Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Cell Phone and Breast Cancer: The Cell Phone-Generated Pulsed 217Hz ELF Magnetic Field Increases Angiogenesis

Akram Mahna [1*], Seyed Mohammad Firoozabadi[2], Amir Atashi[3]

1. Assistant professor of Medical physics, Department of Medical Physics, Tabriz University of Medical Sciences, Tabriz, Iran.
2. Professor of Medical physics, Department of Medical Physics, Tarbiat Modares University, Tehran, Iran.
3. Assistant professor of Hematology, Department of Medical Laboratory Sciences, Shahroud University of Medical Sciences, Shahroud, Iran.

ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Sep 24, 2020
Accepted: Nov 27, 2020

Keywords:
Magnetic Field
Angiogenesis
Endothelial Cells
Mice
Breast Cancer

ABSTRACT

Introduction: Over the last decades, there has been an increasing trend in using cell phones which are exposing us to Radio-Frequency (RF) and Extremely Low Frequency (ELF) magnetic fields with various known and unknown biological effects. This protective study aimed to investigate the impact of environmental 217 Hz (as an ELF) magnetic fields generated by mobile phones on angiogenesis as an essential factor in tumor growth, in vitro and in vivo.

Material and Methods: Magnetic fields with amplitudes of 0.5, 6, 22, 44, 65 & 159 µT were exposed on Human umbilical vein endothelial cells (HUVECs) and proliferation and viability of cells were measured. 3D angiogenesis assay was done by culturing HUVEC-covered microbeads in collagen gel and counting the number of sprouting micro-vessels per microbead. The percent of CD31 positive areas in breast tumor tissues of mice was assessed in the in vivo study.

Results: Results showed that some of the applied amplitudes could increase proliferation as well as the viability of HUVECs. Furthermore, 22 and 44 µT magnetic fields could significantly increase the angiogenesis of breast tumors in the mouse.

Conclusion: There is a promoting effect from ELF magnetic fields generated by cell phones on the angiogenesis of tumors. It will be helpful if we recommend that cancer patients not to be exposed to cell phones.

►*Please cite this article as:*
Mahna A, Firoozabadi SM, Atashi A. Cell Phone and Breast Cancer: The Cell Phone-Generated Pulsed 217Hz ELF Magnetic Field Increases Angiogenesis. Iran J Med Phys 2021; 18: 421-429. 10.22038/IJMP.2020.52303.1859.

Introduction

Nowadays, there are very various electromagnetic fields (EMFs) in our environment. Studies show that EMFs with the frequency of 0-300 Hz can cause biological effects, like accelerating the bone fracture healing process [1], increasing single and double-strand DNA breaks [2-6], promoting or preventing tumor growth [7-10], increasing the viability of endothelial cells [11] and accelerating wound healing [12].

Mobile phones have been substantially popular for many years, and many kinds of research were made on the biological effects of their radiofrequency electromagnetic fields. The radio-frequency GSM (the Global System for Mobile Communications) EMF are 1–2 GHz pulses lasting 577µs, transmitted every 4.615 ms (217-Hz burst rate) at 1–2 watts, delivered from an antenna [13]. The low-frequency GSM EMF is a 217 Hz magnetic field, about 3 mT, generated by the battery of cell phones [14-16]. Some research shows that cell phone radiation affects chromosomes, the expression of specific genes, and cell division [17, 18]. Also, there are some reports on the effects of cell phones on brain tumors, causing DNA damage and chromosomal breaks [19, 20]. However, there is no information about the biological effects of 217Hz pulsed extremely low frequency (ELF) magnetic fields emitted from cell phones.

The amplitudes of 217 Hz ELF magnetic fields have been driven from measuring of ELF magnetic fields around a cell phone by Kaviani et al. 2008. According to the results, amplitudes of 0.46, 5.93, 21.9, 44.1, 65.6 and 159.44 µT were the min of the minimums, mean of minimums, a cumulative average of magnetic field flux, mean of averages, mean of maximums, and a peak of morning exposures respectively. They checked the effect of these magnetic fields on the resting potential of snail neurons and reported some significant variations between unexposed cells and the exposed ones [21-25].

Mansourian et al. 2020 have done a study on the effects of 217Hz ELF magnetic fields of mobile phones on electroporation. They found that chronic exposure of the tumor to 93µT magnetic field before

*Corresponding Author: Tel & Fax: +984133364660; Email: mahna@tbzmed.ac.ir, akram.mahna@gmail.com

electrochemotherapy can increase tumor hypoxia induced by electrochemotherapy [26].

Ashdown et al. reported that a pulsed magnetic field with an intensity of 20 mT in frequencies of 50 and 385 Hz could increase cytotoxicity signal compared to basal protease release by resting control cells at room temperature over the same period (10 min)[27].

With more attention to the previous studies on the biological effects of ELF-EMFs, it is clear that these magnetic fields can change the angiogenesis process [7, 10, 28, 29]. The angiogenesis process is the growth of new capillaries from the existing blood vessels [30]. Angiogenesis is an essential factor during wound healing, human fetal development, tissue repair, menstrual cycle, treatment and progress of cancer, and ischemic and inflammatory diseases [31]. Peng et al. reported an angiogenesis-increasing effect of the pulsed magnetic field with 15Hz, 1.5mT, and 30Hz, 3mT for 45min per day on rats. They found that capillary densities were significantly elevated in the 15Hz and 30Hz PEMF-treated groups as compared to those in the control group [32].

Cancer as a progressive disease needs some protective studies on environmental EM fields because there are many low-frequency EMFs in our environment. Angiogenesis is one of the essential factors in tumor growth or treatment. There are some studies on antiangiogenic drugs to cancer treatment [33]. So, it seems useful to do protective research on the effect of environmental EMFs on angiogenesis.

Some studies have evaluated the effect of magnetic fields on angiogenesis. The results showed that magnetic fields, based on their physical parameters, can decrease or increase angiogenesis. It should be considered that these parameters, like frequencies or amplitudes, have been chosen from the reports on therapeutic magnetic fields. Therefore, there was a lack of knowledge on the effect of environmental magnetic fields on angiogenesis as a protective study. However, understanding the positive or negative impact of these fields on angiogenesis can be helpful in cancer treatment. So, the present study aimed to investigate the effect of chronic and acute exposure regimes (CER and AER) of ELF magnetic fields of cell phones on angiogenesis in vitro and in vivo.

Therefore, influential protocols for amplitudes and duration of magnetic field exposure will be optimized based on viability and proliferation tests on Human umbilical vein endothelial cells (HUVECs). Consequently, the number of sprouting branches of HUVECs in collagen gel was assessed in vitro. Then, the effect of the final selected protocols based on the first experiment results was checked on angiogenesis of mouse breast tumor in vivo.

Materials and Methods

Exposure system

Two 20 cm-diameter Helmholtz coils were used to produce a uniform magnetic field for exposing the cells and mice. They were made of 287 turns of 0.78-mm-diameter insulated copper wire, and they separated by 10 cm. 217 Hz magnetic fields were originated from a signal generator (made in Bioelectromagnetic Laboratory of Tarbiat Modares University based on the results of Kaviani thesis [24] and amplified with a homemade power signal amplifier. The pulse duration was 0.577 ms, and the pulse repetition period was 4.6 ms. Biolab software was used for testing the shape of the pulsed magnetic field (Figure 1). The flux density of MF was measured by a Tesla meter (TES-1394; TES Electrical Electronic Corp., Thedford, Ontario, Canada).

Cell line

The cell line used in this study was HUVECs because it's one of humans' more practical endothelial cells for in vitro assessment of angiogenesis [34]. Endothelial cells are principally inactive in grown-up mammals. Nevertheless, they can quickly turn to an extremely proliferative phase upon stimulation by the angiogenic factors secreted by a tumor to invade the neighboring tissues. They can finally experience differentiation to develop new blood capillaries that provide oxygen and nutrients for tumors [35, 36]. In vitro studies were done on the human umbilical vein endothelial cell (HUVEC) line (cultured in Dulbecco's Modified Eagle's Medium and Ham's F-12 Nutrient Mixture (DMEM-F12) (Gibco, Germany) containing 10% fetal bovine serum (FBS) (Gibco, Germany) and 1% penicillin-streptomycin and incubated in 5% CO2 at the temperature of 37°C).

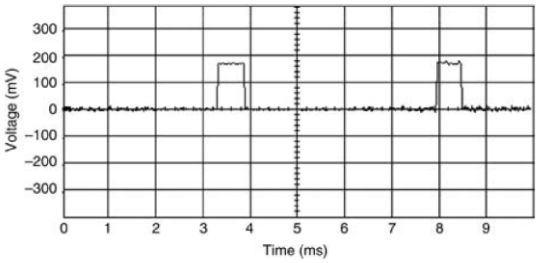


Figure 1. The shape of produced 217 Hz pulsed magnetic field measured by Biolab software (pulse duration is 577µs and pulse repetition period is 4.615ms).

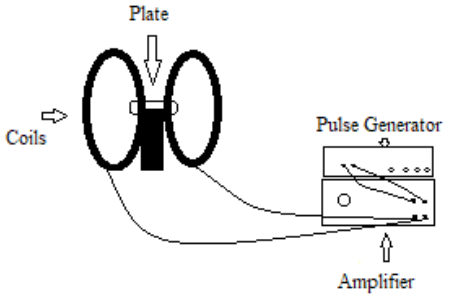


Figure 2. The schematics of exposure system on cells

Experimental groups

For assessment of proliferation and viability of HUVECs, they were seeded 5,000 cells/well in six central wells of a 24-well plate. Then the plates exposed to 217 Hz magnetic field placing between the Helmholtz coils (Figure2). Intensities of 0.5, 6, 22, 44, 65, and 159 µT for 10, 20, and 30 minutes were used only on the 5th day of plating in AER and five consecutive days in CER.

Considering the sham groups (without any exposure but between coils outside the incubator) is useful for reducing the side factors like temperature and humidity on HUVECs.

Determination of cell proliferation

After 24 hours of the final exposure, the proliferation test was done by counting the cells in half wells of every plate using a hemocytometer. The normalized proliferation rate of cells in exposure groups was driven from dividing the mean number of cells in the desired group to the mean number of cells in the control group.

Determination of cell viability

MTT assay (3-(4, 5 dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide) (Invitrogen, USA) was used for assessing the magnetic field cytotoxicity on HUVECs. Moreover, 30 µl of MTT (5 mg/ml) was added to the wells eight days after plating. Then the cells were incubated at a temperature of 37°C for four hours. We added 300 µl dimethyl sulfoxide (DMSO) (Sigma-Aldrich, USA) to each well to dissolve formazan crystals.

To record the optical density (OD), 200 µl of each well Contents was added to the 96-well plate. A mul-ti-scan ELISA reader (LabSystems Multiscan MS, UK) at 540-nm was used for this colorimetric assay. The cell viability of exposure groups was driven from dividing the mean OD in the desired group to the mean OD in the control group. All of the experiments were repeated for three times.

Assessment of sprouting angiogenesis using endothelial cell cultures

In this section of the study, the HUVECs were exposed to magnetic fields in AER and CER protocols selected from proliferation and viability sections on the culture medium included DMEM-F12 and 20% FBS in a flask. For modelling the sprouting angiogenesis, the sterilized cytodex-3 microbeads were immersed in centrifuged exposed cells to cover each bead with almost 30 cells. The mixture was incubated for 4 hours with shaking every 20 min. Then, cell-coated beads were plated in three wells of a 24-well tissue culture plate and incubated for 12-16 h at 37°C and 5% CO2. Finally, beads were immersed in type 1 collagen matrix and incubated for about three days. Capillary-like structures were monitored and counted in each well, and the mean number of sprouts per bead was reported.

Immunohistochemistry studies of angiogenesis

Mice and Tumors

In this study section, we prepared 24 healthy female Balb/C, 5- to 7-week-old mice from the Pasteur Institute (Tehran, Iran). They were kept at 22 ºC with a natural day/night cycle for ten days before the injection. 4T1 is a breast cancer cell line derived from the mammary gland tissue of Balb/c mouse. This tumor cell line is very active, invasive, and also transplantable. It can automatically metastasize from the original tumor in the mammary gland to numerous dispersed body sites. The tumor mice were processed by injecting 800000 4T1 cells/100 µl phosphate buffer saline (PBS) into the right flank of each mouse. They were kept in separate cages. Approximately one week after injection, when the tumor diameter was about 6-7 mm (measured by caliper), the animals (three mice per group [37]) were randomly distributed in groups.

(1) Exposure protocols

Exposure protocols were determined based on the results of the in vitro experiments. AER and CER exposures were included only once on the 10th day after grouping and ten successive days after grouping, respectively, two hours each time. The exposure chamber was built of Plexiglass, and it had some holes to allow air transfer. The chamber was placed between coils.

(2) Immunohistochemistry

The expression of CD31 is a critical way to evaluate angiogenesis changes in tissues. CD31 (platelet endothelial cell adhesion molecule, PECAM-1) is an essential membrane protein that interferes cell to cell adhesion and is revealed on the surface of endothelial cells.

For this purpose, the mice were euthanized by cervical dislocation, and the tumor tissues were removed. The tumors were cut into 12-15 µm thick sections and stained for CD31 in the anatomy department of Tarbiat Modares University of Tehran, Iran. Morphometric analyses for the percent of CD31-positive area in viable and necrotic regions were performed using phase-contrast microscopy on a subset of tumors randomly sampled from the control and exposed groups. Four hot areas were chosen, and marked cells with CD31 antibodies were counted as the number of endothelial cells, and micro-vessel density was determined for each tumor.

The ethics committee approved this proposal of Tarbiat Modares University of Tehran, Iran.

Statistical analysis

The results were presented in bar graphs. Data analyses were performed in IBM-SPSS v. 20 (IBM-SPSS Inc, Chicago, Illinois, USA) using the analysis of variance (ANOVA) and the least significant difference (LSD) test. The p-values of less than 0.05 show significantly effective protocols.

Another method (contrast analysis) was carried out on AER and CER groups and also the exposure duration groups (10, 20, and 30 min).

Results

The results of Proliferation and viability tests were evaluated for various amplitudes (0.5, 6, 22, 44, 65, and 159 μT) and also exposure durations (10, 20, and 30 minutes). Results of different protocols are presented separately. Moreover, the effect of different amplitudes in terms of proliferation and viability of the cells were compared for each duration for both AER and CER.

Effects of AER and CER on HUVEC proliferation

To evaluate the proliferation of HUVECs, the number of cells in treatment groups was measured and normalized to the control group (Figure 3). According to our findings, in AER and CER, the following protocols could significantly increase the proliferation of HUVECs. For AER: 65 μT (20 min) and 22 μT (30 min); and for CER: 44 μT (30 min) and 22 μT (20 min).

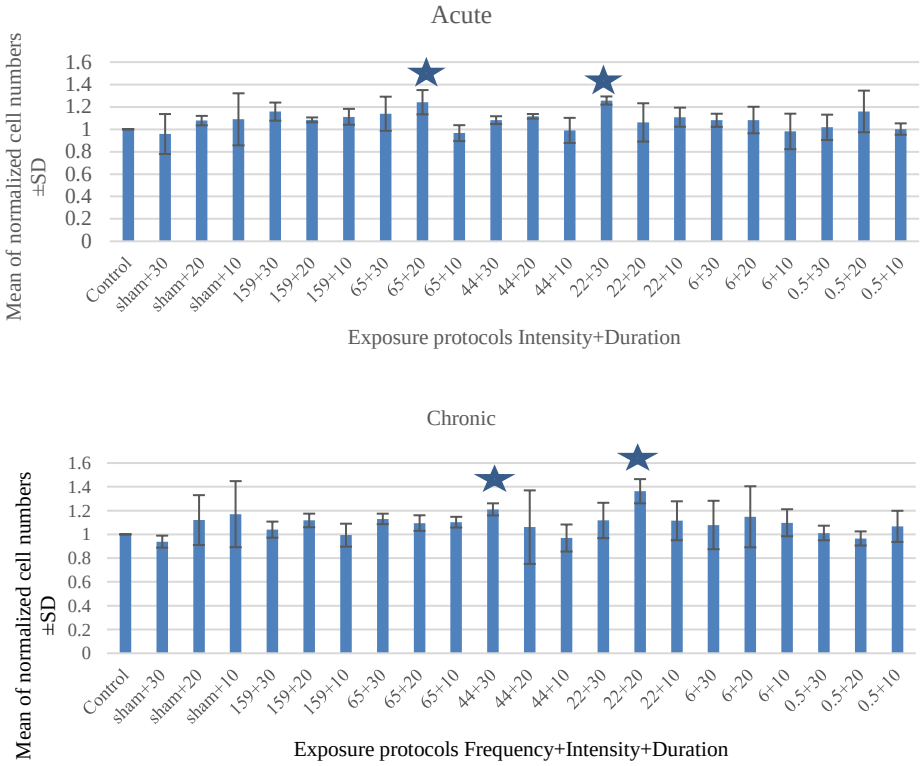
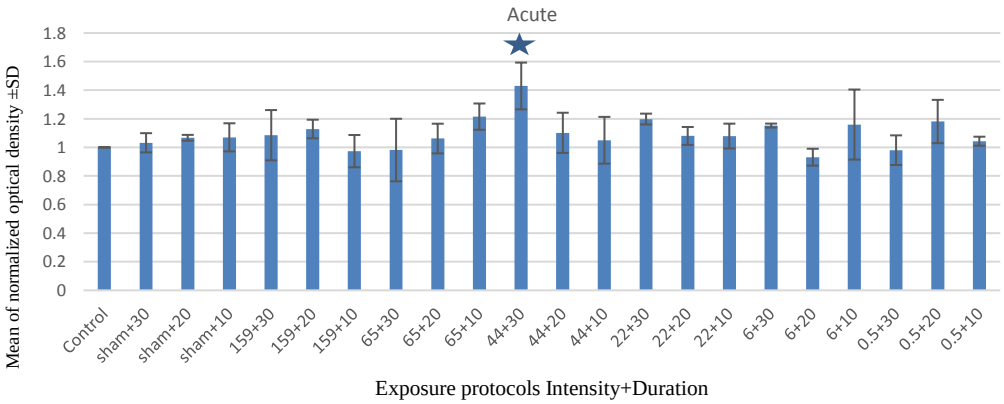


Figure 3. The normalized mean number of HUVECs in AER and CER of 217 Hz magnetic field with different intensities and exposure times (mean±SD). The groups with stars are showing a significant increase ($p<0.05$) compared with the control group on HUVECs proliferation.



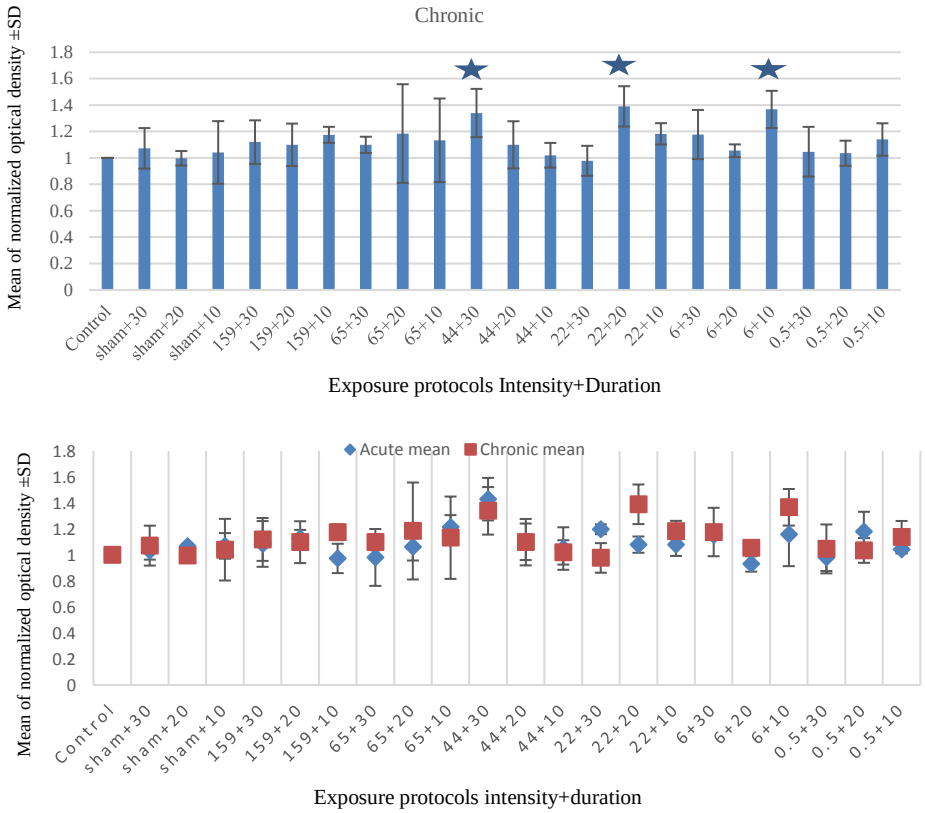


Figure 4. a & b shows the normalized ODs of HUVECs affected by the 217 Hz magnetic field with different intensities (μT) and exposure times (mean±SD). The groups with stars show a significant increase ($p<0.05$) compared with the control group on HUVECs viability. c shows the comparison between normalized ODs of HUVECs in AER and CER of 217 Hz magnetic field with different intensities (μT) and exposure times (mean ± SD). ● shows the acute and ■ shows the chronic protocols.

Effects of AER and CER on HUVECs viability

For assessing the viability of HUVECs, MTT assay was used and mean of normalized OD's of treatment groups to control group has been reported (caused by dissolving purple formazan crystals in DMSO) (Figure 4- a & b). For AERs, 44 μT magnetic field with 30 min duration could significantly increase the viability of HUVECs. Moreover, protocols of 44 μT (30 min), 22 μT (20 min), and 6 μT (10 min) could increase the viability of cells in CERs. Table 1 shows the effective protocols of the 217 Hz ELF magnetic field on the proliferation and viability of HUVECs.

Table 1. The chosen significant efficient exposure protocols of 217 Hz magnetic field on HUVEC proliferation and viability

Exposure condition / Exposure duration (min)	AER Intensity (μT)	CER Intensity(μT)
10	---	6
20	---	22
30	22 44	44

Comparison between the effects of AER and CER of 217 Hz ELF magnetic field on the viability of HUVECs

In this section of the study, differences between acute and chronic groups were analysed by an orthogonal comparison between ODs of AERs vs CERs. The results were presented in Figure 3c (normalized OD's expressed as mean ±SD). There was no significant difference between the results of AER and CER.

Effects of 217 Hz ELF magnetic field on sprouting capability of HUVECs in collagen gel

Sprouting and capillary formation of endothelial cells was quantified after three days of microbeads culture in the collagen gel matrix. The average number of micro-vessels per bead was counted in three areas of collagen gel and normalized to control group results (Figure 5-a). According to the results, sprouting of HUVECs has been significantly increased for two CERs with 22 and 44 μT amplitudes and exposure durations of 20 min and 30 min, respectively. Sprouting micro-vessels around the microbeads in collagen gel are seen in Figure 5-b.

Immunohistochemistry

Figure 6 shows the effect of the 217 Hz ELF magnetic field on the percent of CD31-positive area, which shows tumors' micro-vessels density (MVD).

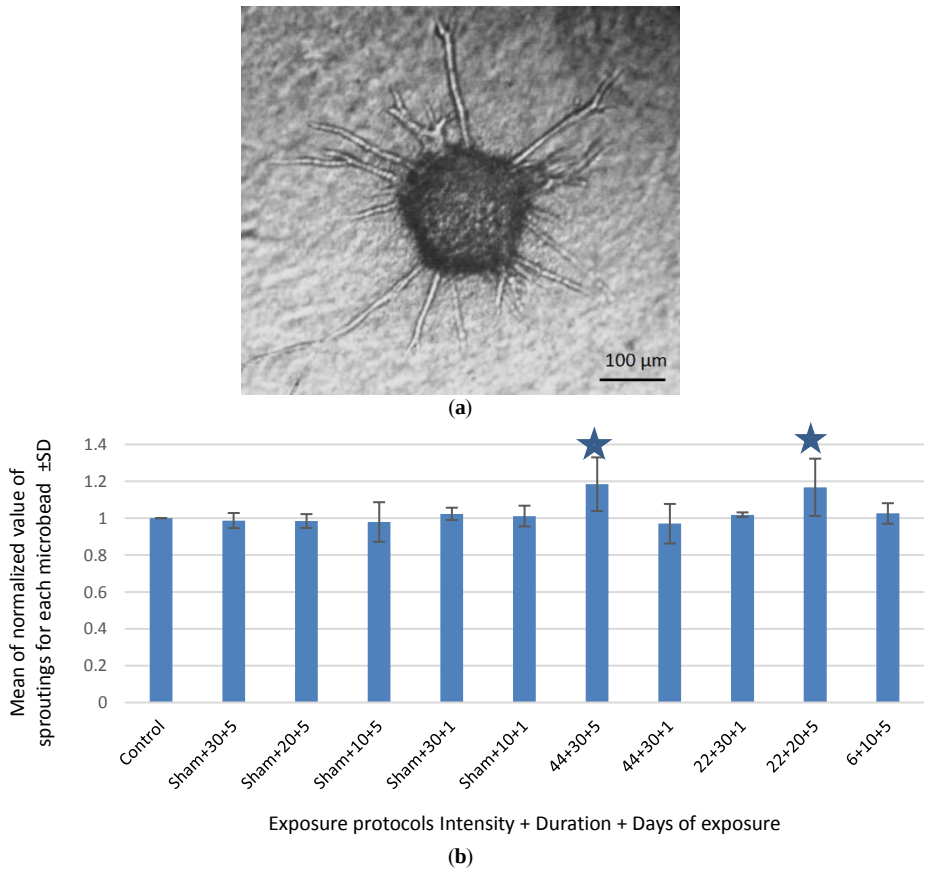


Figure 5. a) Sprouting micro-vessels around the microbeads in collagen gel. b) the Normalized number of sprouting microvessels for each bead in groups of AER (a) and CER (b) of 217 Hz magnetic fields in chosen intensities (µT) and time durations of exposure as mean ± SD are reported. The groups with stars are showing a significant increase ($p<0.05$) compared with the control group on microvessels sprouting.

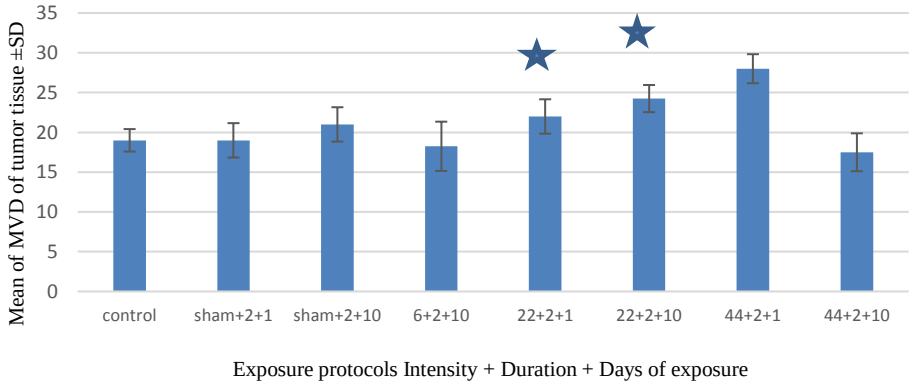


Figure 6. MVD (Microvessel Density) of tumor tissue in groups exposed to 217 Hz magnetic fields in chosen protocols from in vitro section of the study. Data are reported as mean± SD. The groups with stars are showing a significant increase ($p<0.05$) compared with the control group on MVD.

Almost all amplitudes and protocols increased the percent of CD31-positive area. ANOVA indicated that this percentage or mean MVD in the groups exposed to 22 and 44 mT amplitudes of 217 Hz ELF magnetic field in CER and AER, respectively, was significantly more than in the control group ($p<0.05$). Therefore, these environmental magnetic fields could increase the angiogenesis of tumors.

Discussion

With attention to literature, electromagnetic fields can affect cell functions and its responses to various factors in living organisms such as cell proliferation and differentiation, cell cycle disorder, intracellular interactions, DNA replication, gene expression, cellular communications, induction of programmed cell death and free radical production [38]. Besides, the electromagnetic fields have had beneficial effects on treating various pathological problems, like bone

fractures and skin lesions healing [4]. Biological effects of radiofrequency magnetic fields of cell phones have been assessed by Andersen et al. 1997 referring these effects to time alteration of RF fields with as low frequencies as 217, 8, and 2 Hz [14].

In the present study, results indicated that 6, 22 µT (CER) and 44 µT (AER and CER) magnetic fields could significantly increase cell viability and 22 and 44 µT (CER) increase microvessel sprouting in collagen gel, in vitro, and also 22 µT (CER) and 44 µT (AER) could increase tumor micro-vessel density, in vivo. These results agree with Allahveisi et al. 2010 [39], which reported increased mice fibrosarcoma tumor growth after exposure to 217 Hz magnetic field with amplitude of 200 µT.

There is no dose-response relationship between the frequency and amplitude of ELFs and their effects on biological systems. For example, in a study on the impact of long-term exposure of 50 and 217 Hz, magnetic fields on learning and memory of mice by Nooshinfar et al. 2012 [40], 50 Hz magnetic field with medium amplitudes of 1 and 1.5 mT could decrease the learning and the memory of mice. While 217 Hz magnetic field with extreme amplitudes of 0.5 and 2 mT had the same effects [39]. This kind of results is following the principle of biological windows proposed by Dr Ross Adey, especially for magnetic fields [41]. In the present study, the results added another evidence approving the plausibility of offering an amplitude window in effects of ELFs. We found that the ELF with the amplitudes of 6, 22 and 44 µT was able to significantly increase angiogenesis in vitro and in vivo. Another increasing angiogenesis effect was reported by Peng et al. 2019 that 15Hz and 30Hz pulsed magnetic fields with intensities of 1.5 and 3mT could improve the cardiovascular function of rats after exposure [32].

In the present study the ELF MF with the intensity of 44 µT (30 min) in both of AER and CER and 22 µT (20 min) and 6 µT (10 min) in CER could increase the viability of cells, however there were no significant changes in groups exposed to 217Hz magnetic field with intensities of 93,120,159 µT (10 min) in the viability of 4T1 cells in Mansourian et al. study. This is probably because of the type of cells and also the duration of exposure [26]. In another study, Mansourian et al. reported that 217Hz magnetic field of mobile with intensities of 93 and 159 µT could decrease the apoptosis rate of electrochemotherapy-treated cells. This result can confirm our viability increasing results for 217 Hz [42].

Kaviani et al. 2008, have determined the amplitudes of 217 Hz magnetic fields of the cell phones and these fields' effects on the resting potential of neurons of the snail, reporting an amplitude window effect. In this way, 217 Hz magnetic fields with the amplitude of 0.46 and 5.93 µT caused depolarization on the resting potential of membranes. However, high amplitudes of 217 Hz (21.9, 44.1, 65.6 and 229 µT) could cause hyperpolarization on resting potential of membranes. Also, there were more stable effects for low amplitudes [24]. These results were in contradiction with the present study in which all effective amplitudes had an increasing influence on angiogenesis. This discrepancy could be due to the variation of cell types in terms of excitability (neuronal cells vs endothelial cells) and differential durations of exposure regimes.

According to the results, the Effects of AER and CER of 217 Hz magnetic field on the viability and proliferation of HUVECs were not significantly different. This result is in contradiction with Kaviani et al. results in which they reported a reversible effect on the neurological response of the snail to AER of 217 Hz MFs, while for CER, the effect was irreversible [22, 25].

Conclusion

As a protective study, we could deduce that 217 Hz ambient ELF magnetic fields of cell phones can increase angiogenesis in both in vitro and in vivo. Consequently, these fields can probably promote tumor growth. It will be helpful if we recommend cancer patients not to be exposed to cell phones.

Moreover, in the present study, the amplitudes of magnetic fields have been chosen from Kaviani et al. dosimetry data in 2008 [24]. It can be an essential limitation for our study because there is a significant change in the number of cell phones from 2008 to 2019. We can compensate for this limitation with replacing new dosimetry data of our ambient 217 Hz ELF magnetic fields.

Acknowledgment

I would like to express my special thanks of gratitude to staffs of the department of Hematology in Tarbiat Modares University of Tehran, Iran, which gave us the opportunity to do the present project in their lab. Secondly, I would also like to thank Dr Mohammad nejhad for his help in immunohistochemistry studies of this project.

I want to thanks of Dr Nasser Mahna for his help in statistical analysis of results. Also, it's good to say that this research has been funded by Tarbiat Modares University, Tehran, Iran.

References

1. Haddad J, Obolensky A, Shinnick P. The biological effects and therapeutic mechanism of action of electric and electromagnetic field stimulation on bone and cartilage: New findings and a review of earlier work. Altern Complement Med. 2007; 13: 485-90.
2. Ivancsits S, Diem E, Jahn O, Rudiger H. Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way. Int Arch Occup Environ Health. 2003; 76(6): p. 431-36.
3. Ivancsits S, Diem E, Pilger A, Rudiger HW, Jahn O. Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts. Mutat Res Genet Toxicol Environ Mutagen. 2002; 519(1-2): 1-13.
4. McNamee JP, Bellier PV, McLean JRN, Marro L, Gajda GB, Thansandote A. DNA damage and

apoptosis in the immature mouse cerebellum after acute exposure to a 1 mT, 60 Hz magnetic field. Mutat Res Genet Toxicol Environ Mutagen. 2002; 513(1-2): 121-33.
5. Lai H, Singh NP. Acute exposure to a 60 Hz magnetic field increases DNA strand breaks in rat brain cells. Bioelectromagnetics. 1997; 18(2): 156-65.
6. Schmitz C, Keller E, Freuding T, Silny J, Korr H. 50-Hz magnetic field exposure influences DNA repair and mitochondrial DNA synthesis of distinct cell types in brain and kidney of adult mice. Acta Neuropathologica. 2004; 107(3): 257-64.
7. Cameron IL, Markov MS, Hardman WE. Optimization of a therapeutic electromagnetic field (EMF) to retard breast cancer tumor growth and vascularity. Cancer Cell Int. 2014; 14(1).
8. Seze Rd, SophieTuffet, Moreau J-M, Veyret B. Effects of 100mT Time Varying Magnetic Fields on the Growth of Tumors in Mice. Bioelectromagnetics. 2000; 21: 107-111.
9. Tatarov I, Panda A, Petkov D, Kolappaswamy K, Thompson K, Kavirayani A, et al. Effect of Magnetic Fields on Tumor Growth and Viability. Comparative Med. 2011; 61(4): 339-45.
10. Williams CD, Markov MS. Therapeutic electromagnetic field effects on angiogenesis during tumor growth: A pilot study in mice. Electromagn Biol Med. 2001; 20(3): 323-29.
11. Mahna, A., Firoozabadi, S. Environmental 50Hz Magnetic Fields Can Increase Viability of Human Umbilical Vein Endothelial Cells (HUVEC). IJMP, 2016; 13(2): 100-108.
12. Steven LHM, Concannon MMJ, Yee MGJ. The Effect of Magnetic Fields on Wound Healing. ePlasty. 2008; 8: 393-99.
13. Black BA, DiPiazza PS, Ferguson BA. Introduction to wireless systems. Prentice-Hall; 2008.p.304-305.
14. Andersen JB, Pedersen GF. The Technology of Mobile Telephone Systems Relevant for Risk Assessment. Radiat Prot Dosimetry. 1997; 72(3-4): 249-57.
15. Linde T, Mild KH. Measurement of low frequency magnetic fields from digital cellular telephones. Bioelectromagnetics. 1997; 18(2): 184-86.
16. Perentos N, Iskra S, McKenzie R, Cosic I. Characterization of pulsed ELF magnetic fields generated by GSM mobile phone handsets. In: Magjarevic R, Nagel JH, editors. World Congress on Medical Physics and Biomedical Engineering 2006. IFMBE Proceedings. Berlin: Springer; 2007.
17. Baan R, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et al. Carcinogenicity of radiofrequency electromagnetic fields. Lancet Oncol. 2011; 12(7): 624-6.
18. Hardell L, Carlberg M, Hansson MK. Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk of benign brain tumours diagnosed during 1997-2003. Int J Oncol. 2006; 28(2): 509-18.
19. Muscat JE, Malkin MG, Thompson S, Shore RE, Stellman SD, McRee D, et al. Handheld cellular telephone use and risk of brain cancer. JAMA. 2000; 284(23): 3001-7.
20. Panagopoulos DJ, Chavdoula ED, Nezis IP, Margaritis LH. Cell death induced by GSM 900-MHz and DCS 1800-MHz mobile telephony radiation. Mutat Res. 2007; 626(1-2): 69-78.
21. Janahmadi M, Moghadam MK, Firoozabadi SM. Reduction Of F1 Neuronal Excitability By Exposure To 217 Hz Magnetic Fields From GSM 900 Mobile Phone. Cell Journal (Yakhteh). 2009; 11: 176-83.
22. Kaviani Moghadam M, Firoozabadi SM, Lak M, Janahmadi M. The Measurement of Low Frequency Magnetic Field of Two Kinds of GSM900 Mobile Phone. IJMP. 2008; 5(1,2): 43-53.
23. Moghadam MK, Firoozabadi M, Janahmadi M. Effects of weak environmental magnetic fields on the spontaneous bioelectrical activity of snail neurons. J Membr Biol. 2011; 240(2): 63-71.
24. Kaviani Moghadam M. Effect of ELF magnetic fields with 50 and 217 Hz frequency in the range of environmental intensities on the neuronal electrical activities of Helix aspersa [dissertation]. Medical physics: Tarbiat Modares University; 2008.
25. Moghadam MK, Firoozabadi SM, Janahmadi M. 50 Hz alternating extremely low frequency magnetic fields affect excitability, firing and action potential shape through interaction with ionic channels in snail neurones. The Environmentalist. 2008; 28(4): 341-47.
26. Mansourian M, Firoozabadi M, Hassan ZM. The role of 217-Hz ELF magnetic fields emitted from GSM mobile phones on electrochemotherapy mechanisms. Electromagn Biol Med. 2020; 1-11.
27. Ashdown C.P, Johns S. C, Aminov E, Unanian M, Connacher W, Friend J, et al. Pulsed Low-Frequency Magnetic Fields InduceTumor Membrane Disruption and Altered Cell Viability. Biophysical journal. 2020; 118(7): 1552-63.
28. Tepper OM, Callaghan MJ, Chang EI, Galiano RD, Bhatt KA, Baharestani S, et al. Electromagnetic fields increase in vitro and in vivo angiogenesis through endothelial release of FGF-2. The FASEB Journal. 2004.
29. Williams CD, Markov MS, Hardman WE, Cameron IL. Therapeutic electromagnetic field effects on angiogenesis and tumor growth. Anticancer Res. 2001; 21: 3887-92.
30. Klagsbrun M, Moses MA. Molecular angiogenesis. Chem Biol. 1999; 6(8): R217-24.
31. Colpaert CG, Vermeulen PB, Benoy I, Soubry A, van Roy F, van Beest P, et al. Inflammatory breast cancer shows angiogenesis with high endothelial proliferation rate and strong E-cadherin expression. Br J cancer. 2003; 88(5): 718-25.
32. Peng L, Fu C, Liang Z, Zhang Q, Xiong F, Chen L, et al. Pulsed electromagnetic fields increase angiogenesis and improve cardiac function after myocardial ischemia in mice. Circ. J. 2019.
33. Wen Jun L, Pit Foong C, Abd Hamid R. Ardisia crispa root hexane fraction suppressed angiogenesis in human umbilical vein endothelial cells (HUVECs) and in vivo zebrafish embryo model. Biomed Pharmacother. 2019; 118: 109221.
34. Carolyn A. Staton,Claire Lewis, Bicknell R. Endotelial cell migration assays. In: Polytarchou Ch, editors. Angiogenesis Assays: A critical appraisal of current techniques MHaEP. England: Wiley; 2006. p. 65-70.
35. Pandya NM, Dhalla NS, Santani DD. Angiogenesis-a new target for future therapy. Vascul Pharmacol. 2006; 44(5): 265-74.

36. Berridge MJ. Cell cycle and proliferation. cell signalling biology. 2012; 9: 1-42.
37. Charan J, Kantharia ND. How to calculate sample size in animal studies? J Pharmacol Pharmacother. 2013; 4(4): 303-6.
38. Hopper RA, VerHalen JP, Tepper O, Mehrara BJ, Detch R, Chang EI, et al. Osteoblasts stimulated with pulsed electromagnetic fields increase HUVEC proliferation via a VEGF-A independent mechanism. Bioelectromagnetics. 2009; 30(3):189-97.
39. Allah Veisi F, Boloori B, Shooshtarizadeh T. Investigating the Effects of Pulsed 217Hz Magnetic Field on the Growth and Development of a Transplanted Fibrosarcoma Tumor in Balb/c Mice. RJMS. 2010; 16(69): 7-16.
40. Nooshinfar E, Rezaei-Tavirani M, Khodakarim S. Long-term exposure to low frequency electromagnetic fields of 50- and 217-Hz leads to learning and memory deficits in mice. J Paramed Sci. 2012; 3(3).
41. Markov MS. "Biological Windows" : A Tribute to W. Ross Adey. 2005; 25(2): 67-74.
42. Mansourian M, Firoozabadi SM, Shankayi Z, Hassan ZM. Magnetic fields with frequency of 217 Hz can reduce cell apoptosis caused by electrochemotherapy. Electromagn Biol Med. 2013; 32(1):70-8.