Comparison of 2 Methods of Non-invasive Treatment between Transcutaneous Electrical Stimulation and Pulsed Electromagnetic Field Stimulation as replacement of Invasive Manual Acupuncture

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ABSTRACT:

The aim of this study was to find the non-invasive optimal alternative method for Manual Acupuncture. Existing researches had reported that Transcutaneous Electrical Acupoint Stimulation (TEAS) was an effective treatment method instead of manual acupuncture. In place of the TEAS, we suggested the Pulsed Electromagnetic Fields (PEMFs). Thus, we designed the PEMFs system which can stimulate only an acupoint. There have been no researches which reported therapeutic effect when stimulating at an identical acupoint by TEAS and PEMFs. Hence, this study investigated the therapeutic effect on the muscle fatigue after the strenuous knee extension/flexion exercise by two stimulations. We selected the stimulation method of both TEAS and PEMFs by using 2Hz biphasic rectangular wave pulse and pulse width 0.2ms. The magnetic flux was the 30.92mT (309.2gauss) at 2 Hz. The electromyogram (EMG) and the maximal voluntary contraction (MVC) at rectus femoris were measured. The Median Frequency (MF) at TEAS group was significantly effective at 6 minutes (p=0.499). The PEMFs group was recovered to the MF rapidly after 4 minutes (p=0.166). The results of the peak torque indicated that both non-stimulation group and TEAS group did not recover to the peak torque at pre-exercise during the recovery period (p<0.05). In contrast, the significant treatment effect of PEMFs group was found after 14 minutes (p=0.135). The results of this study demonstrated that PEMFs were better than TEAS as a non-invasive method to replace the manual acupuncture.

Key Words: Pulsed electromagnetic fields; Muscle fatigue; Acupuncture point; Transcutaneous electrical nerve stimulation; Electromyogram.

Introduction

Many papers have reported pain during the course of musculoskeletal disorders and existing research has proposed various methods of treating muscle fatigue. In Traditional Chinese Medicine (TCM), the deficiency of life energy (Qi) was considered as the most significant cause of nature of particular disorders including musculoskeletal disorders [1,2]. The Manual Acupuncture has been used to control the imbalance in Qi with two reasons; one is related to the sites where the needling is applied and the other reason is related to the techniques [3,4]. In addition, Electro-Acupuncture (EA) was applied in order to treat a variety of conditions by controlling the imbalance of Qi. However, it is a difficult concept to objectively demonstrate how to control Qi. Still, numerous papers reported that the acupoint stimulation had the therapeutic effect on diverse disorders. Some researchers reported that manual acupuncture was an effective treatment by affecting physical performance capacity and sympathetic nerve activity [5,6]. Moreover, there were papers reported that the functions of mitochondria were maintained and the working time of a muscle was prolonged [7,8].

However, despite the many results of the acupuncture's positive effect on diverse conditions including muscle fatigue [9-11], its application in clinical practice has not been widespread due to its invasive nature. Hence, some researchers have suggested a non-invasive method using the electrical stimulation at an acupoint. In recent, the transcutaneous electrical acupoint stimulation (TEAS) instead of manual acupuncture or EA has been used to treat various disorders and had been reported effective in producing analgesia [12-14].

Hence, TEAS which is a kind of transcutaneous neuromuscular electrical stimulation (TNMES) was applied to improve or restore muscle trophism and its function [15,16]. However, comparing the effects of the manual acupuncture and the TEAS on muscle fatigue recovery with regards to the tennis elbow, research demonstrated that the manual acupuncture rather than TEAS might be more effective stimulation to control hypoalgesia. The cause demonstrated that TEAS was suitable for stimulating only transcutaneous nerve, not the inside of the human body is enough up to the depth of an acupoint location in tissue [17]. Hence, there is a need to propose the new method which can be stimulated up to an acupoint location. So, we proposed the PEMFs as an optimal stimulus which can penetrate acupoint in tissue. This study suggested the PEMFs which were reported as an effective treatment to heal musculoskeletal disorders [18,19]. The PEMFs have demonstrated various therapeutic effects, with results indicating that its stimulation affects microcirculatory [20], skin temperature [21], motor function recovery [22] and synthase activity [23]. Some researchers have reported that the PEMFs in the form of extremely low frequency (ELF, ≤300Hz) had the therapeutic effect of producing analgesia. The PEMFs in the 1-4Hz with a 0.1-0.3mT (1-3gauss) have been widely used to treat acute orthopaedics [24]. And it was reported that PEMFs in the 20-50Hz with a 5mT (50gauss) had a therapeutic effect in a chronic state [25]. In contrary to the results, it was reported that the PEMFs in the 1.25Hz rectangular wave pulse at a width of 3ms with a 60mT (600gauss) has no effect on a laboratory model of acute pain [26]. However, numerous researches had reported the therapeutic effect on myofacial pain [27,28] and muscle fatigue [29] using the PEMFs in the form of the ELF. Therefore, we developed the PEMFs system and the electrode in order to stimulate a local point like an acupoint. To confirm the replaceability and therapeutic effect, we compared and analyzed the TEAS and PEMFs stimulation group in muscle fatigue recovery. This study was conducted to evaluate the effects of both groups on the rate of the recovery of quadriceps force capacity after strenuous knee extension and flexion exercise. The rectus femoris was selected as the induction location on muscle fatigue. In order to avoid inconvenience by attaching the TEAS or PEMFs electrodes during exercise, the muscle except the rectus femoris was selected. Since the Liver meridian (LR) among twelve meridians represents the state of muscle in TCM, LR9 which is located between gracilis muscle and sartorius muscle was selected. Therefore, the aim of this study was to suggest a better way to replace manual acupuncture or EA by their invasive nature.

Materials and Methods

TEAS methods

It has been reported that the local effects of short duration on pain perception/tolerance were produced at high frequency [30,31] and effects that were less localized but of longer duration at low frequency stimulation of 1-4Hz [32-34]. From among such low frequency bandwidth, the 0.6-0.8ms duration of 2Hz was found to be effective in reducing a perceived response [6]. Furthermore, the electric stimulation of 2Hz biphasic rectangular wave pulse lasting at 0.2ms in duration was effective in muscle fatigue recovery (Fig. 1) [35].

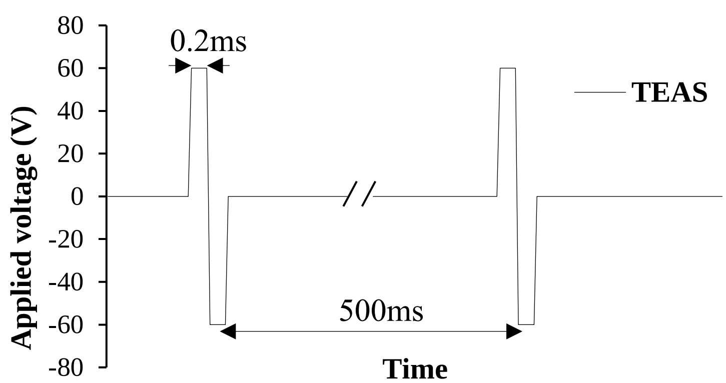

Fig. 1: The waveform of the TEAS treatment (2Hz biphasic rectangular wave pulse, pulse width 0.2ms)

After the introduction of TEAS treatment method, its therapeutic effect has been reported a number of disorders and conditions [36-39]. Hence, this study followed the identical protocol of the proposed TEAS treatment method using a hospital instrument (LECTRON-350RII, DMC Co. Ltd, Korea). A water-based electrical coupling gel (Progel, DA Yo Medical Co. Ltd, Korea) was applied on the electrodes in order to improve the conductance between skin and electrode.

PEMFs system design and methods

For generating a magnetic flux have produced a small size (an external diameter: 14.3mm, length: 80mm, the thickness of a coil: 0.35mm, turns: 2000, the thickness of a core: 3mm) as possible to stimulate a local point like an acupoint (Fig. 2).

Fig. 2: (a) Electrode for generating magnetic flux. (b) Designed system.

The PEMFs system was consisted of 5 parts. The system was ordered and operated by graphic user interface (GUI). The current was switched by the bridge circuit following the selected frequency and voltage. In order to minimize the problems such as heat release at coil, we monitored the generated temperature at coil by using thermistor (Fig. 3).

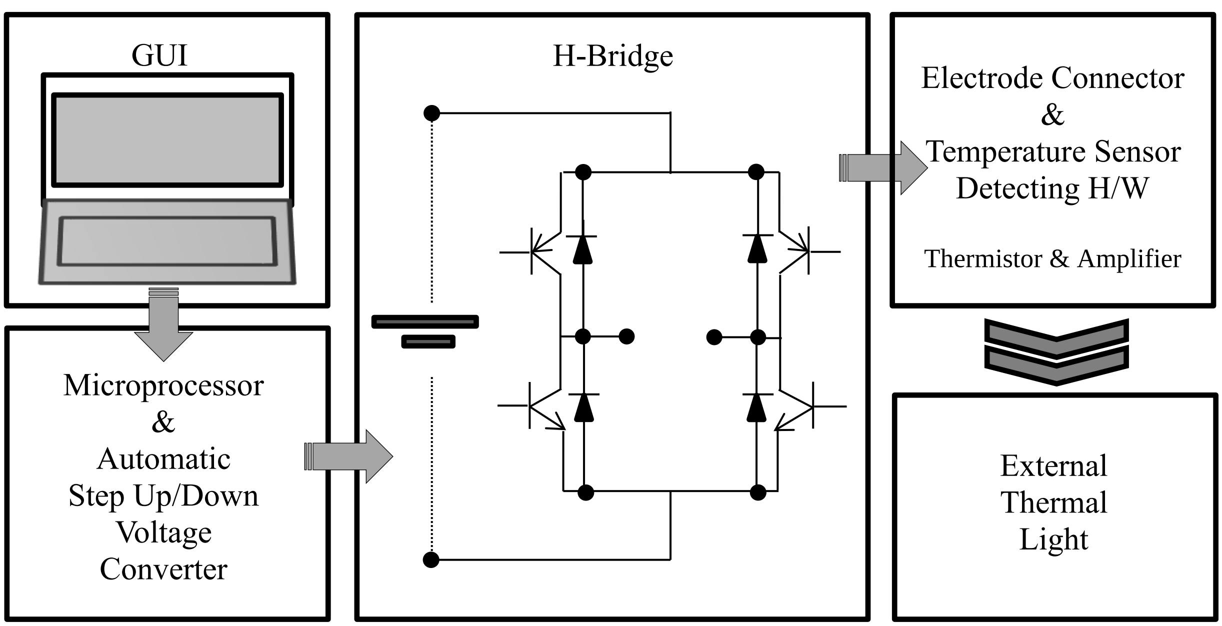

Fig. 3: Block diagram of PEMFs system.

We selected 2Hz biphasic rectangular wave pulse which is the identical frequency and wave form at TEAS treatment in order to confirm the therapeutic effect under identical conditions (Fig. 4). To confirm the magnetic flux, the magnetic flux was measured by the teslameter (Model 460, 3Channel Gaussmeter, Lake Shore Crytronics. Inc, USA). We operated the only magnetic teslameter and turned off the external device in order to reduce the interference of peripheral electromagnetic waves. The teslameter electrode was fixed to the end of core. We repeated the measurement process with 10 sets. The actual measurement at 2Hz was 30.92mT (309.2gauss) as a vector magnitude which consists of 10.02mT (100.2gauss) as X-axis, 9.78mT (97.8gauss) as Y-axis and 27.61mT (276.1gauss) as Z-axis. In addition, we confirmed the PEMFs system which could generate a high magnetic flux up to the highest 31.96mT (319.6gauss) within frequency range from 0.5 to 200kHz including the ELF bandwidths (Fig. 5).

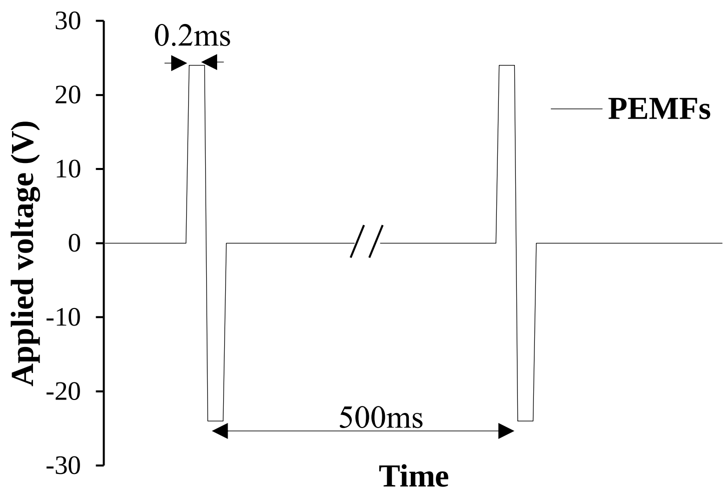

Fig. 4: The waveform of the PEMFs (2Hz biphasic rectangular wave pulse, pulse width 0.2ms)

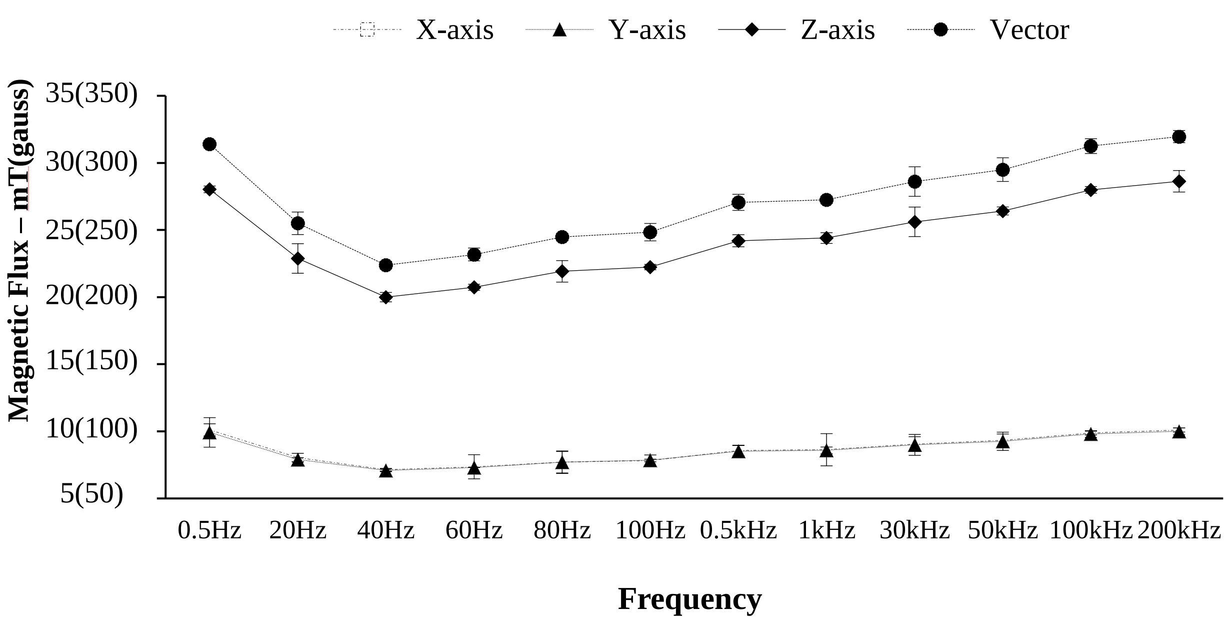

Fig. 5: XYZ-axis magnetic flux and vector of magnetic flux within frequency range from 0.5 to 200kHz including the ELF bandwidths.

Subjects

Subjects (male, n=30) offered a self-report questionnaires on the musculoskeletal condition before inducing fatigue. We identified that they do not have their clinical history related to musculoskeletal disorders. In addition, we limited the subjects which had skin lesions in order to attach surface electrodes. All subjects were divided into three groups (non-stimulation group, TEAS group and PEMFs group) and each group consisted of ten subjects. Three groups were given to a random sample of subjects. All subjects were required to sign their written-informed consent form before participating in the study. The institutional research ethics committee reviewed and approved the proposed experiment design.

Selection of EMG electrode location & an acupoint

We chose the rectus femoris so to measure the Electromyogram (EMG). The surface EMG measurement of the rectus femoris was recorded while exercising the knee extension/flexion. Two circular Ag/AgCl surface electrodes (Electrode #272, diameter: 14mm, interval distance: 18mm, Noraxon, USA) were used and a ground electrode was placed on the lateral fibula head.

In case of TEAS, muscle response occurs variously depending on electrode positioning and amplitude settings [40]. Considering a noise signal caused by the distance from the EMG electrode to the magnetic coil, we selected the LR9 located on the upside from the medial lateral epicondyle of the femur as much as 12.12cm in LR which represented the state of muscle in TCM.

Experimental procedure

All subjects attended the six consecutive testing sessions (Fig. 6). In the first sessions, all subjects conducted 10 repetitions of knee extension/flexion on a Biodex System 3 (Biodex Medical Inc., Shirley, NY, USA) in order to familiarize themselves with the exercise protocol. And we measured Maximal Voluntary Contraction (MVC).

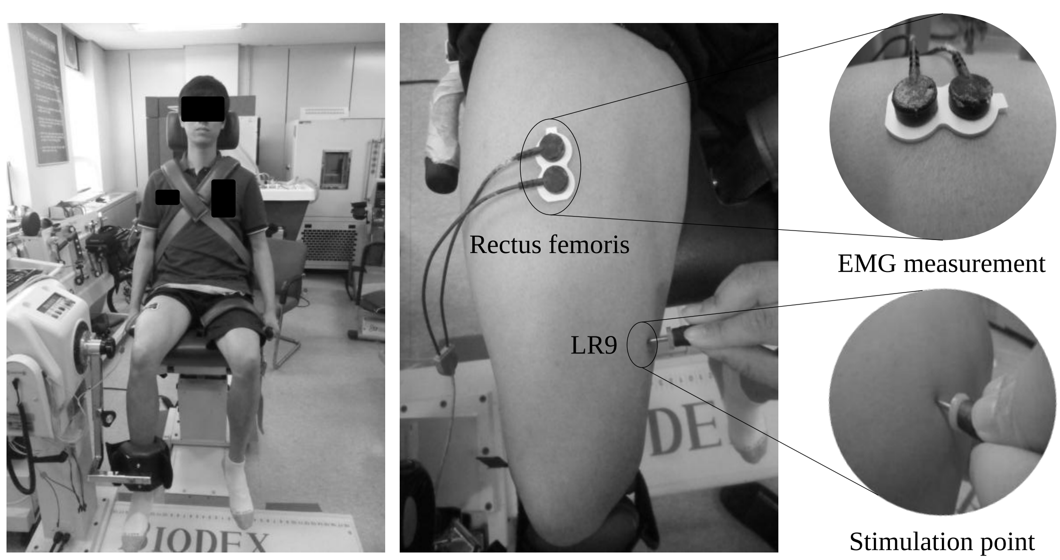

Fig. 6: Experimental setup by using Biodex system 3

In the next sessions, all subjects acclimatized themselves with the knee extension/flexion exercise by doing 10 repetitions in an identical action having a 30% range of measured MVC in a full range of isokinetic movements, at 115° S-1, with 2 minutes rest between 3 sets. In the third sessions that followed, MVC of thirty subjects measured, with 2 minutes rest between 2 sets. In the fourth sessions, thirty subjects performed the identical exercise which included 5 sets of 10 repetitions of isokinetic movement at 115° S-1, with a 65% range of remeasured MVC, with 2 minutes rest between sets. Next, non-stimulation group had the recovery period for 20 minutes. The TEAS and the PEMFs group received the TEAS or PEMFs stimulation for 20 minutes. We measured repeatedly MVC at 2 minutes intervals. In the last sessions, MVC of all subjects were measured at the end of their recovery time.

EMG measurement

The EMG signal was filtered between 10 and 500Hz of the pass band and pre-amplified as 1000 gain. The EMG signal was converted by the 12 bit resolution with a sampling frequency of 1kHz. The digitized EMG signal was monitored and stored in a GUI with Myoresearch XP software (Noraxon, Inc., USA).

The EMG spectral modification may be indicated and quantified by tracking some indicators of the frequency spectrum, such as mean, median and mode frequency spectrum or alternatively by analyzed a ratio of low frequency to high frequency. Among these indicators, median frequency (MF) is less affected by noise and is sensitive to biochemical and physiological process that occur within the muscles during exercise. Hence, it is preferable to use the MF as the fatigue index calculated from the frequency spectrum of the EMG signal [41,42]. Moreover, peak torque has been commonly used for measuring the maximal isometric force that a subject can generate at the monitored joint [43]. Thus, the MF and peak torque has been reported to be a valid measure of the frequency shift or compression associated with fatigue [44]. Therefore, we calculated the MF and peak torque.

Statistics

Before conducting statistical techniques, the EMG signal was modified in the form of normalization. To assess a change in the fatigue of each group, the contrast test based on the one-way repeated measures Analysis of Variance (ANOVA) was conducted on the dependent variables (peak torque, MF) of non-stimulation, TEAS or the PEMFs group as time passed. The significance level of the statistical analysis was set at $p<0.05$.

Results

In the three groups, each MF at immediately post exercise was significantly lower than MF at pre-exercise (Fig. 7). There were significant differences between groups, except the MF at pre-exercise and immediately post exercise. The three groups were commonly recovered to a normal state during recovery period. Approximately after 5 minutes, it was observed that the MF of the PEMFs group was identical to MF at pre-exercise. The MF of the TEAS group after 8 minutes was similar to the MF at pre-exercise. The MF of the non-stimulation group returned to the MF at pre-exercise at about 9 minutes. It was observed that the PEMFs group had the fastest recovery time compared to the non-stimulation and the TEAS group at about 3-4 minutes.

The results of the contrast test on the MF indicated that the PEMFs group recovered to the MF of pre-exercise rapidly rather than the other groups. In the non-stimulation group, the MF at post 6 minutes was significantly recovered to the MF at pre-exercise (p=0.127) (Table 1). In the TEAS group the MF at post 6 minutes was an approximation to the MF at pre-exercise (p=0.499) (Table 2). In the PEMFs group, the MF at post 4 minutes was closed to the MF at pre-exercise (p=0.166) (Table 3).

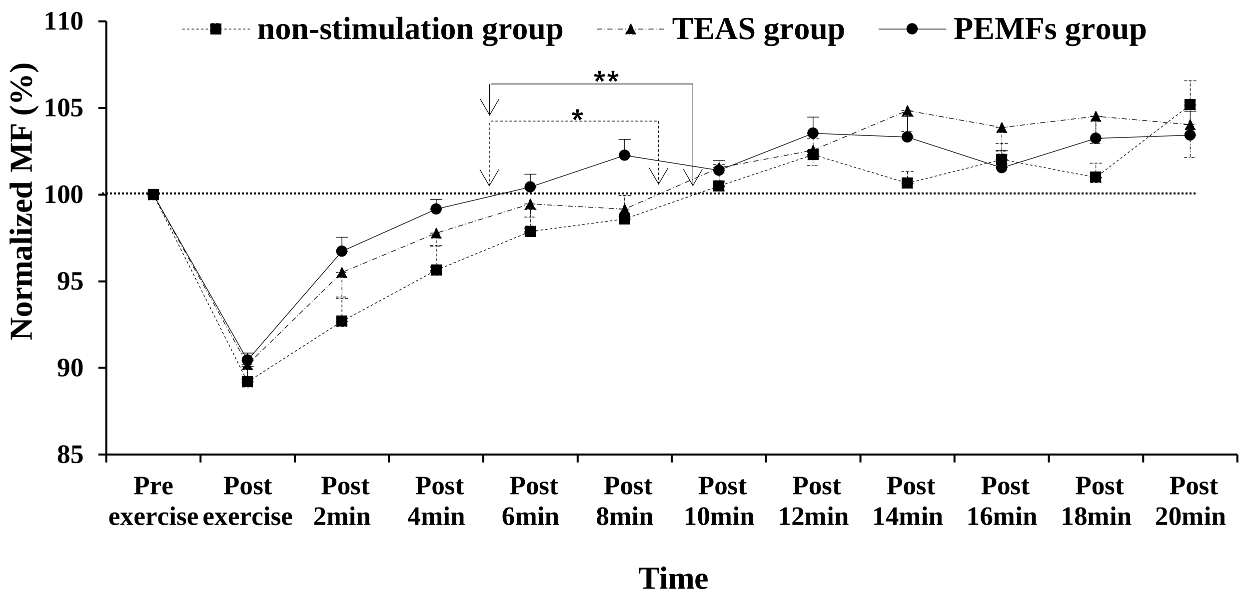

Fig. 7: The mean and standard error of the MF of three groups (The non-stimulation, the TEAS and the PEMFs group), *: The significant difference between the TEAS group and the PEMFs group, **: The significant difference between the non-stimulation group and the PEMFs group.

Table 1: The significance probability analysis of the MF in the non-stimulation group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.000	0.000	0.014	0.127	0.326	0.705	0.032	0.354	0.057	0.252	0.005

Table 2: The significance probability analysis of the MF in the TEAS group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.000	0.016	0.021	0.499	0.085	0.243	0.024	0.005	0.024	0.024	0.070

Table 3: The significance probability analysis of the MF in the PEMFs group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.000	0.003	0.166	0.569	0.036	0.034	0.004	0.021	0.156	0.033	0.035

The significant treatment effect was not only found in peak torque recovery of all groups (Fig. 8). The peak torque of the three groups decreased during the knee extension/flexion exercise. During the recovery period in the three groups, peak torques at post 20 minutes did not increase up to the peak torque at pre-exercise.

The results of the contrast test on the peak torque indicated that both non-stimulation group and TEAS group did not recover to the peak torque at pre-exercise during the recovery period (p<0.05) (Table 4, 5). In contrast, it was an approximation to the peak torque at pre-exercise in the PEMFs group after 14 minutes (p=0.135) (Table 6).

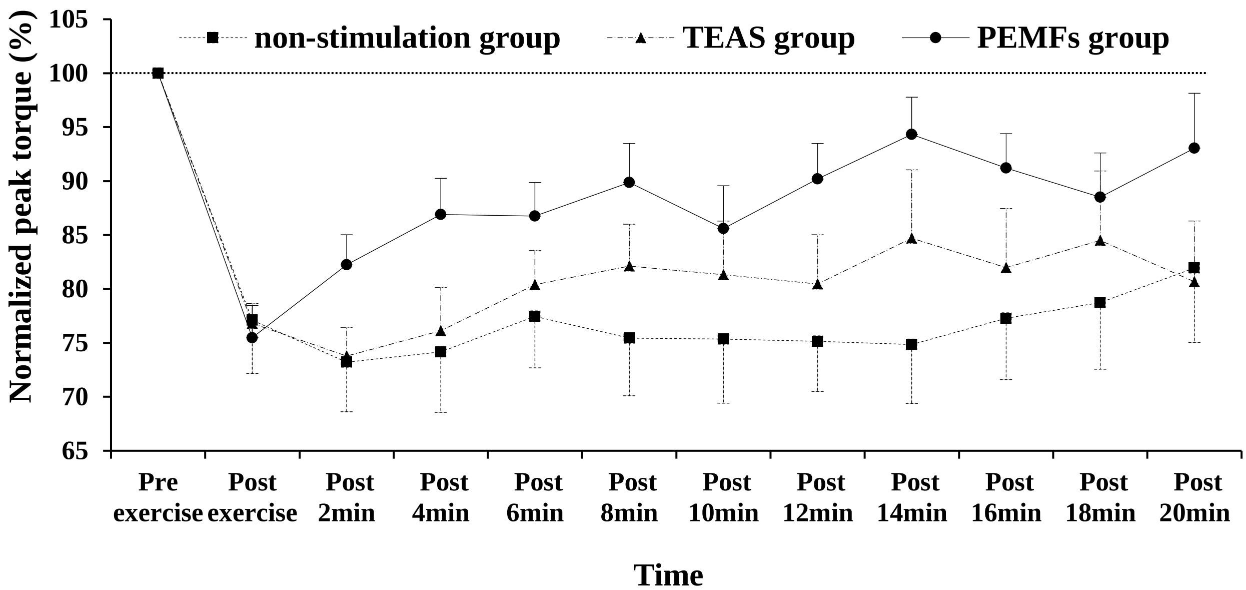

Fig. 8: The mean and standard error of the peak torques of three groups (The non-stimulation, the TEAS and the PEMFs group)

Table 4: The significance probability analysis of the peak torque in the non-stimulation group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.001	0.000	0.001	0.001	0.001	0.003	0.000	0.001	0.003	0.007	0.028

Table 5: The significance probability analysis of the peak torque in the TEAS group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.000	0.000	0.001	0.000	0.002	0.007	0.004	0.047	0.013	0.047	0.011

Table 6: The significance probability analysis of the peak torque in the PEMFs group

n=10	Immediately Post exercise	Post 2min	Post 4min	Post 6min	Post 8min	Post 10min	Post 12min	Post 14min	Post 16min	Post 18min	Post 20min
p value	0.001	0.000	0.004	0.002	0.020	0.005	0.016	0.135	0.022	0.021	0.205

Discussion

There were various results reported that the stimulation at an acupoint by using various treatment methods had a therapeutic effect on the musculoskeletal disorder [5-17]. Upon considering based on these researches, the fatigue recovery in both TEAS and PEMFs group has to be faster than non-stimulation group by restoring the state of bio-ions of an acupoint. The result of MF analysis corresponded with the result of existing researches by observing the recovery from MF in both TEAS and the PEMFs group were faster than the non-stimulation group. Moreover, the peak torques at post 20 minutes did not increase up to the peak torque at pre-exercise during the recovery period in all the groups, but the peak torques in both TEAS and the PEMFs group were higher than its level in the non-stimulation group. These results showed that an acupoint is an important point for recovering from fatigue in musculoskeletal disorder.

Existing researches reported that the bio-ions of an acupoint are influenced by the accumulation of metabolites and substrate depletion due to fatigue [45-47]. Moreover, some phenomenon were observed in an acupoint such as sarcoplasmic Ca^{2+} release, the impairment of reuptake and the disturbance of electrolyte concentrations [48-50] under the influence of fatigue. Such phenomenon has illustrated the indurations of acupoints in TCM.

Hence, result of MF and peak torques in both TEAS and the PEMFs groups indicated that TEAS and PEMFs had an influence on recovery from Ca^{2+} release, the impairment of reuptake and the disturbance of electrolyte concentrations at the acupoint. Therefore, force loss which generates the accumulation of metabolites, substrate depletion, and the accumulation of electrolytes and their effects on excitation-contraction coupling were returned to a normal state.

In comparison between the TEAS and the PEMFs group, it was observed that the PEMFs group had the fastest recovery period of the MF. As a result of the contrast test on the peak torque, it was an approximation to the peak torque at pre-exercise in the PEMFs group after 14 minutes. However, the significant treatment period of peak torque of TEAS group was not found.

After the PEMFs penetrates an electric conductor like a living body, bioelectric currents can generate eddy current in tissue and give impact to various tissues such as the nerve or muscular tissue, etc. The time-changing magnetic field such as the PEMFs induces an electric field based on Faraday's Law of Induction and produces a current in the body's conductive tissue [51-53]. The PEMFs in the form of the ELF induces non-significant heating of the tissue below normall y generates the thermal fluctuation in tissue [54]. Thus, PEMFs was considered the better way that its ability has more therapeutic effect on fatigue due to the positive effect in tissue or an acupoint included by transcutaneous nerve.

Conclusion

There has been an increasing attention in the clinical research of manual acupuncture in TCM [55-57]. However, manual acupuncture in clinical practice has not been widespread due to its invasive nature. Thus, we suggested a new method using the PEMFs which have been widely used as a non-invasive alternative method. In order to confirm therapeutic effect, we compared TEAS on the rate of recovery of quadriceps force capacity after strenuous knee extension/flexion exercise. This study concluded that the PEMFs were a better way to facilitate muscle recovery ra ther than the TEAS.

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