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Effects of Pulsed Electromagnetic Fields on Peripheral Blood Circulation in People With Diabetes: A Randomized Controlled Trial

Jiahui Sun,[1] Rachel Lai-Chu Kwan,[1] Yongping Zheng,[2] and Gladys Lai-Ying Cheing[1]*

[1]*Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region, China*
[2]*Interdisciplinary Division of Biomedical Engineering, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region, China*

Cutaneous blood flow provides nourishment that plays an essential role in maintaining skin health. We examined the effects of pulsed electromagnetic fields (PEMFs) on cutaneous circulation of dorsal feet. Twenty-two patients with diabetes mellitus (DM) and 21 healthy control subjects were randomly allocated to receive either PEMFs or sham PEMFs (0.5 mT, 12 Hz, 30 min). Blood flow velocity and diameter of the small vein were examined by using ultrasound biomicroscopy; also, microcirculation at skin over the base of the 1st metatarsal bone (Flux1) and distal 1st phalange (Flux2) was measured by laser Doppler flowmetry before and after intervention. Results indicated that PEMFs produced significantly greater changes in blood flow velocity of the smallest observable vein than did sham PEMFs (both $P < 0.05$) in both types of subjects. However, no significant difference was found in changes of vein diameter, nor in Flux1 and Flux2, between PEMFs and sham PEMFs groups in subjects with or without DM. We hypothesized that PEMFs would increase blood flow velocity of the smallest observable vein in people with or without DM. Bioelectromagnetics. 37:290–297, 2016. © 2016 Wiley Periodicals, Inc.

Key words: rehabilitation; interventions; PEMFs; foot and ankle; human

INTRODUCTION

Within the circulatory system, blood flows from the large artery downstream to the small artery, then to microcirculation in nutritive capillaries, and finally to the venous system. Microcirculation is the only place to complete transport and exchange of nutritive substances and metabolic wastes between blood and tissue fluid. Therefore, changes of blood flow in microcirculation may play an important role in pathogenesis of tissue damage in lower extremities.

Diabetes mellitus (DM) can lead to micro-angiopathic changes in vascular system [Krentz et al., 2007]. Over time, various DM-associated structural abnormalities can be detected in microvasculature including thickening of the capillary basement membrane and diminished capillary size [Chao and Cheing, 2009]. Pathological changes in vascular system such as hemodynamic abnormality could be the main cause of sensory loss and disturbing neuropathic pain in feet among people with DM [Cameron et al., 2001; Duby et al., 2004], and subsequently lead to amputation of lower extremity [Singh et al., 2005]. These vascular disturbances may reduce epidermal thickness [Chao et al., 2012], which may increase the risk of developing slow-healing or even non-healing wounds. Therefore, reversing

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*Correspondence to: Gladys Lai-Ying Cheing, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong Special Administrative Region, China. E-mail: gladys.cheing@polyu.edu.hk

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vascular dysfunction in people with DM could prevent complications from developing in a foot.

Medication to reduce vascular pressure is the mainstream approach of clinical management for people with DM-associated vascular problems [Tooke, 1996; Brassard, 2000; Rodbard et al., 2007]. These medications are supposed to have a general effect on the whole vascular system. Yet, there is a lack of intervention that improves local peripheral blood circulation in a foot. Pulsed electromagnetic fields (PEMFs) are a non-pharmacological and non-invasive treatment that can be applied on the affected body part, which penetrates through skin and reaches target tissues. A previous study on healthy subjects showed that 40 min of PEMFs could enhance skin perfusion in forearm [Mayrovitz and Larsen, 1992]. In addition, PEMFs could enhance healing of skin ulcer of venous origin in humans [Ieran et al., 1990]. However, there have been few clinical studies reporting the effects of PEMFs on hemodynamic response in people with DM. A study showed that PEMFs significantly increased blood flow in cutaneous microcirculation, as measured by transcutaneous partial pressure of oxygen in the feet of people with diabetic foot problems [Webb et al., 2003]. No previous study has measured the therapeutic effects of PEMFs on localized blood flow velocity in superficial blood vessels of people with DM.

The present study examined the therapeutic effects of a single 30 min session of PEMFs on peripheral blood circulation in terms of cutaneous microcirculation and blood flow velocity of localized small veins in the dorsal skin of the foot. We compared effects of PEMFs versus sham PEMFs in people with DM, and also in healthy control subjects.

METHODS

Subjects

Twenty-two subjects who had confirmed medical diagnosis of type 2 DM were recruited from an outpatient diabetic clinic. Twenty-one healthy control subjects who had no history of DM or any other form of neuropathy or arterial disease were recruited from community through convenient sampling, and all of them passed the 8 h fasting glucose test. Exclusion criteria for both types of subjects were pregnancy, hypertension, chronic smoking, hyperlipidemia, hypercholesterolemia, and epilepsy. Subjects were also excluded if they had peripheral vascular disease as determined by absence of both posterior tibial and dorsal pedal pulses, presence of intermittent claudication or symptoms with ankle brachial index <0.9, or unstable cardiac condition or malignancy. Subjects with electronic implants such as a pacemaker were also excluded. Ethical approval was obtained from The Hong Kong Polytechnic University (Hong Kong Special Administrative Region, China). Written consent was obtained from each subject prior to enrollment.

Intervention

PEMFs therapy (model XKC-660W, Magneto-pulse International, Griffin, Australia) with a magnetic flux density of 0.5 mT at a frequency of 12 Hz (Fig. 1) was delivered for 30 min to the left foot of the subjects, under an inverted U-shaped applicator with an internal diameter of 12 cm and length of 30 cm [Webb et al., 2003]. The left foot was placed at the central space area close to the wall of applicators to ensure delivery of a uniform magnetic field. The train of sinusoidal pulses with a width of 0.08 ms was generated by passing through a pair of concentric 200-turn coils in a rectangular shape of 15×25 cm positioned next to each other and mounted to the shape of the applicator to produce a uniform magnetic field in lateral direction. Maximum flux density was distributed along the applicator's central area where the left foot was positioned. Maximum field applied to the left foot was 0.5 mT and was measured by the handheld Gauss/Tesla meter (Model 4048, F.W. Bell, Milwaukie, OR). Subjects were randomly assigned to receive intervention either through channel A or B using a computer-generated randomization table. Therefore, the present study included four groups: subjects with DM (with PEMFs), subjects with DM (with sham PEMFs), healthy control subjects (with PEMFs), and healthy control subjects (with sham

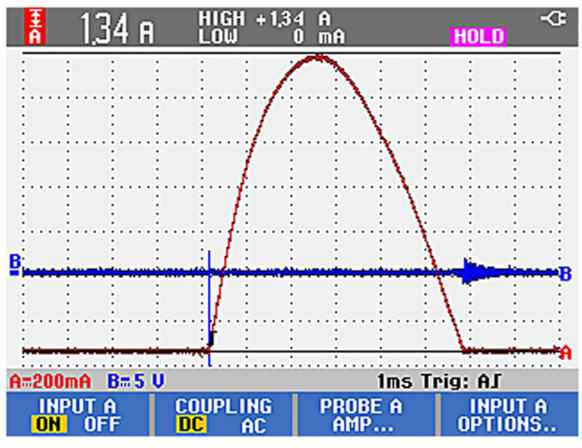

Fig. 1. PEMFs was delivered at 12 Hz with magnetic fields strength of 0.5 mT (red line: current in coils; blue line: gate voltage applied).

PEMFs). The internal circuit of one channel of sham PEMFs unit was disconnected by a technician before the study. The subjects and investigator were blinded to group allocation by not knowing whether channel A or B was active PEMFs channel.

Study Procedures

Before the intervention, blood flow measurement with use of ultrasound biomicroscopy (UBM) was performed, followed by laser Doppler flowmetry (LDF). Post-treatment assessments were performed immediately after intervention. The temperature of the assessment room was kept at 23–25 °C, with humidity controlled at 45–60%. Subjects were asked to rest in a supine position for 10 min prior to blood flow measurements, with knee fully extended and ankle maintained in a relaxed position by using foot stand. Subjects were instructed to relax and maintain normal breathing, but to avoid moving their limbs during assessment period. All measurements were independently performed by same blinded investigator.

Outcome Measures

Blood flow in superficial small vein. A UBM scanner with a Vevo 708 scanhead (VisualSonics, Toronto, Ontario, Canada) with a linear array transducer at frequency of 55 MHz was used to measure peripheral blood flow of superficial small vein at left dorsal foot. Before measurement was performed, longitudinal direction of the smallest observable vein was identified and marked with a permanent marker at the base of the 1st metatarsal bone (Fig. 2). The transducer was placed onto the marked site of the skin, and the ultrasound scan-head was moved in a direction parallel to the longitudinal direction of targeted vessels. Average blood flow velocity (mm/s) of the blood flow and diameter (mm) of the superficial small vein in skin over the base of the 1st metatarsal bone were calculated. Mean velocity of the vein measured by ultrasound biomicroscopy system is highly reproducible [Abdallah et al., 2010].

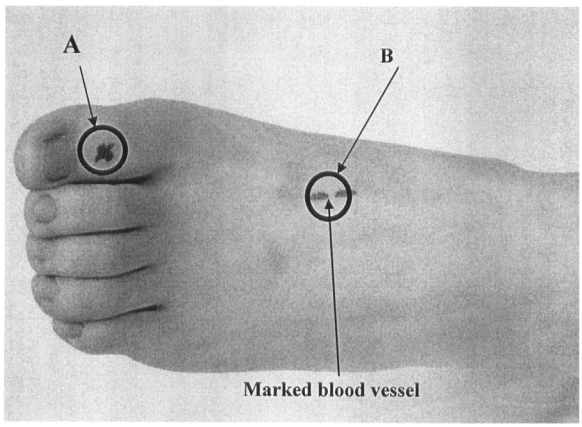

Fig. 2. Measuring sites for laser Doppler flowmetry were (**A**) 1st distal phalange and (**B**) the base of 1st metatarsal bone. One small vein was marked over the base of the 1st metatarsal bone for ultrasound biomicroscopy.

Microcirculation. Cutaneous microcirculation was measured by laser Doppler flowmetry (DRT 4, Moor Instruments, Devon, UK) at left dorsal foot [Conti et al., 2009]. Before measurement was performed, skin of (A) the distal 1st phalange and (B) base of the 1st metatarsal bone on left dorsal foot were marked with a permanent marker (Fig. 2). Probes of the LDF were adhered onto the skin of the marked sites using adhesive discs throughout the study to ensure reproducibility [Lukkari-Rautiarinen et al., 1989]. The data recording lasted for 5 min. Average blood flow (Flux) of microcirculation in the skin over the base of the 1st metatarsal bone (Flux1) and at the distal 1st phalange (Flux2) recorded from the 2 to 4 min were recorded in arbitrary units and used for subsequent analyses.

Statistical Analyses

Data were analyzed using SPSS version 20.0 (IBM, Chicago, IL). Demographic characteristics between PEMFs group and sham PEMFs group were analyzed by independent *t*-test, and gender distribution between groups was analyzed by Chi-square test separately for subjects with DM and healthy control subjects. A three-way analysis of variance (ANOVA) was used to analyze effects of "time" (pre- vs. post-"treatment") with a between-subject factor of "disease" (subjects with DM vs. health control subjects) and "treatment" (PEMFs vs. sham PEMFs) for all data. Time × treatment interaction effects and within-group changes were further explored by analyzing subjects with DM and healthy control subjects separately using two-way repeated measures ANOVA [Portney and Watkins, 2009]. When an overall significant effect was detected by ANOVA, subsequent post hoc analyses were conducted separately for "time" and "treatment" with Bonferroni correction adjusted. Observed ratios and ratio on PEMFs group/Sham PEMFs group were also calculated. In addition, Partial Least Square regression model was performed separately for subjects with diabetes and healthy subjects by using XLSTAT version 2015 (Addinsoft, New York, NY). The level of significance was set at *P*-value of 0.05.

RESULTS

Demographics

Baseline characteristics are shown in Table 1. No significant differences were found between PEMFs and sham PEMFs group (all $P > 0.05$) in subjects with or without DM.

Blood Flow Velocity in Superficial Small Vein

Three-way ANOVA revealed a time × treatment interaction ($P = 0.004$) (Table 2). To explore the nature of this interaction, subsequent two-way ANOVA with repeated measures across time and treatment were performed separately for subjects with DM and healthy control subjects, and revealed that blood flow velocity increased after PEMFs ($P \leq 0.001$), but decreased after sham PEMFs ($P \leq 0.001$). For subjects with DM, changes in the blood flow velocity in superficial small vein of PEMFs group (mean 1.03, SD 0.99 mm/s) were significantly higher than those in sham PEMFs group (mean −0.15, SD 1.28 mm/s) ($P = 0.024$). Similarly, healthy control subjects also showed that changes in the blood flow velocity in superficial small vein of PEMFs group (mean 1.22, SD 1.13 mm/s) were significantly higher than those in sham PEMFs group (mean 0.93, SD 1.04 mm/s) ($P < 0.001$). After receiving PEMFs, an increase in blood flow velocity of the superficial small vein was found in both subjects with DM or healthy control subjects. Table 3 shows the blood flow velocity of the targeted superficial small vein before and after intervention in skin over the base of the 1st metatarsal bone for each subject.

Diameter of the Superficial Small Vein

Diameter of the superficial small veins were recorded before and after intervention in the skin over the base of the 1st metatarsal bone. Three-way ANOVA revealed no main effects of time and treatment between PEMFs and sham PEMFs groups for subjects with DM or healthy control subjects (Table 2). No statistical significant difference in diameter of small veins was found between various groups with conventional ANOVA statistics. Nevertheless, values predicted by applying Partial Least Square regression modeling indicated both healthy and diabetes groups exposed to PEMFs tend to have a smaller diameter than sham PEMFs groups (Fig. 3).

Microcirculation as Measured by LDF

Table 3 shows blood flow (Flux) of the microcirculation recorded before and after intervention in skin over the base of the 1st metatarsal bone (Flux1) and distal 1st phalange (Flux2) for each subject. Both Flux1 and Flux2 tended to decrease after intervention for all subjects in both groups.

DISCUSSION

The present study is the first study that investigated effects of PEMFs on blood flow velocity of a localized superficial blood vessel and microcirculation by means of UBM and LDF among people with DM. Our findings showed that PEMFs produced an increase in blood flow velocity of the superficial small vein as recorded in skin over the base of the 1st metatarsal bone. Influences of PEMFs on increasing blood flow velocity were in parallel for both healthy control and diabetic subjects as seen from the observed ratio. An animal study demonstrated that PEMFs could enhance angiogenesis in both normal mice and diabetic mice [Callghan et al., 2008]. However, PEMFs did not produce any significant effects on changes in the diameter of superficial small veins located in the skin over the base of the 1st metatarsal bone. In addition, magnetic fields might reduce blood viscosity [Tao and Huang, 2011], hence might increase blood flow velocity. Yet in this study, we cannot exclude the possibility of increase in blood flow velocity and decrease in blood flow as an

TABLE 1. Subject Characteristics at Baseline

	Subjects with diabetes		Healthy control subjects	
Characteristics	PEMFs ($n = 11$)	Sham PEMFs ($n = 11$)	PEMFs ($n = 11$)	Sham PEMFs ($n = 10$)
Gender (male)	5 (45%)	2 (18%)	4 (36%)	3 (30%)
Age (years)	65.2 ± 9.2	65.9 ± 7.8	71.5 ± 5.2	69.7 ± 6.8
Body mass index (kg/m^2)	25.0 ± 3.8	24.5 ± 4.2	23.7 ± 3.7	24.1 ± 2.9
8 h fasting plasma glucose (mmol/L)	7.1 ± 1.4	6.5 ± 0.7	5.8 ± 0.6	5.5 ± 0.7
Diabetic history (years)	10.1 ± 5.5	12.6 ± 9.2	—	—

No significant differences were found between the PEMFs and sham PEMFs group (all $P > 0.05$) in either type of subjects. PEMFs, pulsed electromagnetic fields.

TABLE 2. Mean ± SD Score Between Groups for Outcome Measures Made Before and After Intervention

	Subjects with diabetes			Healthy control subjects		
	PEMFs group	Sham PEMFs group	Between-group *P*-value	PEMFs group	Sham PEMFs group	Between-group *P*-value
Blood flow velocity (mm/s)						
Pre	3.92 ± 1.75	5.80 ± 2.57	0.059	4.53 ± 2.59	5.92 ± 2.02	0.188
Post	4.94 ± 1.09	5.64 ± 2.62	0.430	5.75 ± 3.35	5.00 ± 1.63	0.527
Within-subjects *P*-value	0.006*	0.696	—	0.005*	0.020*	—
Observed ratios	1.26 ± 0.63	0.97 ± 0.62	—	1.27 ± 1.04	0.84 ± 0.40	—
PEMFs/Sham PEMFs ratios		1.30 ± 1.05			1.50 ± 1.42	
Time: $P = 0.051$; disease: $P = 0.438$; treatment: $P = 0.270$; time × treatment: $^*P = 0.004$; time × disease × treatment: $P = 0.100$						
Diameter of vein (mm)						
Pre	0.47 ± 0.13	0.49 ± 0.17	0.725	0.45 ± 0.14	0.43 ± 0.11	0.603
Post	0.44 ± 0.11	0.52 ± 0.17	0.182	0.42 ± 0.14	0.43 ± 0.10	0.850
Within-subjects *P*-value	0.041*	0.296	—	0.371	0.941	—
Observed ratios	0.94 ± 0.35	1.06 ± 0.51	—	0.93 ± 0.43	0.96 ± 0.32	—
PEMFs/Sham PEMFs ratios		0.88 ± 0.53			0.98 ± 0.55	
Time: $P = 0.534$; disease: $P = 0.923$; treatment: $P = 0.339$; time × treatment: $P = 0.126$; time × disease × treatment: $P = 0.720$						
Flux1 (arbitrary units)						
Pre	30.05 ± 23.50	25.41 ± 18.72	0.614	38.25 ± 26.72	20.32 ± 8.68	0.057
Post	21.95 ± 9.61	18.65 ± 14.03	0.527	27.44 ± 23.66	16.99 ± 8.26	0.202
Within-subjects *P*-value	0.136	0.315	—	0.188	0.285	—
Observed ratios	0.73 ± 0.62	0.73 ± 0.77	—	0.72 ± 0.80	0.84 ± 0.55	—
PEMFs/Sham PEMFs ratios		1.00 ± 1.38			0.86 ± 1.11	
Time: $P = 0.072$; disease: $P = 0.544$; treatment: $P = 0.436$; time × treatment: $P = 0.370$; time × disease × treatment: $P = 0.681$						
Flux2 (arbitrary units)						
Pre	37.41 ± 21.31	47.57 ± 36.43	0.434	60.07 ± 35.91	46.06 ± 30.66	0.351
Post	35.25 ± 23.75	41.25 ± 19.90	0.529	47.76 ± 36.76	27.17 ± 9.61	0.102
Within-subjects *P*-value	0.738	0.532	—	0.217	0.071	—
Observed ratios	0.94 ± 0.83	0.87 ± 0.78	—	0.80 ± 0.77	0.68 ± 0.57	—
PEMFs/Sham PEMFs ratios		1.09 ± 1.37			1.17 ± 1.51	
Time: $P = 0.138$; disease: $P = 0.712$; treatment: $P = 0.443$; time × treatment: $P = 0.419$; time × disease × treatment: $P = 0.734$						

Flux1, blood flow of microcirculation measured at skin over base of 1st metatarsal bone.
Flux2, blood flow of microcirculation measured at skin over distal 1st phalange.
Pre, before intervention; Post, after intervention. PEMFs, pulsed electromagnetic fields.
$^*P < 0.05$.

effect of decreased capillary area. Interestingly, we found that PEMFs increase blood flow velocity of superficial small vein. An increase in peripheral circulation may accelerate removal of metabolic wastes away from skin tissues, and speed up the healing process of damaged tissue. Musaev et al. [2003] reported that PEMFs restore peripheral nerve function in people with diabetic neuropathy; we postulate that this can be partly due to an increase in peripheral blood flow.

Schuhfried et al. [2005] examined effects of PEMFs (parameters: 0.0001 T, 30 Hz; 30 min) on foot microcirculation of 12 healthy young subjects by using LDF. They reported a decrease in blood flow (Flux) of microcirculation from baseline to during intervention, in both PEMFs group (10.7 vs. 8.8) and sham PEMFs group (11.7 vs. 8.9). Blood flow of microcirculation tended to drop over time, probably due to prolonged rest that they took during the study period. It appears that PEMFs do not eliminate effects of a prolonged rest on microcirculation. The present study found a higher value for blood flow, but same decreasing trend in healthy subjects was observed after receiving intervention (regardless if it was

TABLE 3. Data for the Outcome Measures Made Before and After the Intervention

		Blood flow velocity (mm/s)		Diameter of vein (mm)		Flux 1 (arbitrary units)		Flux 2 (arbitrary units)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Healthy control subjects	PEMFs group	11.19	15.38	0.63	0.55	46.5	87.3	54.4	17.5
		1.49	4.01	0.61	0.22	19.3	30.3	116.3	98.4
		4.68	5.52	0.51	0.50	11.1	19.5	62.4	123.5
		6.31	6.70	0.56	0.49	32.5	12.5	91.1	46.2
		3.57	4.07	0.18	0.19	91.6	48.3	125.6	75.7
		2.73	3.78	0.39	0.35	24.4	9.4	34.5	19.1
		3.46	4.09	0.39	0.39	9.9	5.6	46.7	30.6
		3.78	4.64	0.33	0.43	11.5	12.8	12.1	14.3
		5.82	6.43	0.55	0.56	68.7	28.3	37.8	51.9
		3.09	4.04	0.52	0.59	47.8	12.9	39.7	15.8
		3.70	4.62	0.33	0.33	57.4	34.9	40.2	32.4
	Sham PEMFs group	4.01	3.60	0.48	0.43	30.4	27.4	51.3	34.6
		5.12	5.35	0.30	0.64	11.1	10.4	23.6	15.5
		5.11	3.78	0.46	0.41	15.7	11.1	29.0	23.6
		3.16	3.23	0.48	0.41	16.7	33.3	21.3	26.0
		6.53	5.01	0.38	0.35	28.5	19.6	91.9	39.5
		8.66	7.09	0.51	0.50	34.7	18.0	42.1	40.0
		8.67	5.52	0.39	0.40	15.2	13.2	59.3	12.6
		5.28	4.04	0.26	0.28	18.6	19.3	15.4	23.6
		8.36	8.28	0.64	0.52	23.9	9.3	103.3	27.0
		4.34	4.09	0.35	0.34	8.4	8.3	23.4	29.3
Subjects with diabetes	PEMFs group	4.70	5.43	0.69	0.61	11.5	11.7	17.9	21.1
		3.00	5.52	0.44	0.48	14.7	18.4	13.9	14.1
		2.64	3.82	0.44	0.39	20.6	12.7	34.9	62.3
		7.79	6.68	0.62	0.53	39.0	14.8	39.5	26.2
		3.34	4.07	0.41	0.33	17.2	18.9	49.4	81.1
		2.57	3.36	0.57	0.53	22.0	23.3	37.4	27.5
		2.41	4.33	0.30	0.30	23.3	20.6	14.9	25.7
		2.20	3.98	0.57	0.56	78.2	39.3	75.5	68.7
		6.15	6.31	0.46	0.44	21.2	30.0	73.3	30.0
		3.96	5.72	0.37	0.33	71.8	37.3	25.5	14.3
		4.33	5.20	0.29	0.32	11.1	14.5	29.3	16.8
	Sham PEMFs group	4.34	3.08	0.34	0.49	9.6	11.6	13.2	19.9
		4.01	4.01	0.27	0.36	19.7	18.2	41.3	43.8
		6.47	6.47	0.70	0.85	17.5	57.4	39.2	53.0
		3.20	3.27	0.39	0.33	14.6	5.5	42.2	40.5
		10.62	11.68	0.81	0.78	65.6	27.0	143.5	55.2
		4.73	4.33	0.46	0.46	17.3	16.5	33.6	32.0
		5.06	4.35	0.50	0.42	58.9	19.8	33.3	70.2
		3.78	6.69	0.43	0.60	16.4	13.2	66.1	72.7
		8.08	6.69	0.56	0.60	16.7	10.9	69.9	31.4
		9.70	8.08	0.62	0.53	26.7	11.2	25.2	21.2
		3.78	3.42	0.33	0.34	16.5	13.9	15.8	13.8

PEMFs or sham PEMFs). Note that the mean age of participants in their study was 25.8 years, while the mean age of those who participated in the present study was 71.5 years. Therefore, differences in the absolute perfusion rate reported in the two studies can be explained by the difference in age of participants [James et al., 2006].

Our findings suggest that PEMFs increase circulation on the superficial small vein rather than on general microcirculation in the diabetic foot dorsal surface. But the physiological mechanism of how PEMFs influence blood circulation is unclear. It was proposed that magnetic fields may produce various biological effects, with implications for the solid state theory of cellular function, theory of biologic closed electric circuits, associated-induction hypothesis, and resonance theory [Valbona and Richards, 1999]. However, there is a lack of research evidence

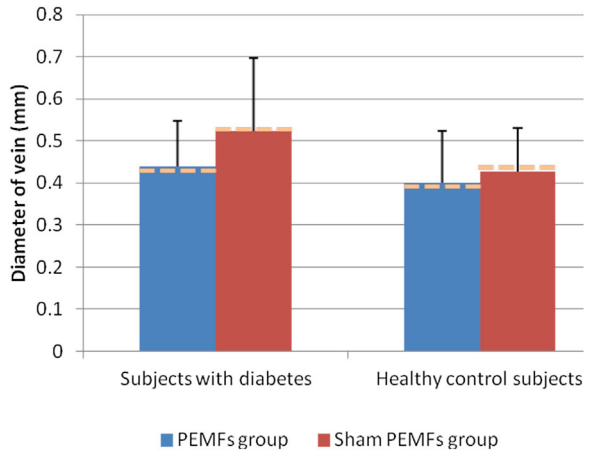

Fig. 3. Diameter in PEMFs groups and sham PEMFs groups for both subjects with diabetes and healthy control subjects post treatment. Dotted line indicates predicted values estimated by Partial Least Square regression modeling.

to support any of these hypothesized biological mechanisms [Markov and Colbert, 2001]. Several researchers have suggested that static electromagnetic fields can induce therapeutic effects on the cell membrane by modifying signal transduction pathways located at cell membrane and cell interior of biological tissues [Markov and Colbert, 2001; Ohkubo et al., 2007; Bachl et al., 2008]. Modification of this signal pathway is successfully completed by changing the conformation of the second messenger such as Ca^{2+} and cAMP, which ensures biochemical cascades relevant to cell function [Markov and Pilla, 1994]. The Ca^{2+} dependent nitric oxide released from the endothelium plays an important role in modulating diameter of vessels in the microcirculation system [Mckay et al., 2007]. Also, growth factors released from endothelial cells also accelerate angiogensis.

Risk of developing diabetic complications in terms of microcirculation disturbance is an important concern for people with DM. The present study is the first to investigate peripheral blood flow and microcirculation by using UBM and laser Doppler in people with DM. However, small sample size in the present study was a limitation. Also, the present study examined acute effects of a single session of PEMFs on peripheral blood circulation without oxygen pressure monitoring. Future research can be done with a course of PEMFs treatment to investigate long-term effect continuance with oxygen pressure measurement.

In conclusion, our findings demonstrated that for both the healthy and diabetes groups, a single session of PEMFs (parameters: 0.5 mT, 12 Hz, and 30 min) produced significantly greater increase in peripheral blood flow velocity in the dorsal foot, as compared to sham PEMFs. However, an increase in blood flow velocity of small veins might be due to decreased diameter of veins in PEMFs groups as predicted by the Partial Least Square regression model, though it does not explain any difference in therapeutic effects. Also, our findings suggest that PEMFs do not increase general microcirculation in the dorsal foot in subjects with or without DM. Further studies are warranted to investigate the effect of pulsed electromagnetic field exposure on microcirculation in patients with diabetes.

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