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Comparative Analysis of Photoplethysmography under Pulsed Magnetic Field and Low Level Laser Stimulus: Motivation for Blood Flow Increase using Stimulus on Acupoint LI4 (Hegu)

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The purpose of this study was to investigate the effect of pulsed magnetic field (PMF) and low frequency low level laser (LFLLL) stimuli on acupoint LI4 (Hegu) using photoplethysmography (PPG). Our PMF system was designed to generate maximum intensity of 0.20 T at a transition time of 0.16 ms, with pulse intervals of 1 Hz. The diode laser with wavelength of 650 nm and power of 5 mW was also employed. It was observed the change of the pulsating blood volume through measuring PPG signals from both hands. These results imply that stimulating acupoint LI4 with PMF and LFLLL improves the circulation of peripheral vascular system. In particular, PMF stimulation brings a big improvement of the blood flow even with short term stimulation of 3-4 minutes compared to LFLLL stimulus.

Keywords : pulsed magnetic field stimulus, low level laser stimulus, acupoint LI4, PPG

1. Introduction

Photoplethysmograpy (PPG) is a signal for measuring the change of blood volume in blood vessel upon cardiac impulse using absorption, reflection, and dispersion of light and useful technique for evaluating volume changes in peripheral vessels, reflecting both central and peripheral arterial factors [1]. The signal is obtained by the reflected wave pattern when a light source such as infrared light was injected into fingertips or around wrists. The blood flow can be measured by observing the pulsating component of PPG signal by irradiating light into fingers since the blood flow in fingers change following the cardiac impulse.

Acupoints are acupuncture points located above the 12 meridians, and the spots for the treatments that control the meridian system including acupuncture and moxibustion. Hegu (LI4) is the original point of the large intestine meridian among the 12 meridians, and known to govern the upper half of the body. Acupoint LI4 is also known to be related to blood and Qi-blood circulations [2]. In Korean medicine, acupoint LI4 is controlled by invasive methods including acupuncture, moxibustion, and acupressure that accompany certain amount of pain. Patients can be uncomfortable and even be reluctant to the treatments accompanying pains. Acupoint LI4 is located at the back of a hand slightly above thumb and index finger. In folk remedies, this point is the usual spot for acupressure treating indigestion.

On the other hand, strong pulsed magnetic field stimulus (PMF) to the human body is known to be used for various diseases including muscular disease since it is non-invasive and able to stimulate the nervous system and muscles in deep tissues generating eddy current [3]. PMF treatment began in 1970s and has been widely used for various pain treatments since the FDA approval in 1979. There has been and still is a great deal of research on the therapeutic effect of PMF [4-6]. There are multiple reports regarding increased therapeutic effect for the patients reluctant to invasive methods including acupuncture [7, 8]. The effect of PMF on blood flow is explained by the fact that the biotic ions in blood vessels move and collide into the vessel walls and remove the sediment from the vessel walls improving the blood flow when the strong PMF stimulates the capillary vessels. An alternative theory is that PMF stimulates the central nervous system to gene-

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rate the contraction and relaxation of blood vessels and the sympathetic signal transferred to brain through the spinal cord affects the capillaries and vessels to increase blood volume. It was observed that the rouleau formation of red blood cells was scattered and blood flow was improved after PMF stimulus of 10 min. in our recent study [9]. Therefore we could conclude that magnetic field influence rouleau formation of red cell in blood vessel and it stimulates blood circulation in whole body.

Medical laser was put to practical use when laser operation devices appeared in 1970s. In Korea, laser operation devices were introduced in late 1970s and diverse types of medical laser are being operated and the acceptance for laser equipment is rapidly increasing. The low frequency low-level laser (LFLLL: 420-900 nm, 20 mA) for medical use does not generate heat and does not penetrate deeply into tissue with little dispersion. It transfers only the light energy penetrating the skin surface without any damage to the internal cells of the body. It expands blood vessels and brings up cell division promotion, cell activation by metabolic promotion, positive effects on immunocyte, and anti-inflammatory effect. The red region of low frequency is known to most effective for treatments. Previous studies also indicate that blood vessel expansion and blood circulation improvement can be achieved by continuous and repetitive irradiation of laser [10, 11]. LFLLL devices are safer for human body than high-level laser devices.

While the number of cases where lasers are used in clinical treatments has increased, the properties of response induced by laser stimulus on acupoints still remain under-researched. This study attempts to compare the change of pulsating blood volume in micro-circulatory system of fingertips before and after the stimuli by measuring PPG of the subjects after stimulating LI4, the acupoint related to blood circulation, with LFLLL and PMF.

2. Experiment

Six subjects of the current study were randomly selected 5 males and 1 female without any experiences of electro-magnetic or low frequency low level laser treatments. They all had no cardiovascular diseases and remained healthy at least for a week prior to the experiment. The ages of the subjects ranged from 20 to 26. The subjects were clearly informed of the purpose and method of the experiment and signed the written agreements. To observe the degrees of the contraction and expansion of capillaries and blood flow wave patterns upon PMF and LFLLL stimuli, we placed both hands at the same height for the individual subjects. Our experiment was done in a shielding room and guided the subjects to take comfortable postures to minimize external stimuli and unnecessary tension of the body. Fig. 1 shows the photographs of experimental setup of measurement system in (a) pulsed magnetic field stimulus and (b) low frequency low level laser stimulus.

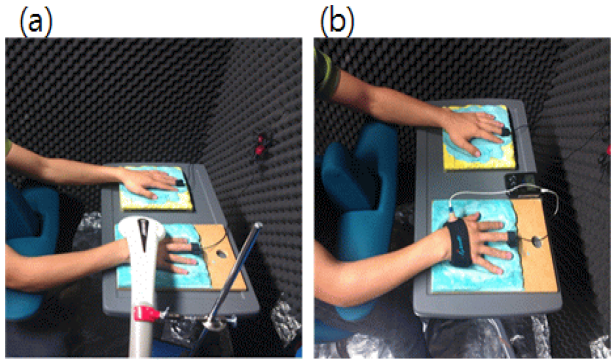

Fig. 1. (Color online) The photographs of measurement system in (a) pulsed magnetic field stimulus and (b) low frequency low level laser stimulus.

Although PMF and LFLLL stimuli were given to right hand acupoint LI4, we also measured the PPG signal from left hand without any stimulus to observe the effects of the stimuli on the blood volume and circulation in the whole body. LFLLL we used was a semiconductor laser (Indium, gallium-aluminum-phosphide) with output of 5 mW, wavelength of 600 nm. The intensity and frequency of our PMF stimulating device were 0.2T and 1 Hz, respectively. We set the sampling frequency of the device as 200 Hz. The subjects were stabilized for 30 minutes before experiment, and PPG sensors were attached to the distal phalanx of the middle fingers of both hands. In order to evaluate blood volume changes in peripheral vessels, the entire PPG data were collected for 3 min. before PMF/LFLLL stimuli and continuously during stimuli of 10 min. and after stimuli. MP35 system (BIOPAC Systems, Inc., Santa Barbara, CA, USA) and Acqknowledge programs were employed to analyze PPG signals.

Fig. 2(a) shows the raw signal of the measured PPG signal. We calculated the temporal change of pulsating blood volume by dividing the PPG data measured for total 16 minutes into a set of 1-minute long segments. As the non-pulsating component signifies the baseline blood flow volume, we can observe the change of the blood flow volume increased by the temporary expansion of blood vessels by looking at the pulsating component when acupoint LI4 is stimulated. In Fig. 2(b), we removed the non-pulsating component from the raw signal after interpolating the lowest points of the raw signal to calculate the pulsating component.

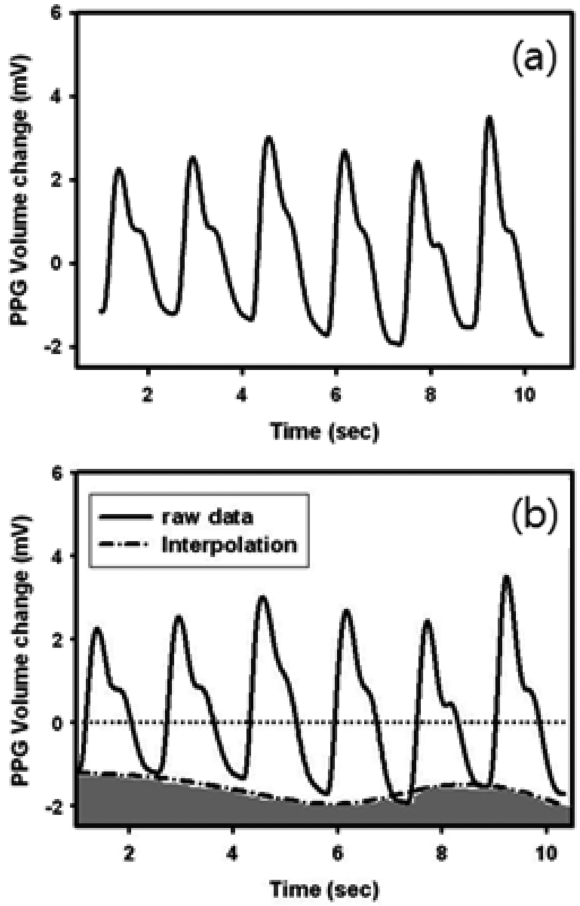

Fig. 2. (a) PPG raw data (b) interpolating the lowest points of the raw PPG signal to calculate the pulsating component.

3. Results

The increased blood flow volume after PMF and LFLLL stimuli was calculated by extracting the pulsating component with removing the non-pulsating component from the PPG signal, as the non-pulsating component of the PPG signal represents the basic blood flow volume.

Fig. 3 shows the varying pulsating blood volume upon stimulation time acquired from the PPG signals of both hands after PMF stimulation. The unit of the calculated blood volume change is V_{ppg}·sec (mV·s), and the values on Y axis are relative values (percentage) because we measure the relative change of the blood volume after stimulation based on the change of blood volume in stabilized period of 3 minutes before the stimulation. According to the result, the change of blood volume of left hand and that of right hand are increased with PMF stimulation. As already mentioned, PPG was measured for both hands to observe the effect of the PMF stimulus on blood volume and circulation in the whole body. This observation confirms the PMF stimulus' role in promoting

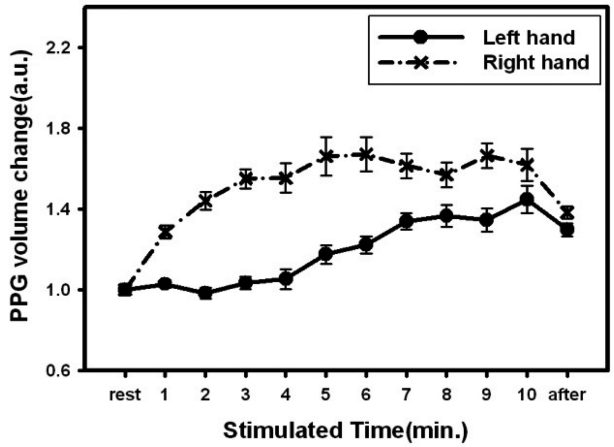

Fig. 3. The varying pulsating blood volume upon the stimulus time acquired from the PPG signals from both hands after stimulating right hand LI4 points with the pulsed magnetic field.

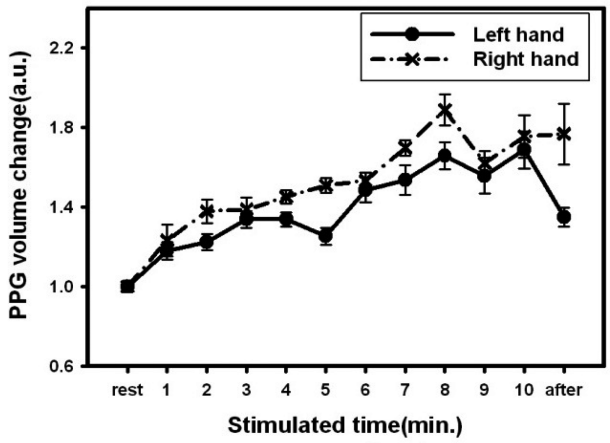

Fig. 4. The varying pulsating blood volume upon the stimulus time acquired from the PPG signals from both hands after stimulating right hand LI4 points with the low level laser.

blood circulation. The blood flow of left hand and right hand exhibited 44% and 60% increases during 10-minute stimulation when we compare the measurements with the baseline measurements in stabilization period. In right hand, the blood flow increased approximately 58% for 3-4 minutes and stabilized without any big increase due to the adaptation response of the autonomous nervous system for the sustained stimulation. We determine that PMF can bring enough blood flow improvement only with 3 to 4 minutes of stimulation.

In Fig. 4, the varying pulsating blood volume upon LELLL stimulation time acquired from the PPG signals from both hands is plotted. The values are relative values compared to the measurements in stabilization period before the stimulation. The blood volume changes of both

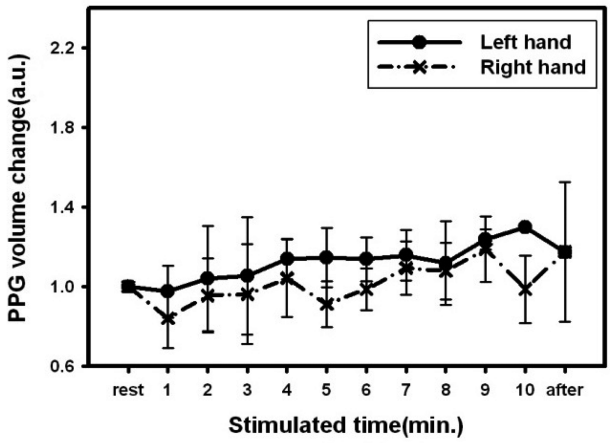

Fig. 5. The varying pulsating blood volume acquired from the PPG signals from both hands without any stimuli.

hands show almost identical aspects for LFLLL stimulation. During the 10-minute LFLLL stimulation, left and right hands exhibited 65% and 85% increases of blood flow, respectively. In right hand, the blood flow increased approximately 85% at 8 minute point, and the increase was maintained even after stopping the stimulation. In left hand, the blood flow increased approximately 60% at 10 minute and decreased after stopping the stimulation. From this observation, we can view that the blood flow decrease occurred in stimulation over 8 minutes is the factor for restraining the sympathetic nerve, which belong to the autonomous nervous system, and activating the parasympathetic nerve.

Fig. 5 displays the varying pulsating blood volume of both hands calculated from the PPG signals measured without any stimulation. It was expected that there would be no change of blood flow rate without stimulating the acupoints. In reality, however, the changes of the blood flow rate were observed even with the comfortable posture guidance and the unnecessary external stimuli minimization. These changes are believed to be caused by the uneasiness of taking maintaining same posture for some time and change of the mood during experiment. However, the variances of the blood flow rate without stimulations are relatively small compared to those of PMF and LFLLL stimulations. Therefore, we determine that stimulating LI4 points with PMF and LFLLL is effective on improving the blood flow rate.

4. Finding and Conclusion

The current study observed the change of the pulsating blood volume through measuring PPG signals from both hands, stimulating the right hand acupoint LI4 with non-invasive PMF and LFLLL. In case of PMF, we saw that the blood volume of left and right hand increased approximately 44% and 60% during 10-minute stimulation, respectively, compared to the baseline measured in stabilization period. In case of LFLLL, we saw that the blood volume of left and right hand increased approximately 65% and 85% during 10-minute stimulation, respectively. These results imply that stimulating acupoint LI4 with PMF and LFLLL improves the circulation of peripheral vascular system. In particular, PMF stimulation brings a big improvement of the blood flow even with short term stimulation of 3-4 minutes compared to LFLLL stimulus.

The increase of blood flow brought by PMF and LFLLL stimuli can be interpreted as follows. PMF directly affects blood vessels to make various ions in the blood vessels to stimulate the vessel walls expanding the vessels resulting the increase of blood flow. LFLLL converts the light energy absorbed by the cells in body to chemical energy that can heal the cell damage and generates the vital facilitation effect.

From the fact that the blood flow improvement was also observed in left hand without stimulation, the stimulation is believed to be effective in blood circulation of the whole body not just stimulated right hand.

Since stimulating acupoint LI4 affects overall blood circulation, we expect that stimulating acupoint LI4 of patients with bad blood circulation in other body parts will improve the blood circulations for the patients. Stimulating acupoint LI4 with PMF and LFLLL also induces rest and relaxation by activating the parasympathetic nervous system that heals stress since the stimulation increases the blood flow and homeostasis.

If the duration of the stimuli exceed certain threshold, the increase of blood flow slows down due to the adaptation response. Consequently, further work is needed regarding optimizing the stimulation conditions including the strengths of PMF and LFLLL, stimulation duration, the frequency and wave pattern of PMF, the wavelength of LFLLL to maximize the blood flow rate improvement.

One of the current study's implications is that stimulating acupoint LI4 with PMF and LFLLL can replace the invasive acupuncture treatment method which sometimes makes patients nervous. We also expect that patients will be able to perform self-care at home if guidelines for PMF and LFLLL stimulation treatments can be provided through a long-term research.

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