blood flow under the skin, exercised muscle and another connective tissues, increased the thickness of subcutaneous tissues, and tend to decrease the thickness of flexors. However, different from our clinical experience, these effects did not last long after vibration. This effect lasts a few days at least in the clinical setting. We usually apply vibration stimulation to the back muscles that belong to the same spinal segments as the sore muscles of the upper or lower limbs. Moreover the vibrator is pressed onto the muscle with a strength that induces pain. It may be necessary to use stronger vibration stimulation in the next experiment to produce more long-lasting effects. Moreover, clinical pain may be different from DOMS.

DOMS decreased in 3 and 7 days after exercise even if no treatment was done. Many clinical pains would not get better just by letting the time pass.

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