

# The Change of Capillaroscopic Features under Pulsed Magnetic Field

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The purpose of present study is to observe the change in capillaroscopic features before and after pulsed magnetic field (PMF) stimulus: the number, shape, length of capillary loop, and diameters of efferent capillary, and images of capillary loop. Nailfold capillary microscopy was used to quantitatively estimate the change of morphological characteristics of the capillaries. Capillary blood flow is recorded using video camera recorded at a frame rate of 60fps attached to the microscope. The velocities of capillary blood cell were  $441 \pm 22$  and  $508 \pm 20$   $\mu\text{m/s}$ , before and after PMF stimulus, respectively. For the nailfold capillary morphologies, compared to before PMF, the more clearly visible loops are arranged as well as the capillary loop lengthened after PMF stimulus. Also the numbers of capillary loop/mm increased after PMF stimulus. In addition, tortuous capillary turned to hairpin shaped loop and the number of tortuous and abnormal capillaries are reduced after PMF stimulus. Our results proved the PMF stimulus on the palm of left hand for 10 min. provide the improvement of capillary blood flow, and it decreases vascular resistance in the blood micro-circulatory system. In addition, our study suggested quantitative and qualitative parameters of the nailfold vasculature in order to elucidate the effect of PMF. For expanding our findings, we need to have more subjects across a wide spectrum of age and with microvascular abnormalities, such as scleroderma, dermatomyositis and related disorders.

**Keywords :** pulse magnetic field, nailfold capillaroscopy, capillary loop, capillary morphology, capillary blood flow velocity

## 1. Introduction

Since pulsed magnetic field (PMF) is known to very useful tool to manipulate chemical and physiological processes in human body, many researchers have studied the influence of magnetic field on various biological phenomena *in vivo* as well as *in vitro* [1, 2]. Therefore, there is a growing interest in the use of magnetic fields. Among many studies on the effects of magnetic fields on the human body, various results depending on the type of magnetic fields have been reported [3, 4].

As an example of the effect of magnetic field on erythrocyte aggregation, Iino *et al.* investigated the effect of homogeneous static magnetic field (SMF) of 6.3T using erythrocyte sedimentation rate (ESR) [5]. Red blood cells (RBCs) exposed in the static field increased aggre-

gation, deformed its shape, and deteriorated blood flow [6]. Ueno *et al.* investigated the effect of alternating magnetic fields (AMF). Their results were a rapid decrease in blood flow and accompanying the pain [7]. Preliminary study in our group has shown that optimum PMF stimulus induce the disaggregation of stacked red blood cells (RBCs) and fast movements of RBCs, and have influence on the blood flow [8]. Although the effects of SMF or AMF have been shown in various ways, the effect of PMF has indirectly been confirmed through bio- signals, such as PPG and ECG, and the study through direct observation was insufficient yet [9].

Blood, tissues, cells, substances, etc. are exchanged in the microcirculatory system. When its dysfunction occurs, a sufficient amount of oxygen and nourishment could not be supplied to tissue cells, and metabolic activity might not be properly performed, resulting in damage to the internal organs, leading to a disease state. Therefore, in order to prevent vascular-related diseases, it is necessary to observe the condition of microvascular vessels steadily.

Particularly, the nailfold region is convenient for microscopic observation of the capillary network because of its immediate access and because the capillaries are placed

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horizontally, allowing them to be visualized on their long axis. Observing nail capillaries might find the cellular diseases or diseases associated with it. Nail capillaries vary in their loop shape, length, and capillary diameter depending on the disease. Therefore, nail capillaries can be used as an indicator of any disease or health condition [10]. Accordingly nail capillary observations are one of the best ways to quickly and directly identify the effects of PMF through blood flow, and are also suitable for observing health conditions due to long-term PMF effects.

The purpose of present study is to observe the change in capillaroscopic features before and after PMF stimulus: shape and images of capillary loop. In addition, we have tried to elucidate quantitatively the effect of PMF on the objective parameters for nailfold vasculature, such as linear capillary density, diameters of efferent capillary and loop length, blood flow and blood velocity. It is also important to verify continuous effect of PMF stimulus.

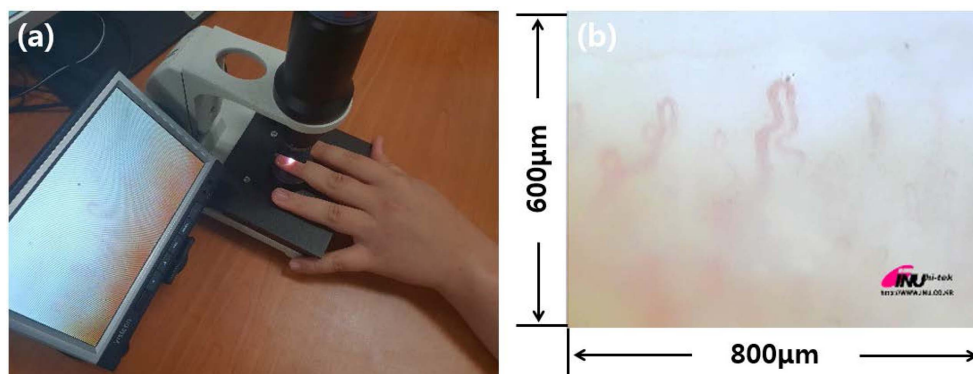
## 2. Experimental Method

Capillary scope (MC500S1) optimized for the observation of nailfold capillary vessel was used to see the changes of

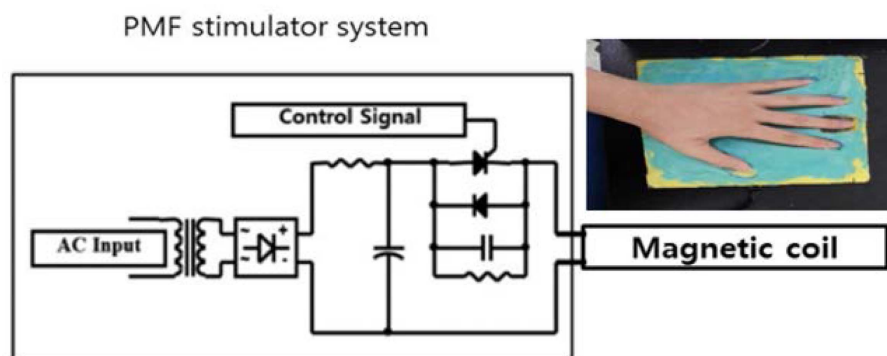
nail capillaroscopic features before and after PMF stimulus, addressing the following parameters: capillary morphology, hemodynamic changes such as blood flow and velocity. The middle finger of left hand was put on the supported base, mounted on the x-y stage of reflective microscope. A drop of mineral oil was spread over the observation site to improve image quality. The entire nailfold bed was observed with microscope with magnification of 210 times and visual field of  $800 \times 600 \mu\text{m}$ , and recorded at a frame rate of 60 fps with attached video camera.

Fig. 1 is an experimental setup for measuring nailfold capillary. Captured optical images of nailfold capillary were  $640 \times 480$  pixels and the spatial resolution is about  $1.25 \mu\text{m}/\text{pixel}$ . All experiments were conducted at room temperature of  $20^\circ\text{C}$ .

Fig. 2 is our PMF stimulator system which consists of single layered coil of 10 turns with an elliptical shape of  $12.0 \times 4.5$  cm. The maximum intensity is 0.27 T, 5 mm away from coil and the pulse duration was  $102 \mu\text{s}$ , including 3 micro-pulses and pulse repetition rate was 1 Hz. Our PMF stimulator system with strong magnetic flux change has shown to be effective on blood perfusion in



**Fig. 1.** (Color online) Experimental setup for measuring nailfold capillary. (a) Capillary scope (MC500S1) with magnification of 210 times and visual field of  $800 \mu\text{m} \times 600 \mu\text{m}$ , and (b) image recorded with attached video camera.



**Fig. 2.** (Color online) Schematic circuit diagram of our designed pulsed magnetic field stimulator system including the magnetic coil. Mold system was used for prevent shaking hand during PMF stimulus.

peripheral vascular system, improvement of erythrocyte rouleaux and increase of blood flow velocity in our previous studies [11, 12]. In order to see the effect of PMF stimulus and understand microvascular flow on the nailfold capillary, the subject’s left palm was exposed to PMF stimulator for 10 min.

Ten volunteers (female: 3, male: 7) with a mean age of 21 years (range: 20-25 years) participated in the study and were obtained the written consent before the study. For removal of any disturbances and interferences, subjects were relaxed for 30 min. before experiment. They were seated in a chair with the left arm at heart level and their blood pressure was measured using electronic sphygmomanometer.

Although capillaroscopic parameters in relation to gender, ethnic classification, and age were reported in a few papers, it is known that for healthy subjects, standard values for linear capillary density, diameters of efferent capillary and loop length are 8-10, 12-17  $\mu\text{m}$  and 130-250  $\mu\text{m}$ , respectively, and normal shape of nailfold capillary is hairpin shaped loop [10].

### 3. Results and Discussion

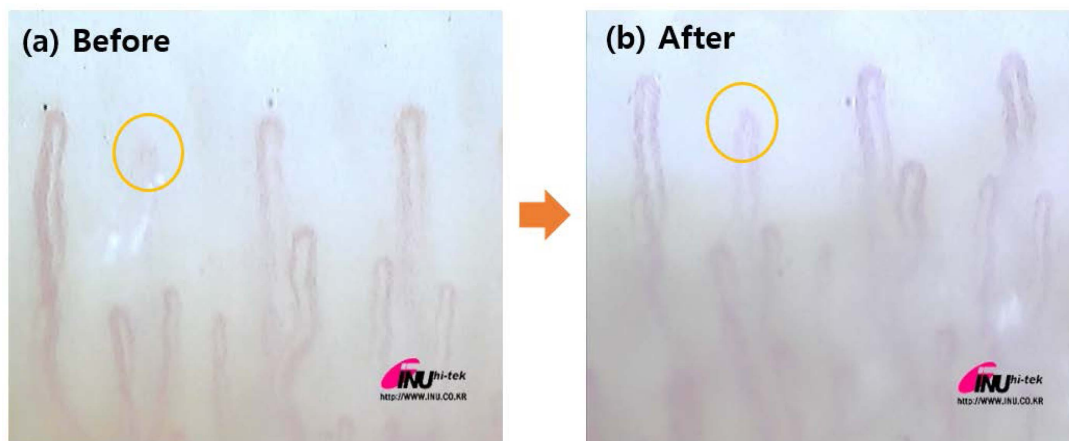
It was known that sudden decrease in the numbers of capillary loop occurs due to blood pressure drops and blood flow decreases. This causes infarcted paralysis or artery constringency. Table 1 indicates functional capillary density for ten subjects. It was counted and averaged the number of capillary loops per millimeter in the distal row capillaries over 3 different spots of nailfold bed in middle finger. The numbers of capillaries/mm increased from  $7.1 \pm 1.1$  to  $8.6 \pm 1.0$  after PMF stimulus of 10 min in the palm of left hand. It could be seen that PMF affects capillary density approaches within the normal range.

**Table 1.** Functional capillary density for ten subjects (numbers of capillary loop/mm)

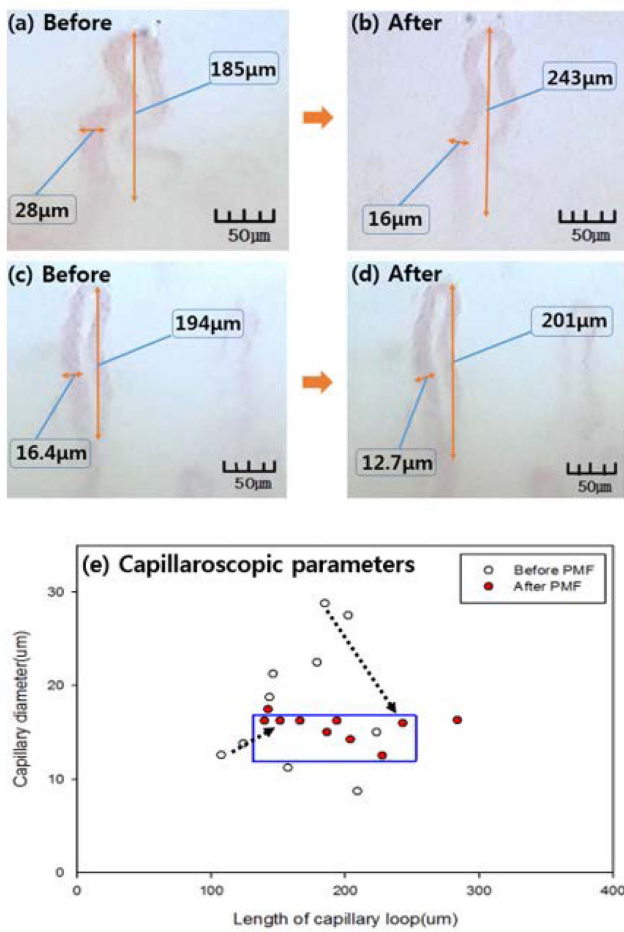
	Number of capillary loop	
	Before PMF	After PMF
Subject A	8	9
Subject B	8	10
Subject C	7	8
Subject D	6	8
Subject E	8	9
Subject F	6	8
Subject G	7	9
Subject H	9	10
Subject I	6	7
Subject J	6	8
	$7.1 \pm 1.1$	$8.6 \pm 1.0$

Fig. 3 shows captured microscopic images in the capillary loop. Fig. 3(a) shows the image of control capillary not exposed to PMF stimulus. Fig. 3(b) is the image observed after exposed to PMF stimulus everyday for 3 months. Compared with circles in (a) and (b), there was morphological change in the apical part of capillary loop, i.e. clearly visible loops were arranged after PMF stimulus.

If the diameter of efferent capillary increases or the loop shape is abnormal like tortuosity, the blood flow velocity decreases. This phenomenon occurs mainly in connective tissue diseases, microglobulinemia, and chronic anoxia. Fig. 4 showed the effect of PMF on capillaroscopic parameters. It can be seen in Fig. 4(a) and (b) that tortuous loop turns into a hairpin shaped loop after PMF stimulus. And the capillary loop lengthened after PMF stimulus from 185  $\mu\text{m}$  to 243  $\mu\text{m}$ . For the other subject in Fig. 4(c) and (d), capillary loop also lengthened from 194 to 201  $\mu\text{m}$ . This trend was explored by analyzing capillary



**Fig. 3.** (Color online) Captured microscopic images in the capillary loop. Fig. 3(a) shows the image of control capillary not exposed to PMF stimulus. Fig. 3(b) is the image observed after exposed to PMF stimulus everyday for 3 months.



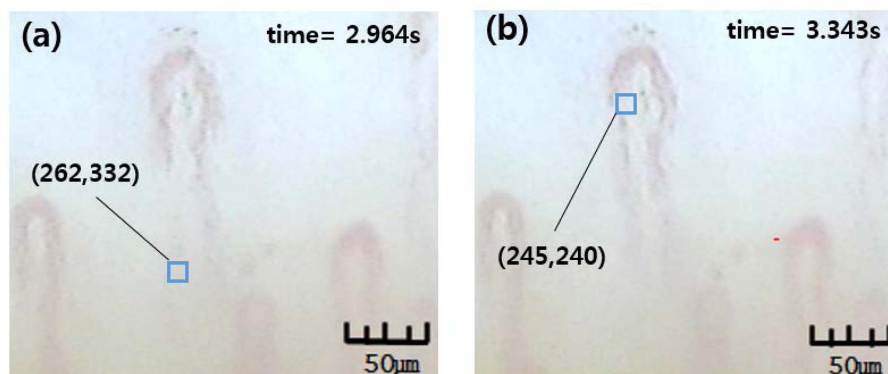
**Fig. 4.** (Color online) Enlarged capillary loop to see the capillaroscopic parameters (a) before PMF, (b) after PMF for Subject A, and (c) before PMF, (d) after PMF for subject B. (e) shows visually how the lengths and diameters of the capillary approach the normal range due to PMF stimulus effect. The blue rectangular box in the Fig. 4(e) represents the normal range of the lengths and diameters of the capillary. The dashed arrows show the change of the length and diameter after PMF stimulus for selected two cases.

loop on the rest of other subjects. Looking at the efferent capillary in Fig. 4(a) and (b), large blood vessels of 28 μm narrowed to 16 μm after PMF stimulus. Fig. 4(c) and (d) also showed the same result as Fig. 4(a) and (b). Fig. 4(e) showed visually how the lengths and diameters of the capillary approach the normal range due to PMF stimulus effect. The blue rectangular box in the Fig. 4(e) represents the normal range of the lengths and diameters of the capillary. The dashed arrows show the change of the length and diameter after PMF stimulus for selected two cases. These results suggest that people underlying disease or instigating cause of vasospastic attacks could be improved by magnetic field treatment. We found that the number of tortuous and abnormal capillaries reduced after continuous PMF stimulus.

Fig. 5 showed continuously captured microscopic images for one selected subject, in order to measure capillary blood flow velocity. The distance between the blue boxes of Fig. 5(a) and (b) showing the blood flow could be calculated using coordinates of the blue box positions and their corresponding time were measured. Calculated velocities increased after PMF stimulus, from  $441 \pm 22$  to  $508 \pm 20$  μm/s. Our results proved the PMF stimulus on hand provide the improvement of capillary flow. Enhancing the flow in the capillary decreases vascular resistance in the blood micro-circulatory system.

#### 4. Conclusion

We have investigated the influence of PMF on the change of capillaroscopic features. Our study focused on quantitative evaluating morphological and functional alterations of nailfold capillary before and after PMF stimulus: linear capillary density, capillary length, diameters of efferent capillary, and images of capillary loop. We found that all these parameters related to the nailfold



**Fig. 5.** (Color online) Continuously captured microscopic images for one selected subject, in order to measure capillary blood flow velocity at (a) 2.964 s and (b) 3.343 s. The time taken for blue box in the Fig. 5 to reach from (a) to (b) was 0.379 s and the distance between two circles was 94 μm.

vasculature have improved and converged to standard values after PMF stimulus of 10 min in the palm of left hand. The numbers of capillaries/mm increased from 7 to 9, and capillary loop lengthened after PMF stimulus. Not only does tortuous capillary loop turn into a hairpin shaped loop, but also the number of tortuous and abnormal capillaries reduced after continuous PMF stimulus. Observing morphological changes of the capillary loop after steady exposure of PMF stimulus for 30 days, clearly visible loops were arranged. Also measured capillary blood flow velocity increased.

Nailfold capillary scope is an important tool for diagnosing and monitoring diseases that are sensitive to the changes of microvascular vessels such as Raynaud's syndrome, diabetes, atherosclerosis [13, 14]. The shape or density of the capillary loop changes under certain conditions. In Raynaud's syndrome, capillary blood vessels are damaged and capillary density is decreased. For further progress, deterioration of capillary structures, such as macro capillaries or distorted blood vessels, are observed. In diabetes, twisted abnormal loop is observed and the blood flow velocity is slower. In atherosclerosis long and thin capillary loop is observed, the thickness of the vessel wall is uneven, and the outline is blurred.

Even though this study was not performed with a group of patients, from our results, PMF stimulus is proposed to achieve improvement of diseases related to microcirculatory system. For expanding our findings, we need to have more subjects across a wide spectrum of age and with microvascular abnormalities, such as scleroderma, dermatomyositis and related disorders.

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