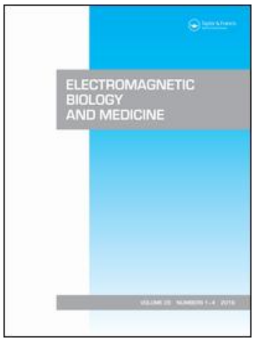

Taylor & Francis
Taylor & Francis Group

Electromagnetic Biology and Medicine

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/iebm20

Finger skin blood perfusion during exposure of ulnar and median nerves to the static magnetic field of a rare-earth magnet: A randomized pilot study

Harvey N. Mayrovitz , Andrea Astudillo & Elham Shams

To cite this article: Harvey N. Mayrovitz , Andrea Astudillo & Elham Shams (2020): Finger skin blood perfusion during exposure of ulnar and median nerves to the static magnetic field of a rare-earth magnet: A randomized pilot study, Electromagnetic Biology and Medicine, DOI: 10.1080/15368378.2020.1856682

To link to this article: https://doi.org/10.1080/15368378.2020.1856682

Published online: 05 Dec 2020.

ELECTROMAGNETIC BIOLOGY AND MEDICINE
https://doi.org/10.1080/15368378.2020.1856682

Finger skin blood perfusion during exposure of ulnar and median nerves to the static magnetic field of a rare-earth magnet: A randomized pilot study

Harvey N. Mayrovitz[a], Andrea Astudillo[b], and Elham Shams[b]

[a]Dr. Kiran C. Patel College of Allopathic Medicine, Nova Southeastern University, Ft. Lauderdale, FL, USA; [b]Dr. Kiran C. Patel College of Osteopathic Medicine, Nova Southeastern University, Ft. Lauderdale, FL, USA

ABSTRACT

This pilot study's goal was to investigate the impacts of static magnetic fields (SMF) on finger skin blood perfusion (SBP) when exposing the ulnar artery and ulnar and medial nerves to a rare earth concentric magnet for 30 minutes. Control SBP was measured in 4th fingers of adults (n = 12, age 26.0 ± 1.4 years) for 15 minutes using laser-Doppler. Then, active-magnets were placed over one arm's ulnar and median nerves at the wrist and sham-magnets placed at corresponding sites on the other arm. Devices were randomly assigned and placed by an investigator "blinded" to device type. The maximum SMF perpendicular to skin was 0.28 T measured 2 mm from magnet surface. The tangential field at this distance was 0.20 T. SBP was analyzed and tested for differential effects attributable to magnets compared to shams in each of the 5-minute intervals over the full 45-minute experiment. Results showed no statistically significant difference between SBP measured on the magnet-treated side compared to the sham side. Magnet and sham side SBP values (mean ± SEM, arbitrary units) prior to device placement were 0.568 ± 0.128 vs. 0.644 ± 0.115, p = .859 and during device placement were 0.627 ± 0.135 vs. 0.645 ± 0.117, p = .857. In conclusion, these findings have failed to uncover any significant effects of the static magnetic field on skin blood perfusion in the young healthy adult population evaluated. Its potential for altering SBP in more mature persons or those with underlying conditions affecting blood flow has not been evaluated but represents the next target of research inquiry. ClinicalTrials.gov registration number is NCT04539704.

ARTICLE HISTORY
Received 3 October 2020
Accepted 24 November 2020

KEYWORDS
Ulnar artery; static magnetic field; median nerve; skin blood flow; laser Doppler; magnet; concentric magnet; magnet therapy

Introduction

The goal of understanding the biological effects of static magnetic fields (SMF) remains an important and continuing effort. Many potential uses of SMF-therapy have been previously well described (Markov 2007) with further elaborations and details provided (Markov 2015, 2013). The present focus is on the possible role of SMF as a modulator of skin blood perfusion (SBP).

This research was in part motivated by various *in vivo* animal studies (Brix et al. 2008; Gmitrov 2007, 2013; Gmitrov et al. 2002; Ichioka et al. 1998, 2000; Ohkubo and Xu 1997), with some investigations carried out on humans (Mayrovitz and Groseclose 2005; Mayrovitz et al. 2005, 2001; Yan et al. 2011), that suggest that SMF may influence aspects of blood circulation control under some conditions. Depending on the magnetic field intensity employed, such possibilities include SMF effects on red blood cells (RBC) due to SMF–RBC interactions that affect RBC orientation (Higashi et al. 1997, 1996; Takeuchi et al. 1995), and blood viscosity or shape change effects (Marcinkowska-Gapinska and Nawrocka-Bogusz 2013; Okazaki et al. 1987; Tao and Huang 2011). Additional reported aspects include SMF effects on vascular smooth muscle and endothelium (Gmitrov et al. 2002; Li et al. 2012; Morris and Skalak 2008) and SMF effects on neural aspects directly (Okano et al. 2012) or via baroreflex modulation and blood pressure (Gmitrov 2007, 2013, 2020, 2010) with other neural effects associated with low frequency (0.16 Hz) (Ahmed and Wieraszko 2015) and higher frequency (Okudera et al. 2015) magnetic stimulation.

Skin microcirculation changes were reported to occur via direct tissue exposure or equivalently by exposure of baroreceptor nerves (Gmitrov 2013). Such findings may indicate that SMF-induced blood flow changes are at least in part due to magnetic field-effects on neural structures. That SMF can influence median nerve induced evoked potentials in humans has been previously demonstrated (Kirimoto et al. 2014) although others have failed to show effects on the compound action potential amplitude (Colbert et al. 2010). When considering blood flow in the human hand and fingers, it is in part dependent on tissue activity caused by motor-related functions of the ulnar, medial and radial nerves. Although nerve-related changes associated with time-varying magnetic fields have

CONTACT Harvey N. Mayrovitz mayrovit@nova.edu College of Allopathic Medicine, Department of Medical Education, Nova Southeastern University, Davie, FL 33328.

been reported when the median nerve was exposed to 50 Hz using field strengths of 1 mT (Comlekci and Coskun 2012) effects attributable to SMF exposure have not been systematically be evaluated. Thus, the goal of the present study was to determine the impact on skin blood perfusion when both the median and ulnar nerves were simultaneously exposed to the SMF of a multipole concentric magnet.

Methods

Subjects

Twelve subjects equally divided between males and females participated in this pilot investigative study. Subject ages ranged from 18 to 35 years with an average age of 26.0 ± 1.4 years (mean ± SD) and average body mass index (BMI) of 23.2 ± 2.3 Kg/m^2. Potential subjects were recruited for inclusion mainly by word of mouth among medical and graduate students and staff. Inclusion criteria Entry requirements were that they have no abnormal skin conditions and were not taking vasoactive medications. Excluded were persons with diabetes or having implanted wires or devices. Prior to any subject participating in the study, it was carefully explained and any of their questions answered. Upon agreeing to participate they signed an informed consent that was previously approved by the Nova Southeastern University Institutional Review Board (IRB) with the designation of 2019–598-NSU and subsequently registered with ClinicalTrials.gov with the registration number of NCT04539704.

Procedures

On the day and time of their scheduled study, subjects took a supine position on a padded wooden examination table located in a dedicated enclosed experimental area. The approximate location of the sites for magnet or sham placement is illustrated for the right arm in Figure 1. Active magnets were placed at both sites on one arm and sham magnets placed at corresponding sites on the other arm. These sites overlie the ulnar artery and nerve and the median nerve. It turns out that these sites also approximately overly acupuncture points HT7 and PC6. HT7 is located at the edge of wrist crease on the radial side of the flexor carpi ulnar tendon and PC6 is located about three finger breadths proximal to the wrist crease on the volar forearm between the flexor carpi radialis tendon and the palmaris longus tendon. In Figure 1 the superimposed lines drawn on the image show nerve and artery partial pathways that show approximate distal distributions that might be affected by subsequent magnet placements.

After marking the target locations denoting where magnet and shams would be placed, laser Doppler multi collector integrating probes (Model VP7a, Moor Instruments, Wilmington DE, USA) were affixed to the pulp of the ring (4^{th}) finger of both hands as shown for the right hand in Figure 2. These probes were coupled to a dual-channel laser-Doppler perfusion monitoring system (Model MBF 3D, Moor Instruments, Wilmington DE, USA). After placement of the laser Doppler probes, skin surface thermal probes (SST-1, Physitemp, Clifton, NJ, USA) were taped to the pulp of each thumb to track skin temperature for the duration of the experiment. These probes have a stated accuracy of 0.1°C and were used in conjunction with the Model TH-8 clinical thermal system (Physitemp, Clifton NJ, USA). Thereafter, the subject's hands and feet were covered with a light blanket to help prevent possible ambient thermal drafts from directly impacting the skin.

Measurements

Laser-Doppler

The primary measurement was bilateral skin blood perfusion (SBP) determined with the MBF3 laser-Doppler monitoring system. This is a dual channel device so SBP can be measured at two sites simultaneously. Probe outputs are processed within the monitoring unit and then data sampled and digitized at a rate of 1000 samples/sec using Windaq acquisition software (Model 720, DataQ Instruments, Akron Ohio, USA). Laser-Doppler-derived SBP monitoring provides an output proportional to the product of average blood velocity and the associated red cell volume concentration within the laser-doppler measurement volume (Nilsson et al. 1980; Oberg 1990). SBP may vary slightly depending on anatomical features (Braverman et al. 1992) and sampling depth may depend on tissue type (Jakobsson and Nilsson 1993) but is little affected by skin pigmentation (Fredriksson et al. 2009) as has been confirmed (Abdulhameed et al. 2019). The laser-Doppler method has been widely used to assess finger skin blood perfusion changes with cold (Creutzig et al. 1997; Lutolf et al. 1993; Suichies et al. 1992) and heat (Freccero et al. 2003; Hung et al. 1993; McGarr et al. 2017) and other blood flow inducing stimuli (Bose et al. 2015; Hilz et al. 2000; Lindblad et al. 1986; Mayrovitz and Groseclose 2002). Baseline SBP under some circumstances shows dynamic patterns (Kano et al. 1993) including flow motion patterns (Kvernmo et al. 1998; Lossius and Eriksen 1995; Toth-Szuki et al. 2020). The method does not distinguish between total SBP and perfusion of skin capillaries (Engelhart et al. 1988; Kastrup et al. 1987) but correlates well with other methods of assessing blood flow (Raamat et al. 2001).

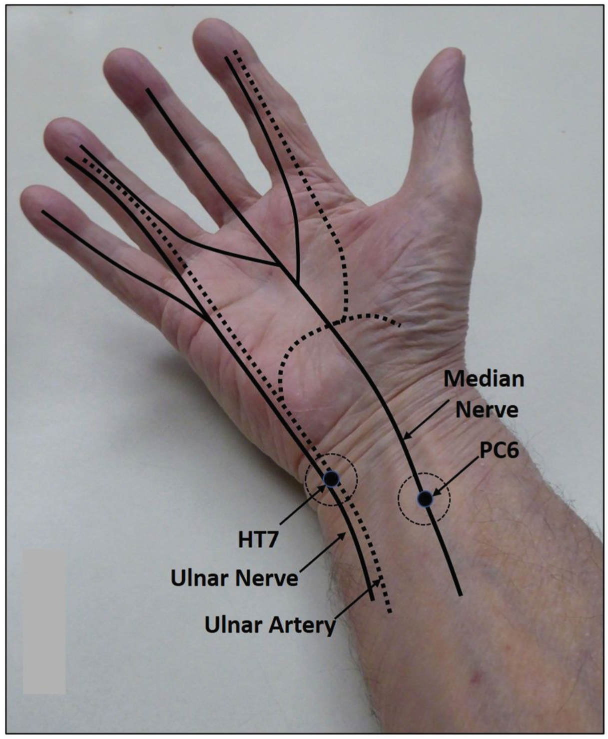

Figure 1. Locations of device placement. Magnets or shams were placed at the indicated locations that overlie the ulnar artery and nerve and the median nerve. These sites also corresponded approximately to acupuncture points HT7 and PC6.

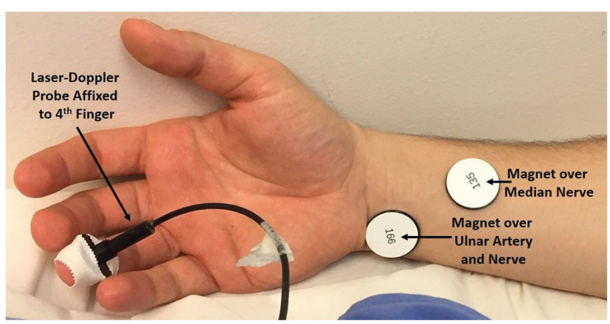

Figure 2. Laser Doppler perfusion monitoring. A laser Doppler probe was affixed to the ring finger pulp of each hand to monitor skin blood perfusion (SBP). Also shown are two devices in position on the right hand of a subject overlying the median nerve and the ulnar nerve and artery.

Sequence

After 10 minutes of supine lying, data recording began and SBP was recorded continuously for 45 minutes. After 15 minutes of recording, devices (magnets and shams) were placed at target sites bilaterally as shown for one side in Figure 2. One side received both active magnets and the other both shams. The decision as to which arm was to receive one pair or the other was decided randomly with a flip of a coin. After device placement, arms were recovered and recording continued for 30 minutes yielding a total 45-minute SBP recording corresponding to 15 minutes prior to device placement and a 30-minute interval during which devices were all in place. An example of a short-duration (90 seconds) SBP recording is shown in Figure 3. At the start and end of each experiment, room temperature and relative humidity were recorded. Laser-Doppler probes were checked for uniformity of outputs weekly using calibration fluid (Probe Flux Standard, Moor Instruments, Wilmington DE, USA).

Devices

The magnet and sham devices used in this study visually appeared similar and had the same dimension and weight as is illustrated in Figure 4a. Each device was labeled with

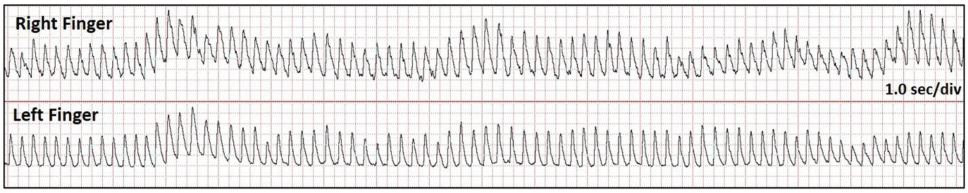

Figure 3. Example short-duration skin blood perfusion recording. An example of a short-duration (about 90-second) SBP recording shows similarities of patterns in right and left finger. The heart rate pulsations are clearly visualized at this time-base. Data are from a subject during baseline measurement.

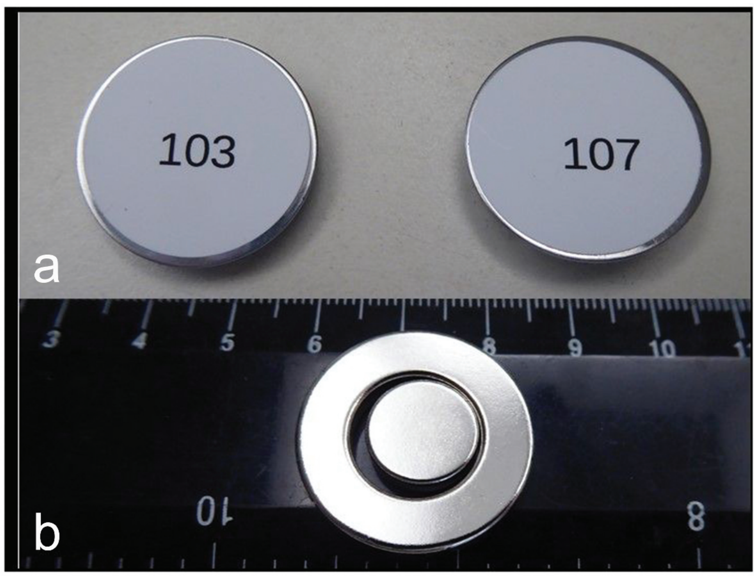

Figure 4. Magnet and sham devices used. (a) Magnet and sham devices used in this study visually appeared similar and had the same dimensions and weight. Each was labeled with a unique random number. (b) The Neodymium-Iron-Boron magnet had two concentric magnets, a central 12 mm diameter one within a 25.4 mm ring magnet producing a single magnetic array. The ruler in the image shows in cm.

a unique number and was provided for use in this research study by Niiomed Inc, Ft. Lauderdale Florida, USA. The magnet (Neodymium Iron Boron) had a conce ntric design (Figure 4b) in which two concentric magnets produce a single magnetic array that, according to descriptions, produces a greater magnetic flux per unit volume and can deliver greater penetration compared to other designs. The concentric design allows adjacent zones of polarity to mutually reinforce the magnetic fields of each resulting in increased intensity at the surface. The device weighs only 14 grams and has a 12 mm diameter central magnet that is magnetically suspended in the core of a 25.4 mm outer diameter ring magnet (Figure 4). Since the magnetic flux from the two components are mutually reinforcing, surface field levels greater than if the central core were of like polarity are potentially achievable. As used, the central magnet provides a North pole facing the skin and the outer magnet provides a South pole. An additional feature of the magnet used in this study relates to the use of a ferromagnetic back plate providing enhanced magnetic field penetration. Since the magnetic flux from the two elements are mutually reinforcing surface field levels of up to 0.4 T are achievable which is 50% greater than if the central core were of like polarity. The magnetic field pattern of the device used is shown in Figure 5. The fields were measured every mm using the Kanetec Tesla meter, model TM-801EXP (Kanetec, Bensenville, IL, USA).

This study was conducted in a double blinded manner. Neither subjects or experimenters knew which arm had magnets or shams. A list of random numbers was used to identify the magnets and shams but the list was only accessible to the principal investigator who compiled the data provided to him from the coinvestigators. It was during the final analysis that the device assignments were decoded and analyzed accordingly.

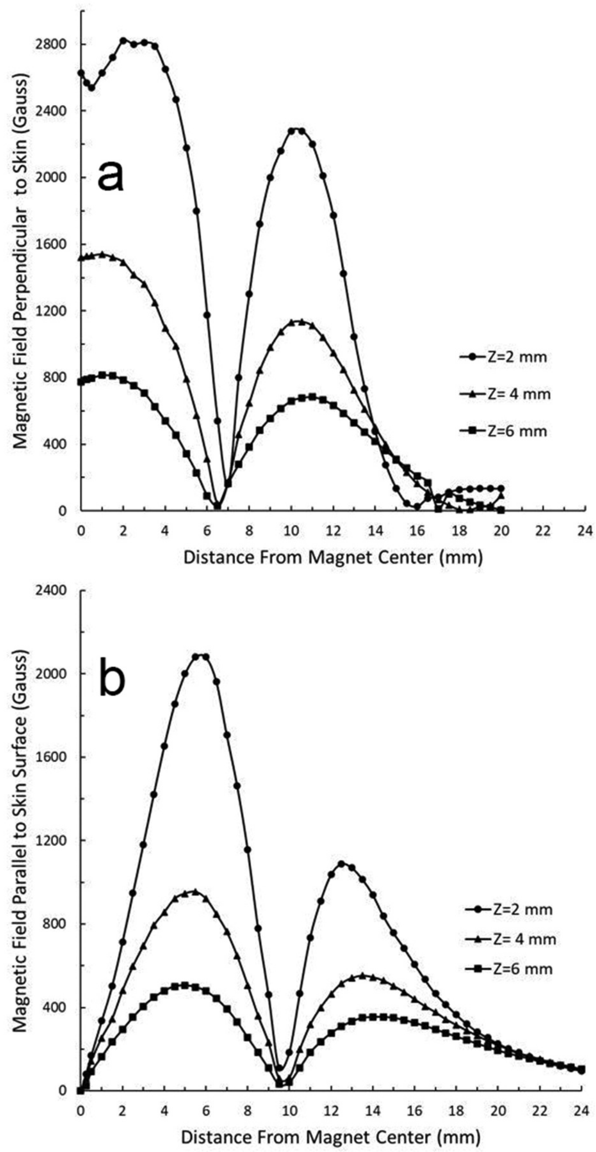

Figure 5. Magnetic fields of the magnet. Magnetic fields measured at z = 2, 4 and 6 mm from the magnet surface at 0.5 mm increments from the magnet center. The field perpendicular to the skin is in (a) and tangential in (b). The field perpendicular to the skin (a) was measured with the magnetic measuring probe aligned parallel to the magnet surface and the tangential field measured with the probe oriented at 90° to the plane of the magnet.

Analysis

The time-averaged SBP was evaluated for each 5-minute interval of the 45-minute experiment as shown in Figure 6. Tests for overall SBP differences among sequential intervals for each finger were done with the Friedman nonparametric test. Tests for possible differences between sham and magnet exposed sides were done by calculating the difference between sides for each interval and then testing for overall differences among them with the Friedman test. A p-value <0.05 was deemed evidence of a statistically significant overall difference. Average SBP values of the pre-exposure control interval (1st 15 minutes) and the device exposure intervals (subsequent 30 minutes) were determined by averaging all values within these intervals. Unless otherwise noted SBP values are presented in arbitrary units (a.u.) as mean ± sem.

Results

SBP values for both the active magnet and sham sides are shown in Figure 7. SBP during the 15-minute pre-exposure interval on the side that would receive the shams was 0.644 ± 0.115 (arbitrary units. a.u., mean ± sem). SBP during the 15-minute pre-exposure interval on the side that would receive the magnets was 0.568 ± 0.128. These pre-exposure values were not statistically different

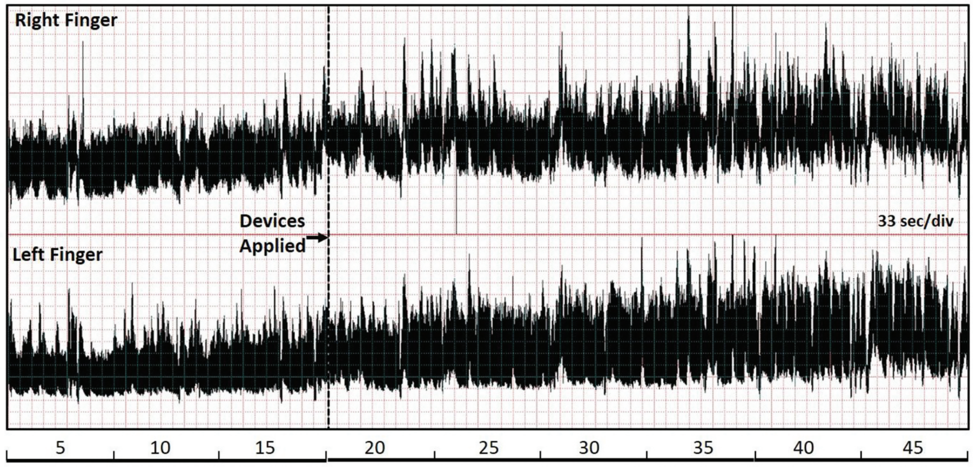

Figure 6. Example full 45-minute experiment SBP recording and procedure. SBP is shown as measured with the laser Doppler system on the right and left ring finger pulp. After 15 minutes of baseline recording, the devices are applied (active-magnet or sham-magnet) to the target sites and recording is continued for the next 30 minutes. The average SBP in each of the 5-minute contiguous segments is determined. For this particular subject, there is a trend for SBP to increase in both fingers.

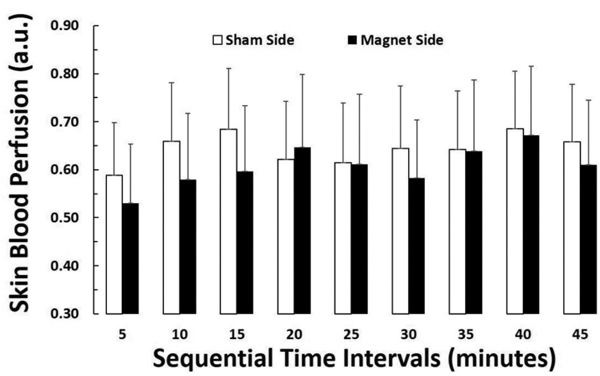

Figure 7. Skin blood perfusion sequential results. Finger skin blood perfusion (SBP) in each contiguous 5-minute interval is shown for the side exposed to the active-magnet and exposed to the sham-magnet. Application of the magnet after the 15-minute control interval resulted in no detectible significant change in SBP. Bars are 1 SEM.

(p = .859). There appeared to be a slight increase in SBP on both sides during the pre-exposure interval likely due to covering of the hand, thermal stabilization and settling of the subject during this control interval. During the 30 minutes of device application, the perfusion pattern showed no specific trend with sham side and magnet side SBP values being 0.644 ± 0.117 and 0.627 ± 0.135, respectively (p = .859).

Based on the Friedman test for related samples, there was no overall statistically significant difference in finger SBP among temporal intervals for either sham or magnet exposed sides. Chi-Square and significance values for the sham exposed side were 11.95 and 0.153, respectively. Corresponding values for the magnet exposed side were 4.75 and 0.784. Further, no statistical difference was found between sham and magnet exposed sides (Chi-Square = 9.30 and significance = 0.318).

During the 45-minute experiment, room temperature changed by less than 1°C (0.90 ± 1.13°C) going from 26.3 ± 1.5 at start to 27.1 ± 1.1°C at end. Thumb finger skin temperature remained essentially constant starting at 33.6 ± 4.3°C and ending at 33.6 ± 3.9°C on the magnet-treated side and starting at 32.4 ± 3.7°C on the sham-treated side and ending at 32.9 ± 3.9°C, both being non-significant changes. Relative humidity changed by less than 1% starting at 40.9 ± 4.3% and ending at 41.2% ± 4.5%.

Discussion

The specific aim of the present research was to investigate the potential impact on skin blood perfusion due to the placement of concentric multipole magnets at two strategic anatomical sites. The sites chosen were over the median and ulnar nerve and the ulnar artery that also corresponded approximately to acupuncture points HT7 and PC6.

According to available literature, a stimulation of HT7 may be associated with alterations in autonomic activity (Chae et al. 2011) which could impact vascular tone and thereby blood flow. Such effects may be associated with alterations in heart rate and heart rate variability (Huang et al. 2015; Shinohara 1997) and those that mediate autonomic responses to external stressors (Maccariello et al. 2018). Further, there are reports of altered blood flow patterns being associated with stimulation of other acupuncture points including at ST36 (Kim et al. 2019). Other hemodynamic impacts have been reported via stimulation of ST36 (Kim et al. 2017) and the presently used PC6 point (Xu et al. 2019). However, as summarized (Kim et al. 2016) it remains unclear as to the full extent of such effects on blood flow. The present study focused only on one location of SBP measurement and thus does not evaluate possible SBP impacts that might be present at other sites due to such stimulation.

The physiological component that led to the choice of target sites was related to the intended SBP measurement location on the 4th finger. This area derives its blood flow most directly from the ulnar artery with distal innervation of part of the finger via the ulnar nerve and part via the median nerve. By choosing the specific locations the magnet was directly overlying these structures so that if the static magnetic field were to have some impact on distal perfusion these would appear to be well-chosen sites.

However, the main finding indicates that application of active-magnets of the present configuration to these target sites caused no significant change in distal finger average skin blood perfusion. In fact, the active-magnet affect did not differ from that caused by sham-magnets placed at corresponding sites on the contralateral side. This outcome needs to be considered in the context of previous reports related to impacts of static magnetic fields on blood flow. One of these relates to potential physical effects of the magnetic field on red blood cells (RBC) moving within the magnetic field. Vessel diameter and peak blood flow in ulnar arteries at the wrist in 200 normal hands have been reported as 3.41 ± 0.31 mm and 86.9 ± 49.5 ml/min, respectively (Doscher et al. 1983). Corresponding values in the radial artery are 3.39 ± 0.32 mm and 72.2 ± 41.6 ml/min. Based on these data, one may calculate average peak blood velocities in ulnar and radial arteries as approximately 4 cm/sec and 3.3 cm/sec, respectively. Although some studies have reported magnetic-field-related changes in RBC orientation (Higashi et al. 1997, 1996; Okazaki et al. 1987; Takeuchi et al. 1995), anticlotting (Li et al. 2020) and blood viscosity decreases (Javadzadegan et al. 2018; Tao and Huang 2011), increases (Yamamoto et al. 2004) or no change (Marcinkowska-Gapinska and Nawrocka-Bogusz 2013), it is unclear if the magnitude of the present magnetic field intensities (Figure 5) would be sufficient to cause such effects.

Beyond these reported changes in blood properties, there are multiple reports detailing investigations of blood flow changes in response to static magnetic fields in experimental animals and in humans. Exposure of rabbit ear vascular network or its carotid sinus to SMF of 0.25–0.35 Tesla are reported to increase microcirculatory flow by 17.8% and 23.4%, respectively (Gmitrov 2013). The direct effect of the SMF on the vascular network as an increase in microcirculatory flow is consistent with an earlier report in which a similar procedure resulted in an increase of about 22% during SMF application (Gmitrov et al. 2002) with possible mechanisms recently discussed (Gmitrov 2020). Other workers, also using animal models have contrastingly reported decreases in blood flow (Brix et al. 2008; Ichioka et al. 1998, 2000; Strieth et al. 2008). Blood flow decreases as a result of high-intensity SMF exposure have also been suggested based on in vitro and numerical analyses (Keltner et al. 1990; Tenforde 2005). The extension of the findings of these animal studies to SMF impacts on blood flow in humans is unknown as human studies are far less numerous. However, prior studies in which finger or hand skin blood flow has been assessed have reported either no significant change (Mayrovitz et al. 2005, 2001) consistent with the present findings or a slight decrease in flow associated with SMF exposure (Mayrovitz and Groseclose 2005).

In conclusion, the present findings have failed to uncover any significant effects of the static magnetic field on skin blood perfusion in the young healthy adult population evaluated when ulnar and median nerves and ulnar artery were exposed to the field of the magnets employed. Its potential for altering blood perfusion in a larger sample size or in more mature persons or those with underlying conditions affecting blood perfusion have not been evaluated but represent the next target of research inquiry.

Acknowledgments

The authors thank the research subjects without which this study could not have been completed. We also sincerely thank Niiomed Inc. of Ft. Lauderdale for kindly supplying magnets and sham devices.

ORCID

Harvey N. Mayrovitz http://orcid.org/0000-0003-2690-7922

Declaration of interest

The authors report no conflict of interest.

References

Abdulhameed, Y. A., G. Lancaster, P. V. E. McClintock, A. Stefanovska. 2019. On the suitability of laser-Doppler flowmetry for capturing microvascular blood flow dynamics from darkly pigmented skin. *Physiol. Meas.* 40:074005. doi:10.1088/1361-6579/ab2651.

Ahmed, Z., and A. Wieraszko. 2015. Pulsed magnetic stimulation modifies amplitude of action potentials in vitro via ionic channels-dependent mechanism. *Bioelectromagnetics* 36:386–97.

Bose, N., J. Bena, and S. Chatterjee. 2015. Evaluation of the effect of ambrisentan on digital microvascular flow in patients with systemic sclerosis using laser Doppler perfusion imaging: A 12-week randomized double-blind placebo controlled trial. *Arthritis Res. Ther.* 17:44. doi:10.1186/s13075-015-0558-9.

Braverman, I. M., J. S. Schechner, D. G. Silverman, A. Keh-Yen. 1992. Topographic mapping of the cutaneous microcirculation using two outputs of laser-Doppler flowmetry: Flux and the concentration of moving blood cells. *Microvasc. Res.* 44:33–48. doi:10.1016/0026-2862(92)90100-4.

Brix, G., S. Strieth, D. Strelczyk, M. Dellian, J. Griebel, M. E. Eichhorn, W. Andra, M. E. Bellemann. 2008. Static magnetic fields affect capillary flow of red blood cells in striated skin muscle. *Microcirculation* 15:15–26. doi:10.1080/10739680701410850.

Chae, Y., H.-J. Park, O.-S. Kang, H.-J. Lee, S.-Y. Kim, C.-S. Yin, H. Lee. 2011. Acupuncture attenuates autonomic responses to smoking-related visual cues. *Complement. Ther. Med.* 19:S1–7. doi:10.1016/j.ctim.2010.09.003.

Colbert, A. P., M. S. Markov, N. Carlson, W. L. Gregory, H. Carlson, P. J. Elmer. 2010. Static magnetic field therapy for carpal tunnel syndrome: A feasibility study. *Arch. Phys. Med. Rehabil.* 91:1098–104. doi:10.1016/j.apmr.2010.02.013.

Comlekci, S., and O. Coskun. 2012. Influence of 50 Hz-1 mT magnetic field on human median nerve. *Electromagn. Biol. Med.* 31:285–92. doi:10.3109/15368378.2012.662190.

Creutzig, A., Hiller, S., Appiah, R.,Thum, J., Caspary, L. 1997. Nailfold capillaroscopy and laser Doppler fluxmetry for evaluation of Raynaud's phenomenon: How valid is the local cooling test? *Vasa* 26:205–09.

Doscher, W., B. Viswanathan, T. Stein, I. B. Margolis. 1983. Hemodynamic assessment of the circulation in 200 normal hands. *Ann. Surg.* 198:776–79. doi:10.1097/00000658-198312000-00018.

Engelhart, M., L. J. Petersen, and J. K. Kristensen. 1988. The local regulation of blood flow evaluated simultaneously by 133-xenon washout and laser Doppler flowmetry. *J. Invest. Dermatol.* 91:451–53. doi:10.1111/1523-1747.ep12476572.

Freccero, C., F. Holmlund, S. Bornmyr, J. Castenfors, A.-M. Johansson, G. Sundkvist, H. Svensson, P. Wollmer. 2003. Laser Doppler perfusion monitoring of skin blood flow at different depths in finger and arm upon local heating. *Microvasc. Res.* 66:183–89. doi:10.1016/j.mvr.2003.06.001.

Fredriksson, I., M. Larsson, and T. Stromberg. 2009. Measurement depth and volume in laser Doppler flowmetry. *Microvasc. Res.* 78:4–13. doi:10.1016/j.mvr.2009.02.008.

Gmitrov, J. 2007. Static magnetic field effect on the arterial baroreflex-mediated control of microcirculation: Implications for cardiovascular effects due to environmental magnetic fields. *Radiat Environ Biophys* 46:281–90. doi:10.1007/s00411-007-0115-2.

Gmitrov, J. 2010. Static magnetic field blood pressure buffering, baroreflex vs. vascular blood pressure control mechanism. *Int. J. Radiat. Biol.* 86:89–101. doi:10.3109/09553000903419973.

Gmitrov, J. 2013. Static magnetic field effect on microcirculation, direct versus baroreflex-mediated approach. *Electromagn. Biol. Med.* 32:448–62. doi:10.3109/15368378.2012.743905.

Gmitrov, J. 2020. Static magnetic field versus systemic calcium channel blockade effect on microcirculation: Possible mechanisms and clinical implementation. *Bioelectromagnetics* 41:447–57. doi:10.1002/bem.22272.

Gmitrov, J., C. Ohkubo, and H. Okano. 2002. Effect of 0.25 T static magnetic field on microcirculation in rabbits. *Bioelectromagnetics* 23:224–29. doi:10.1002/bem.10007.

Higashi, T., N. Asjoda, and T. Takeuchi. 1997. Orientation of blood cells in static magnetic field. *Physica B* 237-238:616–20. doi:10.1016/S0921-4526(97)00276-7.

Higashi, T., S. Sagawa, N. Ashida, T. Takeuchi. 1996. Orientation of glutaraldehyde-fixed erythrocytes in strong static magnetic fields. *Bioelectromagnetics* 17:335–38. doi:10.1002/(SICI)1521-186X(1996)17:4<335::AID-BEM10>3.0.CO;2-N.

Hilz, M. J., M. J. Hecht, M. Berghoff, W. Singer, B. Neundoerfer. 2000. Abnormal vasoreaction to arousal stimuli–an early sign of diabetic sympathetic neuropathy demonstrated by laser Doppler flowmetry. *J. Clin. Neurophysiol.* 17:419–25. doi:10.1097/00004691-200007000-00008.

Huang, H., Z. Zhong, J. Chen, Y. Huang, J. Luo, J. Wu, H. Liao, E. Zhen, R. Lin, O. B. Fasmer. 2015. Effect of acupuncture at HT7 on heart rate variability: An exploratory study. *Acupunct Med* 33:30–35. doi:10.1136/acupmed-2013-010441.

Hung, L. K., J. C. Cheng, and S. K. Lee. 1993. Response of fingertip circulation to local warming in the injured hand – A study using laser Doppler flowmetry. *J. Hand. Surg. Br.* 18:770–73. doi:10.1016/0266-7681(93)90242-8.

Ichioka, S., M. Iwasaka, M. Shibata, K. Harii, A. Kamiya, S. Ueno. 1998. Biological effects of static magnetic fields on the microcirculatory blood flow in vivo: A preliminary report. *Med. Biol. Eng. Comput.* 36:91–95. doi:10.1007/BF02522863.

Ichioka, S., M. Minegishi, M. Iwasaka, M. Shibata, T. Nakatsuka, K. Harii, A. Kamiya, S. Ueno. 2000. High-intensity static magnetic fields modulate skin microcirculation and temperature in vivo. *Bioelectromagnetics* 21:183–88. doi:10.1002/(SICI)1521-186X(200004)21:3<183::AID-BEM5>3.0.CO;2-5.

Jakobsson, A., and G. E. Nilsson. 1993. Prediction of sampling depth and photon pathlength in laser Doppler flowmetry. *Med. Biol. Eng. Comput.* 31:301–07. doi:10.1007/BF02458050.

Javadzadegan, A., A. Moshfegh, and M. Behnia. 2018. Effect of magnetic field on haemodynamic perturbations in atherosclerotic coronary arteries. *J. Med. Eng. Technol.* 42:148–56. doi:10.1080/03091902.2018.1447034.

Kano, T., O. Shimoda, K. Higashi, M. Sadanaga, M. Sakamoto. 1993. Fundamental patterns and characteristics of the laser-Doppler skin blood flow waves recorded from the finger or toe. *J. Auton. Nerv. Syst.* 45:191–99. doi:10.1016/0165-1838(93)90051-U.

Kastrup, J., J. Bulow, and N. A. Lassen. 1987. A comparison between 133Xenon washout technique and Laser Doppler flowmetry in the measurement of local vasoconstrictor effects on the microcirculation in subcutaneous tissue and skin. *Clin. Physiol.* 7:403–09. doi:10.1111/j.1475-097X.1987.tb00182.x.

Keltner, J. R., M. S. Roos, P. R. Brakeman, T. F. Budinger. 1990. Magnetohydrodynamics of blood flow. *Magn Reson Med* 16:139–49. doi:10.1002/mrm.1910160113.

Kim, K. W., S. Hong, H. S. Kim, T. Kim, J. Ahn, H.-S. Song, Y.-K. Kim, J.-Y. Oh, T.-Y. Hwang, H. Lee. 2019. Physiological impact of nanoporous acupuncture needles: Laser Doppler perfusion imaging in healthy volunteers. *PLoS One* 14: e0226304. doi:10.1371/journal.pone.0226304.

Kim, S. Y., S. Min, H. Lee, S. Cheon, X. Zhang, J.-Y. Park, T.-J. Song, H.-J. Park. 2016. Changes of local blood flow in response to acupuncture stimulation: A systematic review. *Evid. Based Complement. Alternat. Med.* 2016:9874207. doi:10.1155/2016/9874207.

Kim, T. H., B. Ku, J.-H. Bae, J.-Y. Shin, M.-H. Jun, J. W. Kang, J. Kim, J.-H. Lee, J. U. Kim. 2017. Hemodynamic changes caused by acupuncture in healthy volunteers: A prospective, single-arm exploratory clinical study. *BMC Complement. Altern. Med.* 17:274. doi:10.1186/s12906-017-1787-z.

Kirimoto, H., H. Tamaki, T. Matsumoto, K. Sugawara, M. Suzuki, M. Oyama, H. Onishi. 2014. Effect of transcranial static magnetic field stimulation over the sensorimotor cortex on somatosensory evoked potentials in humans. *Brain Stimul.* 7:836–40. doi:10.1016/j.brs.2014.09.016.

Kvernmo, H. D., A. Stefanovska, M. Bracic, K. A. Kirkebøen, K. Kvernebo. 1998. Spectral analysis of the laser Doppler perfusion signal in human skin before and after exercise. *Microvasc. Res.* 56:173–82. doi:10.1006/mvre.1998.2108.

Li, Q., Z. Liao, L. Gu, L. Zhang, L. Zhang, X. Tian, J. Li, Z. Fang, X. Zhang. 2020. Moderate intensity static magnetic fields prevent thrombus formation in rats and mice. *Bioelectromagnetics* 41:52–62. doi:10.1002/bem.22232.

Li, Y., L.-Q. Song, M. Q. Chen, Y.-M. Zhang, J. Li, X.-Y. Feng, W. Li, W. Guo, G. Jia, H. Wang. 2012. Low strength static magnetic field inhibits the proliferation, migration, and adhesion of human vascular smooth muscle cells in a restenosis model through mediating integrins beta1-FAK, Ca2+ signaling pathway. *Ann. Biomed. Eng.* 40:2611–18. doi:10.1007/s10439-012-0602-8.

Lindblad, L. E., L. Ekenvall, K. Ancker, H. Rohman, P. Å. Öberg. 1986. Laser Doppler flow-meter assessment of iontophoretically applied norepinephrine on human finger skin circulation. *J. Invest. Dermatol.* 87:634–36. doi:10.1111/1523-1747.ep12456288.

Lossius, K., and M. Eriksen. 1995. Spontaneous flow waves detected by laser Doppler in human skin. *Microvasc. Res.* 50:94–104. doi:10.1006/mvre.1995.1041.

Lutolf, O., D. Chen, T. Zehnder, F. Mahler. 1993. Influence of local finger cooling on laser Doppler flux and nailfold capillary blood flow velocity in normal subjects and in patients with Raynaud's phenomenon. *Microvasc. Res.* 46:374–82. doi:10.1006/mvre.1993.1060.

Maccariello, C. E. M., C. C. Franzini de Souza, L. Morena, D. P. M. Dias, M. A. D. Medeiros. 2018. Effects of acupuncture on the heart rate variability, cortisol levels and behavioural response induced by thunder sound in beagles. *Physiol. Behav.* 186:37–44. doi:10.1016/j.physbeh.2018.01.006.

Marcinkowska-Gapinska, A., and H. Nawrocka-Bogusz. 2013. Analysis of the magnetic field influence on the rheological properties of healthy persons blood. *Biomed. Res. Int.* 2013:490410. doi:10.1155/2013/490410.

Markov, M. 2015. XXIst century magnetotherapy. *Electromagn. Biol. Med.* 34:190–96. doi:10.3109/15368378.2015.1077338.

Markov, M. S. 2007. Magnetic field therapy: A review. *Electromagn. Biol. Med.* 26:1–23.

Markov, M. S. 2013. Effects of electromagnetic fields on biological systems. *Electromagn. Biol. Med.* 32:121–22. doi:10.3109/15368378.2013.776333.

Mayrovitz, H. N., and E. E. Groseclose. 2002. Neurovascular responses to sequential deep inspirations assessed via laser-Doppler perfusion changes in dorsal finger skin. *Clin. Physiol. Funct. Imaging* 22:49–54. doi:10.1046/j.1475-097X.2002.00404.x.

Mayrovitz, H. N., and E. E. Groseclose. 2005. Effects of a static magnetic field of either polarity on skin microcirculation. *Microvasc. Res.* 69:24–27. doi:10.1016/j.mvr.2004.11.002.

Mayrovitz, H. N., E. E. Groseclose, and D. King. 2005. No effect of 85 mT permanent magnets on laser-Doppler measured blood flow response to inspiratory gasps. *Bioelectromagnetics* 26:331–35. doi:10.1002/bem.20096.

Mayrovitz, H. N., E. E. Groseclose, M. Markov, A. A. Pilla. 2001. Effects of permanent magnets on resting skin blood perfusion in healthy persons assessed by laser Doppler flowmetry and imaging. *Bioelectromagnetics* 22:494–502. doi:10.1002/bem.78.

McGarr, G. W., G. J. Hodges, and S. S. Cheung. 2017. Between-day reliability of local thermal hyperemia in the forearm and index finger using single-point laser Doppler flowmetry. *Microcirculation* 24 (8).

Morris, C. E., and T. C. Skalak. 2008. Acute exposure to a moderate strength static magnetic field reduces edema formation in rats. *Am. J. Physiol. Heart Circ. Physiol.* 294: H50–7. doi:10.1152/ajpheart.00529.2007.

Nilsson, G. E., T. Tenland, and P. A. Oberg. 1980. Evaluation of a laser Doppler flowmeter for measurement of tissue blood flow. *IEEE Trans. Biomed. Eng.* 27:597–604. doi:10.1109/TBME.1980.326582.

Oberg, P. A. 1990. Laser-Doppler flowmetry. *Crit. Rev. Biomed. Eng.* 18:125–63.

Ohkubo, C., and S. Xu. 1997. Acute effects of static magnetic fields on cutaneous microcirculation in rabbits. *In Vivo (Brooklyn)* 11:221–25.

Okano, H., H. Ino, Y. Osawa, T. Osuga, H. Tatsuoka. 2012. The effects of moderate-intensity gradient static magnetic fields on nerve conduction. *Bioelectromagnetics* 33:518–26. doi:10.1002/bem.21717.

Okazaki, M., N. Maeda, and T. Shiga. 1987. Effects of an inhomogeneous magnetic field on flowing erythrocytes. *Eur. Biophys. J.* 14:139–45. doi:10.1007/BF00253838.

Okudera, Y., T. Matsunaga, M. Sato, S. Chida, K. Hatakeyama, M. Watanabe, Y. Shimada. 2015. The impact of high-frequency magnetic stimulation of peripheral nerves: Muscle hardness, venous blood flow, and motor function of upper extremity in healthy subjects. *Biomed. Res.* 36:81–87. doi:10.2220/biomedres.36.81.

Raamat, R., B. Kudimov, and K. Jagomagi. 2001. Similarity of fingertip skin blood flow patterns recorded by the model-based thermal clearance and large area laser Doppler probes. *Med. Eng. Phys.* 23:665–71. doi:10.1016/S1350-4533(01)00090-X.

Shinohara, M. 1997. Decreasing heart rate and shortening of the arterial pulse propagation time by acupuncture in the spectral analyses. *Masui* 46:213–21.

Strieth, S., D. Strelczyk, M. E. Eichhorn, M. Dellian, S. Luedemann, J. Griebel, M. Bellemann, A. Berghaus, G. Brix. 2008. Static magnetic fields induce blood flow decrease and platelet adherence in tumor microvessels. *Cancer Biol. Ther.* 7:814–19. doi:10.4161/cbt.7.6.5837.

Suichies, H. E., J. G. Aarnoudse, A. A. Wouda, H. W. Jentink, F. F. M. de Mul, J. Greve. 1992. Digital blood flow in cooled and contralateral finger in patients with Raynaud's phenomenon. Comparative measurements between photoelectrical plethysmography and laser Doppler flowmetry. *Angiology* 43:134–41. doi:10.1177/000331979204300207.

Takeuchi, T., T. Mizuno, T. Higashi, A. Yamagishi, M. Date. 1995. Orientation of red blood cells in high magnetic field. *J. Magnetism Magnetic Mater.* 140-144:1462–63. doi:10.1016/0304-8853(94)01351-9.

Tao, R., and K. Huang. 2011. Reducing blood viscosity with magnetic fields. *Phys. Rev. E Stat. Nonlin. Soft. Matter. Phys.* 84:011905. doi:10.1103/PhysRevE.84.011905.

Tenforde, T. S. 2005. Magnetically induced electric fields and currents in the circulatory system. *Prog. Biophys. Mol. Biol.* 87:279–88. doi:10.1016/j.pbiomolbio.2004.08.003.

Toth-Szuki, V., F. Bari, and F. Domoki. 2020. Stable laser-Doppler flow-motion patterns in the human cutaneous microcirculation: Implications for prospective geroscience studies. *Physiol. Int.* 107:134–44. doi:10.1556/2060.2020.00013.

Xu, G., Xi, Q., Tang, W., Liu, T., Gao, M., Li, S., Wen, J., Yang, H. 2019. Effect of different twirling and rotating acupuncture manipulation techniques on the blood flow perfusion at acupoints. *J. Tradit. Chin. Med.* 39:730–39.

Yamamoto, T., Y. Nagayama, and M. Tamura. 2004. A blood-oxygenation-dependent increase in blood viscosity due to a static magnetic field. *Phys. Med. Biol.* 49:3267–77. doi:10.1088/0031-9155/49/14/017.

Yan, Y., G. Shen, K. Xie, C. Tang, X. Wu, Q. Xu, J. Liu, J. Song, X. Jiang, E. Luo. 2011. Wavelet analysis of acute effects of static magnetic field on resting skin blood flow at the nail wall in young men. *Microvasc. Res.* 82:277–83. doi:10.1016/j.mvr.2011.03.008.