

## Study on Improvement of Blood Stagnation by Pulsed Magnetic Field

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**This study explored the effect of pulsed magnetic field (PMF) stimulus on the improvement of blood stagnation by means of photoplethysmography (PPG). Our stimulus system was designed to generate PMF with a maximum intensity variation of 0.20 T at a transition time of 160  $\mu$ s, with pulse intervals of 1 Hz. In order to quantitatively estimate vascular condition, indices such as blood vessel tension (BVT), stress power (SP), differential pulse wave index (DPI) and remained blood volume (RBV) were calculated from the second derivative of the PPG signal and power density spectrum (PDS). Our results showed that non-invasive PMF stimulus was effective in improving blood stagnation. Therefore, it may be concluded that appropriate PMF stimulus affects the blood circulatory system.**

**Keywords :** pulsed magnetic field (PMF), photoplethysmography (PPG), blood stagnation

### 1. Introduction

According to traditional Chinese medicine (TCM), blood stagnation is known as a common and damaging pathogenic factor that is at the root of many serious diseases such as coronary heart disease, abdominal masses, tumors, high blood pressure, strokes, etc. It is described as a slowing or pooling of the blood due to disruption of Heart Qi and is understood in biomedical terms of hematological disorders such as hemorrhage, congestion, thrombosis, and local ischemia and tissue changes [1].

The formation of blood stagnation is caused by the aging of blood vessels, abnormality of the circulatory metabolism or traumatic injury. Its characteristic can occur only after a prolonged period of time, and it was mainly found in the elderly and accompanied by disorders of peripheral arterial circulation. Since there are risk factors for cardiovascular complications such as stroke, hyperlipidemia, hypertension, atherosclerosis, etc, and those can develop into more serious diseases, it is necessary to treat blood stagnation in its initial stages [2].

Meanwhile, pulsed magnetic field (PMF) stimulus to the human body is widely known as a therapeutic appli-

cation for the improvement of neurological disorders, musculoskeletal disorders, rheumatological disorders, spinal fusions, and soft-tissue regeneration, due to its inducing electric fields and current flow in muscles and nerves and conducting impulses toward the deep tissues [3].

Many researches related to PMF stimulus therapy have been published. For example, it was effective in reducing muscle soreness in marathon runners [4]. The effects of PMF stimulus on the autonomic nervous system and frontal lobe activities were evaluated in several papers [5, 6]. Shupak et al. showed that exposure to PMF stimulus has a potential analgesic effect with increased pain thresholds [3]. Also it has been reported that PMF stimulus increases the therapeutic effect due to reducing the reluctance of patients to undertake acupuncture therapy [7].

The physiological mechanism for the effect of PMF stimulus on blood flow has not yet been clarified, but it might be explained macroscopically that a strong PMF stimulates the capillary vessels, makes the biotic ions in vessel walls collide with each other, removes sediment from the vessel walls, and improves the blood flow.

Photoplethysmography (PPG) is a noninvasive technique for measuring the blood volume changes in peripheral vessels, reflecting both central and peripheral arterial factors [8]. The signal is obtained by detecting changes in reflected or transmitted light when a light source such as infrared light is injected into the fingertips or around the

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wrists. The light received in a photo detector is closely related to changes in the blood flow volume in the underlying tissue. Measuring the intensity of radiation through an optical receiver of the PPG sensor could detect a change in the blood flow that is synchronized to the heart beat.

Acceleration photoplethysmogram (APG), as a second-order derivative of the pulse wave signal detected by the PPG sensor, indicates subtle changes to the pulse wave and can be used to evaluate the peripheral blood circulation. Five PPG analysis indices obtained from APG are defined as: differential pulse wave index (DPI); stress power (SP); blood vessel tension (BVT); remained blood volume (RBV); and wave type (WT) of APG. They can be used for diagnosis of vascular aging and vascular flexibility as well as blood stagnation.

DPI is closely related to the aging of blood vessels and its values are decrease with age. SP reflects the extensibility of blood vessels [9]. BVT is a measure of the elasticity in contracting and releasing the blood vessels. The larger the absolute values of SP and BVT are, the better the condition of the blood vessels. RBV indicates the remained blood volume after the contraction of blood vessels, so a low value means that the blood is flowing well in the vessels. In the case of atherosclerosis, RBV increases [10]. Fig. 1 shows the shape of the WT level. The lower the level of WT is, the better the condition of the blood vessels.

Therefore, the purpose of this study was to determine if PMF stimulus would have a significant effect on blood flow, by means of PPG analysis, and to investigate quantitatively if PMF stimulus would improve the blood stagnation syndrome closely related with blood flow.

## 2. Experiment

Our experiment was carried out in a shielding room. We guided the subjects to make themselves comfortable, to minimize external stimuli and unnecessary tension of the body. The subjects were stabilized for 30 minutes before the experiment, and one specialist conducted a

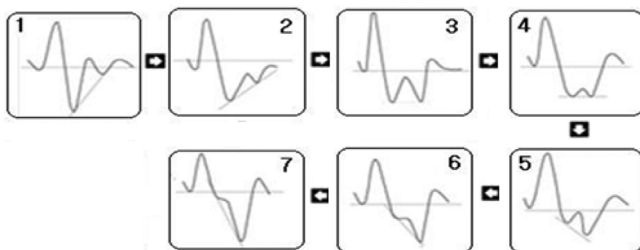


Fig. 1. Definition of wave type level for APG waveform.

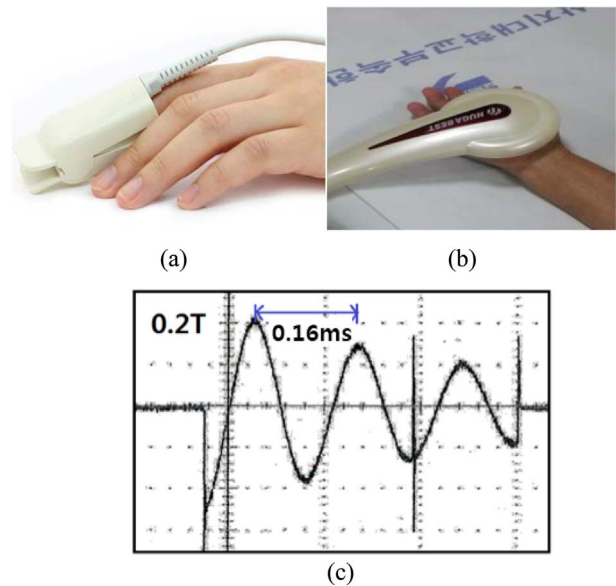


Fig. 2. (Color online) Experimental set-up for: (a) PPG sensor attached to the index fingers; (b) PMF stimulator applied on the palm; (c) intensity and pulse duration of our PMF system.

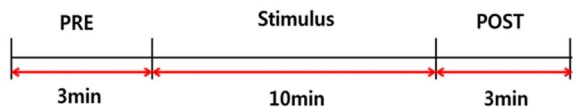
questionnaire analysis for blood stagnation in order to obtain consistent results for all subjects. All subjects were clearly informed of the purpose and method of the experiment and provided their written agreements, approved by Sangji Institutional Review Board.

Ten subjects in their 60s or older (five males and five females, average ages:  $75.4 \pm 7.9$  years) and four subjects in their 20s (two males and two females, average ages:  $21 \pm 1.8$  years) participated in the study. The average scores of the questionnaire analysis for blood stagnation were 12 and 4 for the 60+ group and the 20s group, respectively. The higher questionnaire score means that blood stagnation syndrome had appeared.

SA-6000 (Medicore) and MP 36 system (Biopac Systems, Inc., Santa Barbara, California, USA) were employed to collect PPG signals. PPG sensors were attached to the distal phalanx of the index finger of the subjects' left hands and PMF stimulus was applied to the palm of subjects' right hands (see Fig. 2(a), (b)).

The entire PPG data were collected with the subjects alert but with eyes closed, and were recorded during a three-minute resting period before PMF stimulus began, and continuously during and after PMF stimulus. Figure 3 shows the timeline of the experiments, indicating the order of events. The PPG signals were digitized by an analog-digital converter with sampling rate of 100 Hz, and were high-pass-filtered at 0.5 Hz and low-pass-filtered at 50 Hz.

Our PMF stimulator was a prototype manufactured by



**Fig. 3.** (Color online) Timeline of the experiment, indicating the order of events.

Nuga Medical Co. Ltd, Korea, and was certified as MRT-II by the Ministry of Food and Drug Safety in Korea. The PMF device consisted of a magnetic field generator and a flat multiple layer disk coil, and it generated a time-varying PMF stimulus which had a peak magnetic field intensity of 0.2 T, 5 mm away from coil, and a magnetic field pulse duration of 160  $\mu$ s. The pulse duration was 480  $\mu$ s, including three micro-pulses, and the pulse repetition rate was 1 Hz (see Fig. 2(c)).

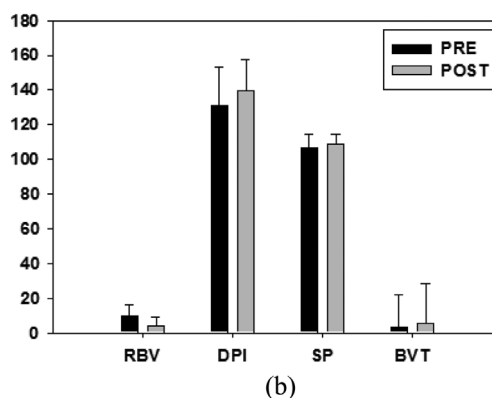
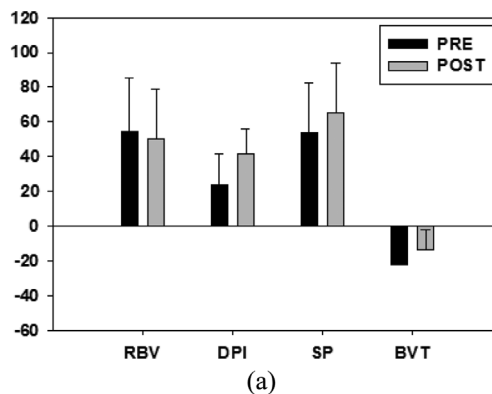
To investigate the change of the blood flow in the peripheral vessel caused by PMF stimulus, the PPG signals were analyzed using Acknowledge software. The power density spectrum (PDS) obtained from a fast Fourier transform (FFT) of the PPG signal was employed to analyze the change in peak amplitude of the first, second and third harmonic waves. It is known that the harmonic peaks of the PDS signal are related to vasodilation. Increases in the amplitudes of peaks of the PDS means improved vascular compliance [12].

According to the questionnaire analysis for blood stagnation, the five PPG analysis indices, DPI, SP, BVT, RBV and WT, were highly correlated with blood stagnation syndrome [11]. Therefore, we compared PPG analysis indices in order to observe the relation between the improvement of blood stagnation and the effect of PMF stimulus.

### 3. Results

It is not easy to observe improvement of blood stagnation syndrome with a PPG raw pulse wave. Therefore, APG and PDS analyses were introduced, and the five PPG analysis indices validated with the questionnaire analysis for blood stagnation were compared before and after PMF stimulus.

Fig. 4 shows the changes to four of the PPG indices (DPI, SP, BVT and RBV) after PMF stimulus to the 60+ group and the 20s group. DPI, SP and BVT all increased after PMF stimulus, and RBV decreased. These phenomena were the same in both age groups. As mentioned above, increased DPI, SP and BVT mean improved elasticity and extensibility of the blood vessels. In addition, since RBV is the remained blood volume, a decreased RBV could be explained by blood flowing



**Fig. 4.** The changes of PPG indices DPI, SP, BVT and RBV after PMF stimulus in (a) the 60+ group and (b) the 20s group.

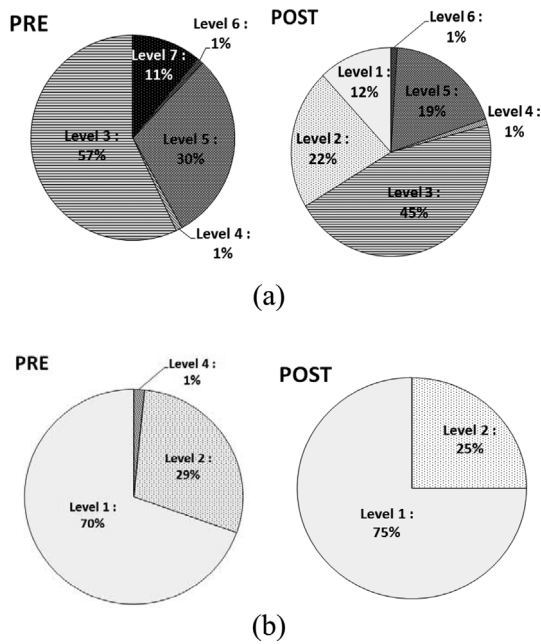
well. Therefore, PMF stimulus was effective on the blood stagnation syndrome.

Fig. 5 shows the percentage change in the level of WT after PMF stimulus. In both groups of subjects, the percentage change at the lower levels in WT increased remarkably in comparison to that at the higher levels in WT.

As shown in Fig. 5(a), in the 60+ group, there was data spread across all seven levels before PMF stimulus, but after PMF stimulus the ratio of levels 1-3 was larger than that of levels 4-7. Meanwhile, in the 20s group, there was data in levels 1-4 before PMF stimulus. But after PMF stimulus, level 4 of WT disappeared and the percentage change at level 1 increased to approximately 75%.

As a whole, the ratio of lower levels increased after PMF stimulus. This means that PMF stimulus could improve the state of blood vessels.

In Fig. 6, the PDS obtained from the FFT of PPG raw data are plotted, which show the results compared before and after PMF stimulus for the subjects in both age groups. The maximum values of the fundamental peaks in PDS exhibited 711% and 160% increases after PMF stimulus in the 60+ group and the 20s group, respectively,



**Fig. 5.** The percentage changes in the level of wave type after PMF stimulus in the subjects of (a) the 60+ group and (b) the 20s group.

compared with before PMF stimulus. These results support the proposition that PMF stimulus could be used to improve vascular compliance.

First, second and third harmonic waves were clearly in evidence in the results of the 20s group, but not in the 60+ group. This is because the state of the blood vessels in the 20s group was much better than for those in the 60+ group. Our questionnaire scores for blood stagnation exactly support this result.

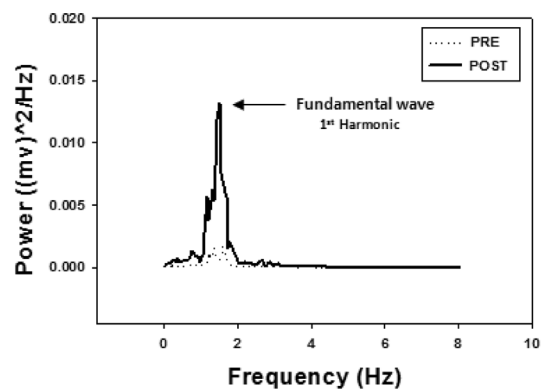
Based on the results obtained from the five PPG analysis indices (DPI, SP, BVT, RBV and WT), and the amplitude of the PDS curves shown in Figs. 4-6, it could be concluded that PMF stimulus is more effective for improvement of blood stagnation syndrome in the 20s group than in the 60+ group. The reason is that the older subjects are more likely to accompany the peripheral circulatory disturbance, so 10 minutes of PMF stimulus is not sufficient to bring about an immediate effect.

As support for our hypothesis, the youngest subject in the 60+ group, who was 63 years old, showed the best results among the group in all PPG analysis indices. For the oldest, who was 88 years old, the effect of 10 minutes of PMF stimulus showed incomplete.

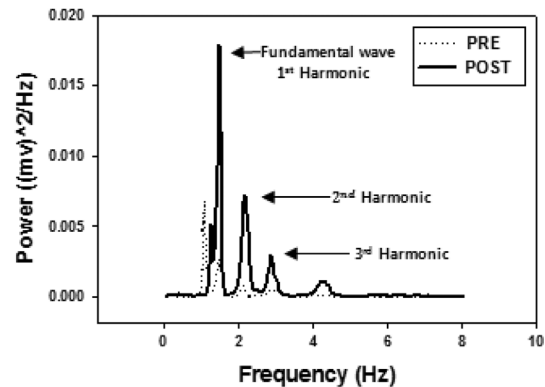
Therefore, in order to see clearly the effect of PMF stimulus in the 60+ group, it was repeatedly applied to two subjects, A and B, for 10 minutes every 2-3 days over a period of two weeks. Subjects A and B were 66 and 81 years old, respectively.

**Table 1.** The percentage change of wave type level after continuous PMF stimulus, every 2-3 days for two weeks.

wave type level	Subject A		Subject B	
	PRE (%)	POST (%)	PRE (%)	POST (%)
1	0	0	0	0
2	0	0	0	0
3	40	100	0	0
4	0	0	1	2
5	60	0	38	90
6	0	0	7	6
7	0	0	54	2



(a)

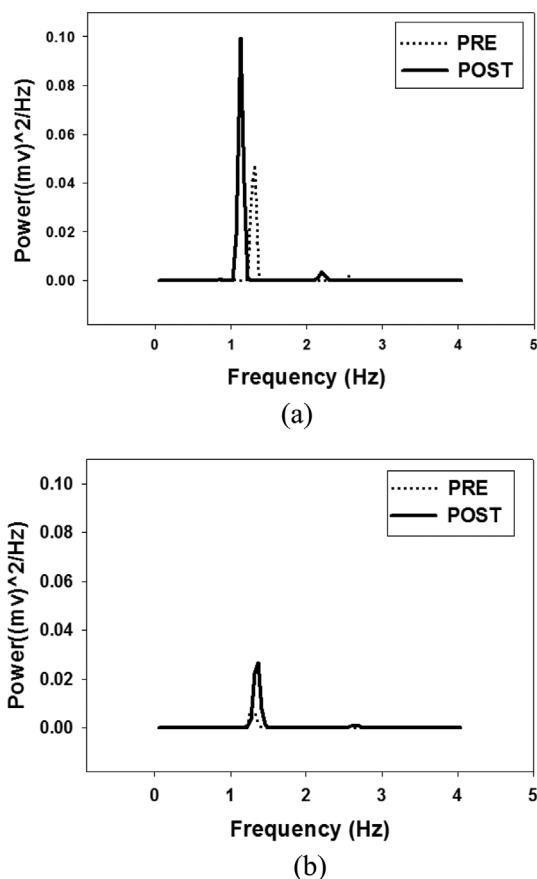


(b)

**Fig. 6.** The change of power density spectrum obtained from FFT of PPG raw data, showing the results before and after PMF stimulus in (a) the 60+ group and (b) the 20s group.

As shown in Table 1, for subject A, the WT level was shown in levels 3-5 before PMF stimulus. But it was observed that the level 5 disappeared and the percentage change of level 3 increased after PMF stimulus. For subject B, it was observed that the WT levels were spread between levels 5 and 7. After PMF stimulus this changed to level 5, with a reduced percentage change of level 7.

Receiving PMF stimulus regularly could verify the



**Fig. 7.** The change of power density spectrum of (a) subject A and (b) subject B upon frequency, calculated from FFT of PPG raw data before and after PMF stimulus.

lowered level of WT and the good condition of the blood vessels. This observation confirms the role of PMF stimulus in promoting blood circulation and improving blood stagnation.

Fig. 7 shows the PDS of subjects A and B upon frequency calculated from FFT of PPG raw data before and after PMF stimulus. According to the result, peak amplitude of the first harmonic wave in PDS increased with regular PMF stimulus for both subjects, but was more dominant in subject A, who was younger than subject B. Unlike for the 20s group shown in Fig. 6(b), the second and third harmonic peaks barely appeared in either subject. Since the first peak was more noticeable in subject A, the younger subject showed the better vascular conditions.

Accordingly, by stimulating the palm of the right hand with non-invasive PMF, the current study observed improvements to blood stagnation syndrome by quantitatively estimating blood flow, elasticity and extensibility of blood vessel, and vascular compliance by means of PPG analysis indices (DPI, SP, BVT, RVB, WT) and PDS.

## 4. Finding and Conclusion

For the 60+ age group, the PMF stimulus effect appeared considerably weaker than in the 20s age group. However, among the 60+ subjects, the youngest subject showed better results in all the PPG analysis indices than the oldest subject.

Therefore, it could be concluded that the effects of PMF stimulus were slower to appear in the older adults progressing vaso-aging because of their slower bodily reactions. In order to improve blood flow for the 60+ group, continuous PMF stimulus for several days is more effective than PMF stimulus for a short period of time.

More experiments are required to discover the optimum conditions for older adults, such as the duration of stimulus and the intensity of PMF. In addition, live blood analysis is needed to verify our results, and to understand the relation between the rouleau condition of red blood cells and blood stagnation. Therefore this study may suggest that PMF stimulus could be used as a non-invasive therapy for improving blood stagnation symptoms by comparison of the PPG analysis indices before and after PMF stimulus.

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