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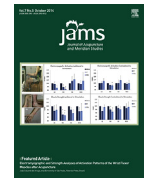

RESEARCH ARTICLE

# Electromagnetic Acupuncture to Enhance the Effects of Manual Acupuncture on Recovery from Muscle Fatigue of the Quadriceps

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**Abstract**
The aim of this study was to investigate a new method of manual acupuncture that used a magnetic field to stimulate only one acupoint vertically. We developed an eight-channel electromagnetic acupuncture (EMA) system that uses a solenoid-type electrode to insert the manual acupuncture needle into a hole in an electrode. We used a manual acupuncture needle for magnetic induction in order to penetrate vertically and deeply into tissues. In order to confirm the usefulness of EMA, we investigated the effects of treatment on muscle fatigue after strenuous knee extension/flexion exercises that had been performed by three groups: the nonstimulation, the manual acupuncture, and the EMA groups. Electromyograms showed that the median frequency (MF) in the EMA group

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had rapidly recovered after 4 minutes ($p = 0.608$), but that the peak torque had not recovered to the normal state ($p < 0.05$). Thus, we confirmed that compared with manual acupuncture, EMA resulted in better recovery from muscle fatigue.

## 1. Introduction

In recent years, there has been increasing interest in clinical research on Traditional Korean Medicine (TKM) [1]. An expanding number of papers reported the treatment effects of manual acupuncture techniques for certain conditions [2]. In order to suggest an objective treatment mechanism for manual acupuncture, many studies were conducted. Effects of manual acupuncture including activation of nerves, internal secretion, and effects on the cerebrospinal fluid were reported [3,4]. Moreover, studies on many different ailments including osteoporosis [5], hyperlipidemia [6], and pain relief [7] have reported on the treatment benefits of manual acupuncture.

To enhance the treatment effects of manual acupuncture, this study suggested a new method using magnetic fields. After a magnetic field penetrates an electric conductor such as the living body, bioelectric currents can generate an eddy current that has an impact on various tissues, such as nerve or muscular tissue, etc. Previous research on magnetic fields reported various treatment effects for fracture, pain relief, arteriosclerosis, Parkinson's disease, and neurological disease [8—12]. In addition, on the basis of the results of proven treatment effects, many studies applied the magnetic fields to the acupoints and also verified the treatment effect [11,12]. The majority of papers used a noninvasive method by applying an electrode that can generate magnetic flux density at the location of an acupoint. Because the generated magnetic flux density decreases geometrically according to the distance from the electrode, the noninvasive method cannot deliver enough stimulation to an acupoint located in the inner part under the subcutaneous tissue. However, it is possible to stimulate only one acupoint, if the manual acupuncture needle inserted into the body or an acupoint can generate magnetic flux density. Therefore, we selected electromagnetic acupuncture (EMA), which uses a solenoid-type electrode that enables insertion of the manual acupuncture needle into a hole as a new stimulus in order to generate the bioelectric current without any external potential interference and to penetrate vertically into the tissues. In order to conduct fundamental research for observing the usefulness of EMA in comparison to manual acupuncture, we developed an eight-channel EMA system and performed a muscle fatigue recovery experiment. We then analyzed the electromyography (EMG) signal.

We selected pulsed electromagnetic fields (PEMFs) to generate the magnetic flux density; this method was reported as an effective treatment for musculoskeletal disorders [13,14]. PEMFs have demonstrated their various treatment effects in many different ways, including microcirculatory effects, skin temperature, motor function recovery, and synthase activity [15—18]. Moreover, various researchers reported that extremely low frequency (ELF) PEMFs ($\leq$300 Hz) induced analgesia. A magnetic flux density of 0.1—0.3 millitesla (mT; 1—3 gauss) within the frequency range from 1 Hz to 4 Hz was widely used to treat acute orthopedics [19].

To compare the treatment effects under identical conditions, we selected vertical insertion of the manual acupuncture needle. The manual acupuncture applied at the acupoints of the Liver (LR) meridian had a treatment effect on muscular skeletal disorders [20]. Considering the inconvenience of applying the electrode and inserting the manual acupuncture needle, we selected the rectus femoris, which is close to the LR meridian, as the induction location for generating muscle fatigue. We selected LR9 which is 12.12 cm from the medial lateral epicondyle of the femur, because of the EMG noise induced by the interference between the EMG measurement electrode and the EMA electrode.

The aim of our study was to suggest EMA as a treatment option and observe its usefulness in comparison with manual acupuncture.

## 2. Material and methods

### 2.1. Eight-channel EMA system design and stimulation method

Figs. 1 and 2 show the eight-channel EMA system and the solenoid coil, which was 15 mm in diameter and 20 mm in length. The core was 5 mm in diameter and 16 mm in length and was made of the material SM45C. The diameter of the hole was 2 mm in the center of the core for inserting the manual acupuncture needle. The coil used a wire, which

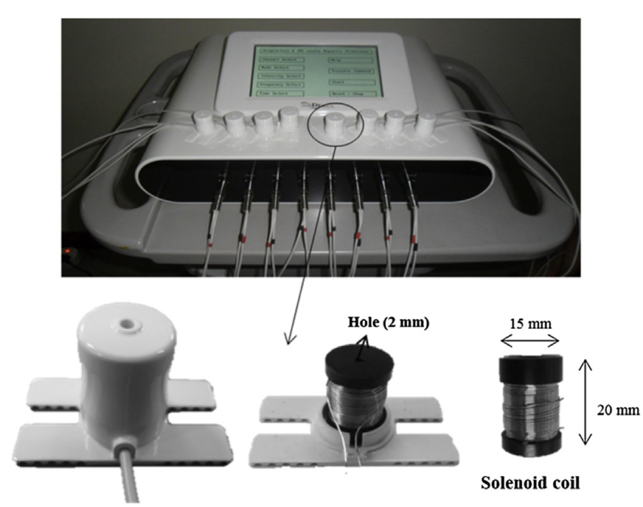


**Figure 1** The solenoid coil for magnetizing acupuncture needles and the eight-channel pulsed electromagnetic field (PEMF) stimulator.

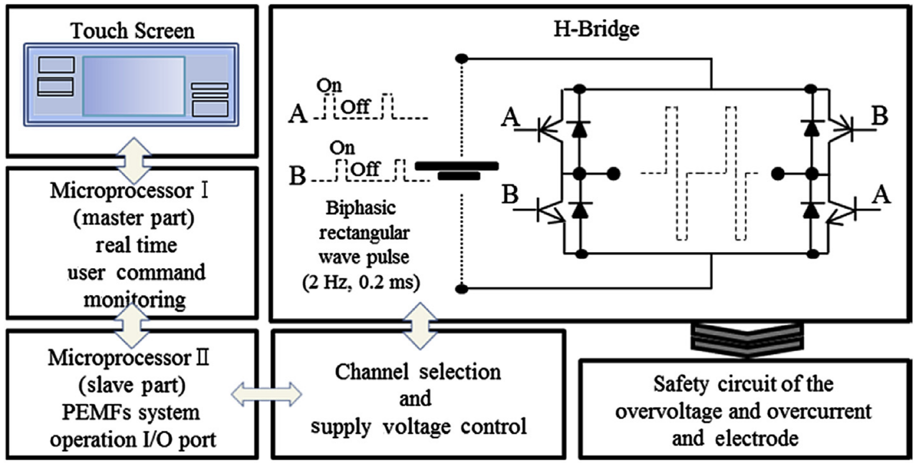


**Figure 2** Block diagram of the eight-channel electromagnetic acupuncture (EMA) system.

was 0.35 mm in diameter. The coil was wound 370 times. Also, we designed the electrode case in order to attach it to the acupoint conveniently and indirectly.

Transcutaneous electrical nerve stimulation (TENS) was used in order to stimulate an acupoint for a long period of time. It was revealed that the local effects of a short duration of TENS on pain perception/tolerance were generated at a high frequency [21,22] and the effects that were less localized but longer in duration were at a low frequency (between 1 Hz and 4 Hz) [23—26]. The 0.6—0.8 ms duration of 2 Hz was reported to be effective in reducing a perceived response [27]. Hence, we selected the 2-Hz biphasic rectangular wave pulse in order to reduce the pain perception/tolerance of the participant. We selected an insertion depth of 3 cm for the manual acupuncture needle (stainless steel, diameter 0.3 mm, length 30 mm; DongBang Acupuncture Inc., Boryeoung, Korea) in order to stimulate LR9 sufficiently. Hence, the manual acupuncture needle was inserted and fixed at a distance of 3 cm from the electrode in order to measure the magnetic flux density using Teslameter (Model 460, 3-Channel Gaussmeter; Lake Shore Crytronics Inc., Westerville, OH, USA; Fig. 3). Fig. 4 indicated the measured magnetic flux density by the change in frequency. We observed that a biphasic wave rather than a monophasic wave generated a higher magnetic flux density. The actual measurement from the

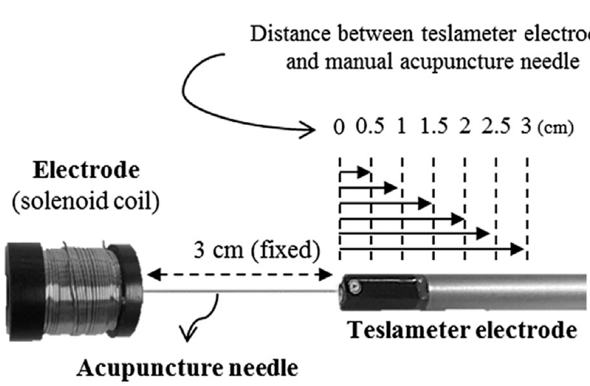


**Figure 3** The method used for the magnetic flux density measurement.

manual acupuncture needle at 2 Hz was 48.59 mT (485.9 gauss) as the vector magnitude, which consists of 13.65 mT (136.5 gauss) as the X-axis, 13.11 mT (131.1 gauss) as the Y-axis, and 44.74 mT (447.4 gauss) as the Z-axis. Fig. 5 shows the changes in magnetic flux density according to distance between the teslameter electrode and the manual acupuncture needle.

## 2.2. Participants

Thirty healthy males (age: 22 $\pm$ 3.6 years old; height: 171 $\pm$ 5.8 cm; and weight: 74 $\pm$ 14.2 kg) participated in this experiment. They were given self-report questionnaires on their musculoskeletal condition prior to inducing fatigue. After noting their medical history, we selected individuals who would participate in the experiment voluntarily. All participants gave their written informed consent prior to participation. The 30 males were divided into three groups of 10, the nonstimulation group, the manual acupuncture group, and the EMA group. The three groups were divided randomly among the volunteers.

## 2.3. Experimental procedure for generating fatigue

Thirty individuals participated in six consecutive testing sessions. In the first session, the participants took part in the pre-exercise knee extension/flexion using Biodex System 3 (Biodex Medical Inc., Shirley, NY, USA; Fig. 6), in order to measure the maximal voluntary contraction (MVC). In the second session, all participants performed the knee extension/flexion exercise, which is a form of full range isokinetic exercise, at 115° S-1 and within 30% of the range of the measured MVC. They repeated the exercise 10 times in a set, repeating the set three times, with 2 minutes of rest between sets. In the third session, we measured the MVC up to two sets, with 2 minutes rest between the sets. In the fourth session, all participants repeated the exercise, which included five sets of 10 repetitions of the isokinetic movement at 115° S-1, within 65% of the range of the remeasured MVC, with 2 minutes rest between sets. In the fifth session, all participants spent some time recovering. The manual acupuncture group and the EMA group received the designated stimulation for 20 minutes. In the

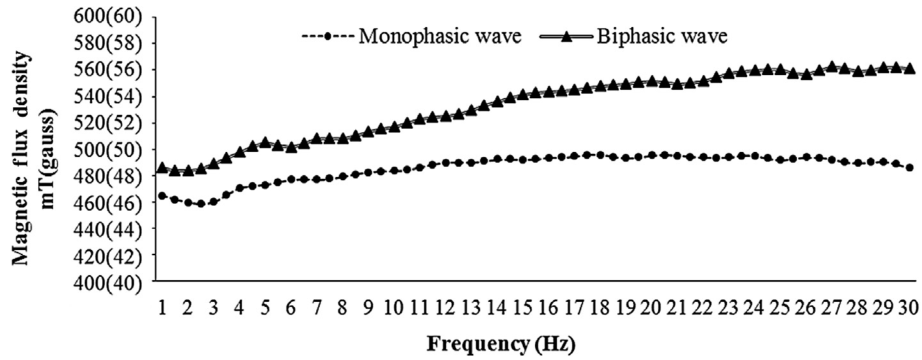


**Figure 4** The relationship between magnetic flux density and stimulation frequency.

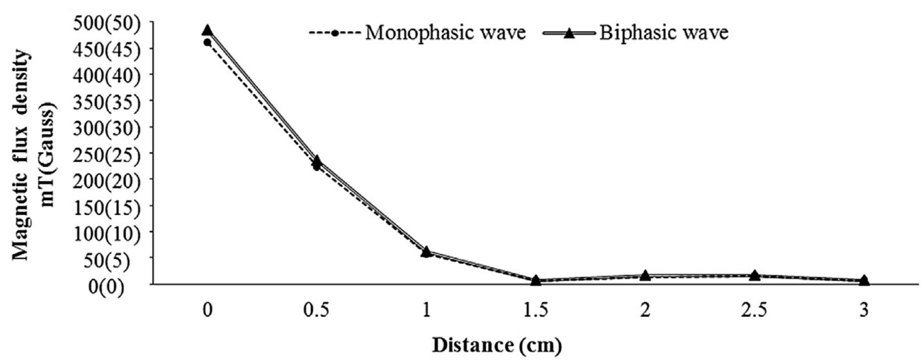


**Figure 5** The relationship between the magnetic flux density and the distance between the teslameter electrode and the manual acupuncture needle.

sixth session, the MVC of all participants was measured at 2 minute intervals in the recovery period. The experimental procedure was approved by the Institutional Review Board of Yonsei University, Wonju, Korea.

## 2.4. EMG measurements

We chose the rectus femoris to measure the EMG. The surface EMG measurement of the rectus was recorded during the knee extension/flexion exercise. Two circular Ag/AgCl surface electrodes (Electrode #272, diameter 14 mm and interval distance 18 mm; Noraxon, Scottsdale, AZ, USA) were used and a ground electrode was placed on the lateral fibula head. The interelectrode distance was set to 2.5 cm. The EMG signal was set between 10 Hz and 500 Hz of the pass band and pre-amplified to 1000 gain. The EMG signal converted the 12-bit resolution with a sampling frequency of 1 kHz. The digitized EMG signal was monitored

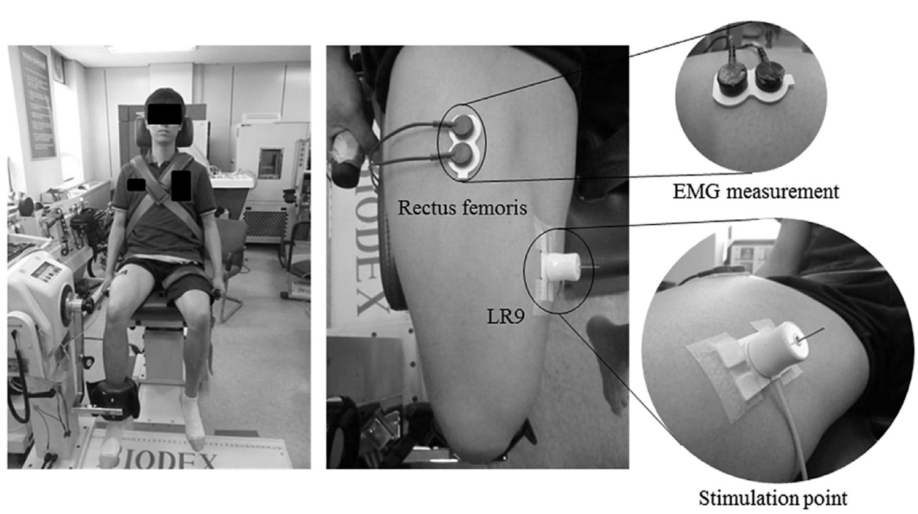


**Figure 6** The experimental setup for using Biodex System 3. EMG = electromyography; LR = Liver.

and stored in the graphical user interface (GUI) with Noraxon Myoresearch XP software (Noraxon, Inc.), and the power spectrum was analyzed in a short period of time.

EMG spectral analysis has been used to find muscle conditions such as fatigue by tracking indicators of the frequency spectrum. Biochemical and physiological reactions of muscle are reflected in mean, median, and mode frequency spectrums. Because median frequency (MF) among some indicators is less influenced by noise and has a high reflection rate of biochemical and physiological reactions in muscles, MF is commonly used to find the pattern of motor unit activity related to fatigue [28]. Moreover, peak torque has been commonly used for measuring the maximum isometric force that an individual can generate at the monitored joint [29]. Thus, MF and peak torque have been reported to be a valid measure of the frequency shift or compression related to fatigue. Hence, we analyzed the MF and peak torque. All indicators on the participants were normalized, and the data measured first was considered as 1.

## 2.5. Statistical analysis

Prior to conducting the statistical techniques, the EMG signal was normalized in order to consider 1 as all factors prior to the exercise. To assess the change in fatigue of each group, the contrast test based on the one-way repeated measures analysis of variance (RM ANOVA) was conducted on the dependent variables (peak torque, MF) of the nonstimulation, the manual acupuncture, and the EMA groups in 2-minute intervals up to 20 minutes. We analyzed significant recovery time by conducting a simple comparison of RM ANOVA between each variable at the pre-exercise state as reference and each variable from post-exercise to 20 minutes. The significance level of the statistical analysis was set at $p < 0.05$.

# 3. Results

The MF immediately after the exercise was significantly lower than the MF at the pre-exercise stage in all groups (Fig. 7). There were significant differences between the MF at pre-exercise and immediately after the exercise due to fatigue in all groups ($p < 0.005$). The MF of all participants recovered to the MF level of the pre-exercise during the recovery period. At approximately 8 minutes and 10 minutes after exercise, the MF of the nonstimulation group was close to the MF at the pre-exercise stage. The MF of the manual acupuncture group at approximately 6 minutes and 8 minutes after exercise was similar to the MF at the pre-exercise stage. At about 4 minutes and 6 minutes after exercise, the MF of the EMA group returned to the MF at the pre-exercise. It was observed that the EMA group had a significantly faster recovery time compared to the other groups.

The results of the contrast test on the MF indicated that the MF at 8 minutes after exercise in the nonstimulation group was significantly recovered to the MF at the pre-exercise ($p = 0.511$). The MF at 6 minutes after exercise was significantly closed to the MF at the pre-exercise in the manual acupuncture group ($p = 0.530$). In the EMA group, the MF at 4 minutes after exercise was significantly similar to the MF at the pre-exercise.

The peak torque of the three groups immediately after exercise decreased significantly. However, we observed that the peak torque did not increase up to the peak torque at the pre-exercise until 20 minutes after exercise. As a result, significant recovery was not found in all groups (Fig. 8). The results of the contrast test on the peak torque indicated that all three groups during the recovery period did not recover to the peak torque at the pre-exercise ($p < 0.05$).

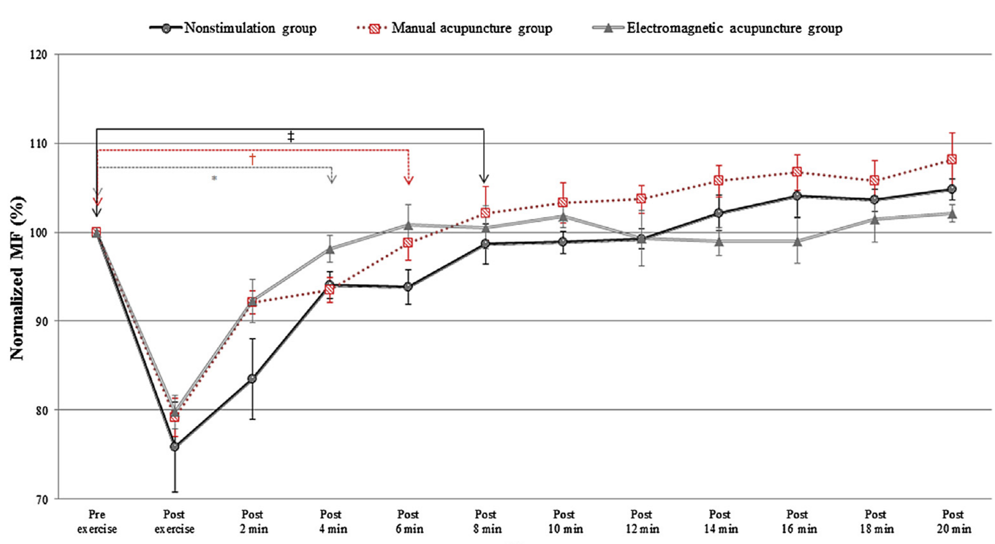


**Figure 7** The mean and standard error of the MF of the three groups: nonstimulation, manual acupuncture, and EMA. * The first significant closest point between the pre-exercise and recovery period in the nonstimulation group. † The first significant closest point between the pre-exercise and recovery period in the manual acupuncture group. ‡ The first significant closest point between the pre-exercise and recovery period in the EMA group. EMA = electromagnetic acupuncture; MF = median frequency.

## 4. Discussion

Numerous papers reported that manual acupuncture had treatment effects on multiple physiological systems. Thus, manual acupuncture was used to treat psychosomatic disorders including anxiety, depression, pain, and visceral dysfunctions [30,31]. Also, many researchers reported treatment effects in relief of pain among various disorders [32,33]. Manual acupuncture produced an increase in pain threshold, which is influenced by a transient increase in sympathetic nerve activity of the muscles [27]. The MF at 6 minutes after exercise was significantly close to the MF at pre-exercise in the manual acupuncture group ($p = 0.530$). The results of the contrast test on the MF indicated that the MF at 8 minutes after exercise in the nonstimulation group significantly recovered to the MF at pre-exercise ($p = 0.511$). The MF in the manual acupuncture group has a faster recovery time than the nonstimulation group. The result of the MF analysis in the manual acupuncture group corresponded with the results of previous studies, which report treatment effects on pain and musculoskeletal disorders. By contrast, the peak torque after 20 minutes was still not recovered in all groups. The results of the contrast test on the peak torque indicated that all groups did not recover to the peak torque at pre-exercise during the recovery period ($p < 0.05$). However, the peak torque during the recovery period was still higher than its level in the nonstimulation group. The results of the MF and the peak torque demonstrated that manual acupuncture is an effective treatment for recovering from fatigue in those with musculoskeletal disorders.

In the EMA group, the MF at 4 minutes after generating fatigue was significantly similar to the MF at pre-exercise ($p = 0.608$). Hence, we observed that the EMA group had a significantly faster recovery time than other groups. The peak torque in the EMA group was found as a relatively high recovery progress from other groups, but it was not fully recovered to the peak torque at the pre-exercise. In the extremely low frequency ranges of the PEMFs, experimental treatment effects have been reported in many different fields such as nonunion bone fractures, skin ulcers, migraines, and degenerative nerves [34,35]. It was reported that the PEMFs resulted in significant improvements in performance capability, such as bladder control, cognitive function, fatigue level, etc [10]. Time-changing magnetic fields such as the PEMF induce an electric field based on Faraday's Law of Induction that generates an eddy current in the body's conductive tissues [36–38]. Hence, these phenomena in the body give an impact to various tissues such as the nerve or muscular tissues, etc., without another electrode. PEMFs in the form of ELF induced nonsignificant heating of the tissue [39]. Thus, EMA was considered as a better way of recovering from fatigue due to the positive effects of PEMFs at the tissues or acupoint.

It has been reported that the treatment effects of manual acupuncture techniques were associated with two components. One component is the location where the manual acupuncture needle is applied, and the other component is the technique used for applying the manual acupuncture needle [40,41]. Numerous studies reported that the interactions of the two components had a considerable influence on the treatment effects [42–44]. The insertion techniques are divided in order to attain a balance of Qi. The strong insertion technique known as sedating is preferred to decrease the body's energy, and the mild insertion technique known as tonifying is suited to intensifying Qi. Also, manual acupuncture needles vary according to the specific type of therapy. The filiform steel needle is widely used in TKM. We compared the manual acupuncture group and the EMA group in identical experiment conditions with regard to the acupuncture location and filiform steel needle. However, this study addressed only the insertion of the manual acupuncture needle, not the techniques for controlling the imbalance in Qi. The insertion of a manual acupuncture needle may slightly affect the recovery from fatigue.

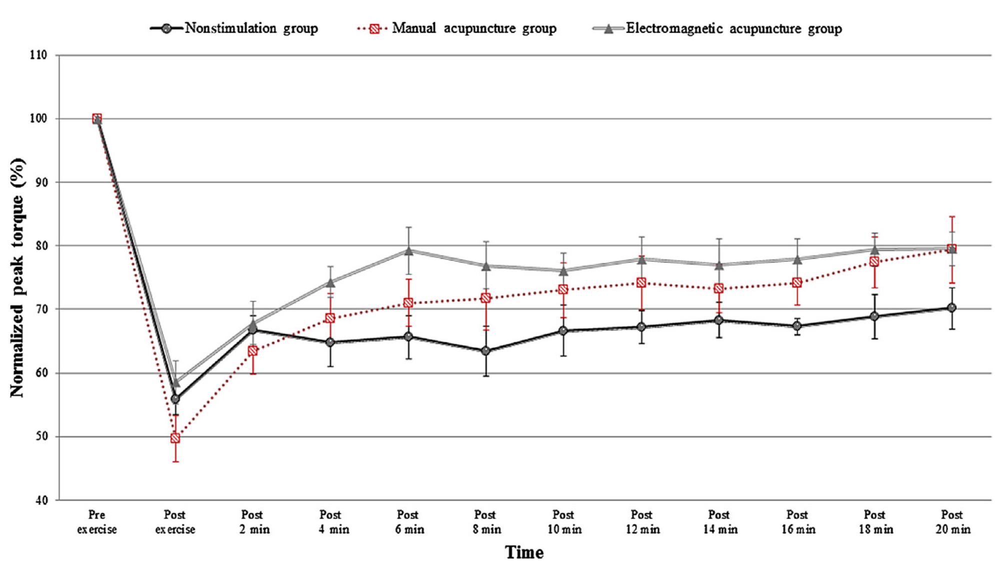


**Figure 8** The mean and standard error of the peak torque of the three groups: nonstimulation, manual acupuncture, and electromagnetic acupuncture (EMA).

## 5. Conclusion

In conclusion, this study is the first study to suggest the EMA method to enhance the treatment effects of manual acupuncture. We developed a PEMF system that can stimulate only a local point such as an acupoint. In order to confirm the treatment effects between manual acupuncture and EMA, we investigated the fatigue recovery of the quadriceps after regular knee extension/flexion exercises through EMG analysis in three groups (nonstimulation group, manual acupuncture group, and EMA group). The results of the MF and peak torque indicated that the EMA, rather than other groups, showed a significant treatment effect on muscle fatigue recovery. We confirmed the treatment effects of the EMA compared with vertically inserted manual acupuncture needles. A limitation of this study is that a manual acupuncture technique was not applied such as twist and twirl. Hence, it is required to compare it with the manual acupuncture techniques, which was known as the treatment method, effective for musculoskeletal disorders.

## Disclosure statement

The author affirms there are no conflicts of interest and the author has no financial interest related to the material of this manuscript.

## Acknowledgment

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