Non-Thermal Biological Effects of Electromagnetic Field on Bacteria-A Review

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Abstract

This paper was aimed to review of non-thermal biological effects of electromagnetic fields on bacterial growth, bactericidal, DNA characteristics, morphology of bacterial cells and sensitivity of bacteria against antibiotics. Several studies were showed biological effects of electromagnetic field on bacteria at different frequencies such as low, intermediate and high- frequency electromagnetic field.

Keyword: Electromagnetic field, irradiations, Bacteria and Biological effects

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Introduction

Use of electrical appliances such as power lines and structures in addition to the common utility devices used in the premises of work places and houses often results in enhanced exposure to electromagnetic fields (EMFs) and irradiation emitted by such devices. Exposure of living cells to EMFs often influence the biological functions of organisms and recently investigations on the effect of EMFs has emerged as an emerging area of concern with respect to ecological effects on human health (Segatore *et al*., 2012). The basic knowledge on exposure to electromagnetic radiation (EMR) is very important, because of its widespread impact on living cells almost in any environment.

Electromagnetic fields include microwaves, radio waves, light rays, infrared rays, ultraviolet rays, gamma rays and X-rays. They (EMF) exist in the form of magnetic energy and electric waves together in space. The electromagnetic radiations (EMR) can be divided into two main types. First are non-ionizing radiations such as radio waves, electric and magnetic fields, radio-frequency wave which contains microwaves, ultraviolet, infrared and visible radiation; and second are ionizing radiations such as gamma rays and X-rays (FCC, 1999; ARPANSA, 2011).

Electromagnetic field (EMF) causes biological response-simulative and discouraged effects on organisms at all stages of life, including bacteria (Banik *et al*., 2003; Guofen *et al*., 2002; Belyaev, 2005; Ruediger, 2009). The aim of the current review was to assess the literature that suggested that electromagnetic field (EMF) had non-thermal biological effects on bacteria.

1. Effects on bacterial growth

Several investigators have reported that EMF causes different effects, including bactericidal ones. These depend on the frequency or wavelength of EMF, intensity, coherence, post-exposure, duration of time of exposure, mediated and frequency of irradiation (Belyaev *et al*., 1992, 1993, 1996; Bulgakova *et al*., 1996; Shcheglov *et al*., 2002; Alipov *et al*., 2003; Isakhanyan and Trchounian, 2005; Tadevosyan *et al*., 2006, 2007, 2008; Torgomyan *et al*., 2011, 2012), besides growth phase of bacteria, aerobic or anaerobic conditions, density of cells, growth media composition, genetic features, cell-to-cell interaction, peculiarities of membrane properties and metabolism in species of bacteria or strains (Torgomyan and Trchounian, 2012).

Bacterial effects of EMF are known for different environmental conditions such as water suspension, a surface (agar) and a biofilm. Water is a major essential requirement of biological systems and culture medium. At low intensities extremely high frequencies EMF affects H_2O molecules leading to biological responses. Different harmful effects on the viability and growth of *E. coli* after bacterial suspension exposure to high frequency- electromagnetic fields HF-EMF (51.8 to 73 GHz) have been reported (Tadevosyan *et al*., 2007, 2008; Torgomyan *et al*., 2011; Torgomyan and Trchounian, 2011, 2012). Effects of EMF on *E. coli* suspension have strong confirmations at the various frequencies (50.3, 51.8, 64.5, 65.5, 95, 105 GHz), that are resonant for H_2O molecules (Fesenko *et al*., 1995; Betskii *et al*., 2000; Sinitsyn *et al*., 2000; Isakhanyan and

Trchounian, 2005; Tadevosyan *et al*., 2006, 2007). Fojt *et al*., (2004) compared three different bacterial species; *E. coli*, *L. adecarbodxylata* and *S. aureus* which were exposed to low frequency electromagnetic field (LF-EMF) at 50 Hz. The activity of *E. coli* was significantly reduced compared to the other two species. Among them *S. aureus* was the least affected. Furthermore, prolonged exposure to 50 Hz was observed to affect transposition activity in *E. coli* (Del Re *et al*., 2003). Also, Soghomonyan and Trchounian, (2013) studied of effects of extremely high frequency electromagnetic irradiation (EHF-EMI) at 51.8 and 53 GHz on survival and growth of *L. acidophilus* and compared with antibacterial effects of antibiotic ceftazidime. The study showed decrease in growth rate of *L. acidophilus* when exposed to EMI and comparable with the inhibition effect of ceftazidime. Further, no synergistic action was shown with combined effects of the antibiotic and exposed to EMI. However, exposure to EMI improved antibiotic inhibition effect on survival of bacteria.

2. Bactericidal Effects

Some of the studies focused on the bactericidal effects of microwave (MW) radiation exposure (Apostolou *et al*., 2005; Aziz *et al*., 2002; Bookwalter *et al*. 1982; Farber *et al*. 1998; Fujikawa *et al*., 1992; Heddleson and Doores 1994; Woo *et al*., 2000). The interaction of MW radiation, at sub-lethal bulk temperatures with the membranes of prokaryotic cells can be used to provide important information about the mechanisms of MW exposure. Microwave radiation (MR) at a frequency of 18 GHz and 45°C has been used to sterilize transplant biomaterial of pathogenic bacteria such as *S. aureus* and *E. coli* without compromising tissue durability and functionality (Shamis *et al*., 2009). No clarification was given as to the causes of the bactericidal effects of the MW exposure. Fairly, this study referred to the MW effect as being non-thermal in nature, because the processing temperature was maintained below 45°C.

Irradiation of bacteria directly on solid growth media with 51.8, 53, 70.6 and 73 GHz frequencies decreased the colonies numbers compared with that of controls which were not-exposed to irradiation. The effects were more with 51.8 GH and 53 GHz. Interestingly, the EMF influence not only led to decreases in the colonies numbers, but also on their dimensions (Torgomyan *et al*., 2011). It is known well, that EMF of 41-43 GHz, 53 GHz, 70.6 GH and 73 GHz frequencies can have resonant-like bactericidal effects on *E. coli*, which probably occur by their direct interaction with bacteria (Guofen *et al*., 2002; Torgomyan *et al*., 2011). Bactericidal effects were studied by Yumoto *et al*., (2012) on electromagnetic wave irradiation (EMWI) (0.5–1 MHz, 5 to 15 times, for 1 s time^{-1}) on oral bacterial pathogens (*P. gingivalis*, *E.*

faecalis, *S. intermedius*, *S. mutans*). Viable Counts of survived bacteria exposed to EMW revealed noticeable bactericidal activity against all tested bacteria. Observations of scanning electron microscopic (SEM), after exposure to EMW at 0.5 MHz, showed that the chain of *S. mutans* cells was reduced to five times and the rough draft of cells of bacteria (*P. gingivalis* and *S. mutans)* were unclear after exposure for 5-10 times. According to Yumoto *et al*., (2012) irradiation with these conditions may be used for medical uses such as sterilization and disinfection.

3. Effect of EMF on bacterial DNA

Carcinogenesis probably includes DNA damage and the genetic toxicity of power frequency EMFs has been broadly studied with model organisms such as microbes, insects, plants and animals by several investigators (McCann *et al*., 1998; Murphy *et al*., 1993). In fact contrasting results have been shown on the possible genotoxicity of EMFs with shorter frequency than radiofrequencies used in communication technologies involving mobile phone handsets (800MHz- 2GHz). Extremely low-frequency magnetic fields generated from power lines were reported to be genotoxic (Tabrah *et al.* 1994), while another study showed that static magnetic fields generated from magnetic resonance imaging did not induce bacterial reverse mutation (Schreiber *et al.*, 2001). It was reported that exposure of *S. typhimurium* to static direct current electric fields of 200 to 800 kV/m led to increase in the rate of reverse mutation (Hungate *et al.* 1979). Further it was suggested that exposure of *E. coli* into magnetic fields can stimulate DNA transposition as a stress-response process (Chow and Tung, 2000), indicating that magnetic fields may induce instability of genome.

Genetic effect of electromagnetic fields (EMF) on DNA when expose to electromagnetic field at 50 Hz was studied using amplified fragment length polymorphism (AFLP) technique to estimate the presence of micro-or macroevolutions. DNA fingerprinting revealed no remarkable differences among the DNA patterns at each conditions of this study (Cellini *et al*., 2008). Similar unvaried Random Amplified Polymorphic DNA (RAPD) electrophoretic patterns among exposed *E. coli* XL-1 cells and respective controls in *in vivo* experiments were reported by Potenza *et al*., (2004). They studied genome stability also in *in vitro* tests obtaining DNA variations and established that magnetic fields can cause DNA alterations normalized in living microorganisms.

Chang *et al*., (2005) studied the biological effects of exposure to EMF at 835MHz on bacterial reverse mutation using Ames method and analysed stability of DNA (*in vitro* degradation of DNA). The results of bacterial reverse mutation studies showed mutagenic or co-mutagenic effects when exposed to 835-MHz radiation which were not significantly frequent in other related strains with same type of mutation and in degradation of DNA. The exposure to 835-MHz EMF did not change the rate of degradation observed using plasmid pBluescript SK (+) as an indicator. Thus, they suggested that exposure to EMF at 835-MHz, according the conditions of their study, did not affect the reverse mutation rate and accelerated degradation of DNA.

4. Effect of EMF on cell morphology

A study conducted by Shamis *et al*., (2011) on the effects of MW radiation on *E. coli* cells at sub-lethal temperatures by two microscopic analyses revealed that the bacterial cells showed different cell morphology directly when exposed to MW radiation. The cells appeared dehydrated and shrunken compared to that when the exposure had stopped after 10 min, at which period morphology of the cell resembled to those not exposed (thermally heated cells). Further, Confocal laser scanning microscopy also showed that the cells exposed to MW radiation could take up fluorescein isothiocyanate conjugated dextran probes (150kDa), suggesting formation of provisional pores in membrane of the cell. Formation of temporary pores within the membrane of bacteria indicated that the MW-cell relation was electro kinetic in nature in the said environment.

Fojt *et al.* (2007) observed no change in the morphology of *Escherichia coli* and *Pseudomonas denitrificans* when exposed to EMF at 50 Hz for one hour suggesting that shape of bacteria does not play any significant importance in the interaction with radiation of magnetic field. Whereas it was observed that exposure to an ELF-EMF with frequency of 50 Hz for short-term (20 to 120 min) affected both cell morphology and viability of *E. coli* (Cellini *et al*., 2008). Under these conditions, EMF also caused transcriptional alterations resistance acquisition to Cephalosporins such as Ceftazidime and Cefuroxime.

5. Effect of EMF on bacterial sensitivity to antibiotics

The potential of a synergistic and/or antagonistic impact evoked using specific antibiotics with appropriate doses in response to electromagnetic fields deserves special care in the light of the risk that antibiotic resistance poses to public health. Presently, most of the microorganisms including bacteria are becoming more resistant to nearly all currently available antibiotics and consequently resistance to antibiotics has become an international problem of highest importance (Bush *et al*., 2011; Levy, 2001).

Several antibiotics including chloramphenicol, tetracycline, ceftriaxone and kanamycin at their minimal inhibition concentrations affect growth and survival of *E. coli* and these effects could be strengthened using EHF-EMF (Tadevosyan *et al*., 2008; Torgomyan and Trchounian, 2012; Torgomyan *et al*., 2011). Similar effects have been shown with *Enterococcus hirae* (Torgomyan *et al*., 2012). EMF is assumed to change antibiotic resistance or sensitivity, which depends on frequencies of EMF. Those effects have been observed with 51.8 GHz and more by 53 GHz (Torgomyan *et al*., 2011; Tadevosyan *et al*., 2008; Torgomyan and Trchounian, 2012). Discharge of proton-motive force and permeabilization of membrane generated using the F_0F_1-ATPase under fermentation conditions; disturbances in H^+, K^+ and Na^+ transport, decrease in ATP levels and modifications in suitable transport systems (Trchounian, 2004) as well as changes in membrane proteome can contribute to enhanced sensitivity to antibiotics (Xu *et al*., 2006). Moreover, change in DNA gyrase and other alterations in expression of genes or synthesis of proteins are also significant factors which could influence antibiotics sensitivity (Cambau and Gutmann, 1993). These sepculations were considered to be in accordance with the results of changed sensitivity of *S. aureus* to several antibiotics using EHF-EMF with non-thermal intensity (Bulgakova *et al*., 1996). Moreover, that is likely to have bioelectric effect with radio frequency alternating electric current (10MHz) for *E. coli* biofilms treated with the other antibiotics (Blenkinsopp *et al*., 1992). Spectacular increase of the antibiotic efficacy in biofilms due to a particular action of the radio frequency EMF on molecules of H_2O in liquid or in biofilms matrix was also described (Caubet *et al*., 2004).

Susceptibility of *P. aeruginosa* and *E. coli* to numerous antibiotics (*in vitro*) when exposed to extremely low frequency (ELF-EMF) was studied by Segatore *et al*., (2012). Their study did not show any significant change in minimum inhibition concentration (MIC) values for treated cells and for the untreated cells with ELF-EMF. They were also observed to not affect the antibiotic susceptibility degree of *P. aeruginosa* and *E. coli*. Further the study, which tested the influence of ELF-EMF on the bacterial growth rate, showed no significant differences in bacterial growth rate between those exposed bacteria and unexposed bacteria (control). Conversely, study of Segatore *et al*., (2012) did not concur with results of previous study on the ability of ELF-EMF to make changes in sensitivity to antibiotic and cell growth of *E. coli* (Stansell *et al*., 2001, Fojt *et al*., 2004, Fojt *et al*., 2009, Gaafar *et al.*, 2006, Justo *et al.*, 2006, Belyaev, 2011) and other strains (Fojt *et al*., 2007, Fojt *et al*., 2009, Grosman *et al*., 1992). The influence of ELF-EMF on *E. coli* was also studied by Justo *et al*., (2006) who observed that the exposure of *E. coli* to an ELF-EMF with frequency of 50 Hz induced noticeable changes in the resistance and sensitivity to some antibiotics such as erythromycin, nalidixic acid and amoxicillin (Gaafar *et al*., 2006, Gaafar *et al*., 2008). Stansell *et al.* (2001) showed that static fields at moderate intensity were able to cause a reduction in the resistance and sensitivity to antibiotic by *E. coli*. Whereas Grosman *et al*. (1992) showed that static magnetic fields had no significant influence on the antibiotic sensitivity and growth rate of *S. aureus* and *E. coli*.

Microorganisms, in particular bacteria, in biofilm are noticeably different, physiologically and environmentally, from planktonic bacteria of the same strains (Kolter, 2010). For example, bacterial strains in a biofilm environment can be more than1000 times resistant to a specific antibiotic; than the same bacterial strains in a planktonic environment (Zielinski *et al*., 2007; Caubet *et al*., 2004). It was shown earlier, that electric field (Blenkinsopp *et al*., 1992) and RF-EMF at10 MHz (Caubet *et al*., 2004) can increase the efficacy of antibiotic on *E. coli* biofilms.

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References

Alipov, E. D., Shchegtov, V. S., Sarimov, R. M. and Belyaev, I. Y. (2003). Cell-density dependent effects of low-dose ionizing radiation on *E. coli* cells. Radiate Biol. Radioecol, 43,167-171.

Apostolou, I., Papadopoulou, C., Levidiotou, S. and Ioannides, K. (2005). The effect of short-time microwave exposures on *Escherichia coli* O157:H7 inoculated onto chicken meat portions and whole chickens. Int. J.Food Microbiol. 101:105–110.

ARPANSA, (2011). Introduction to radiation basics. http://www.arpansa.gov.au/RadiationProtection/basics/index.cfm.

Aziz, N. H., Mahrous, S. R and Youssef, B. M. (2002). Effect of gamma-ray and microwave treatment on the shelf-life of beef products stored at 5°C. Food Control 13:437–444.

Banik, S., Bandyopadhyay, S. and Ganguly, S. (2003). Bioeffects of microwave—a brief review. Bioresource Techn. 87, 155–159.

Belyaev, I. (2005). Non-thermal biological effects of microwaves: Current knowledge, further perspective, and urgent needs. Electromagnetic Bio.Medic, 24, 375–403.

Belyaev, I. (2011). Toxicity and SOS-response to ELF magnetic fields and nalidixic acid in *E. coli* cells. Mut. Res. 722 (1): 56–61.

Belyaev, I. Y., Shcheglov ,V. S., Alipov, Y. D. and Polunin, V. A. (1996). Resonance effect of millimeter waves in the power range from 10(-19) to 3 x 10 (-3) W/cm2 on *Escherichia coli* cells at different concentrations. Bioetectrom. 17,312-321.

Belyaev, I.Y, Scheglov, V.S., Alipov, Y. D. and Kadko, S. R. (1993). Regularities of separate and combined effects of circularly polarized millimeter waves on *E. coli* cells at different phases of culture growth. Bioelecrrochem. Bioenerg. 31, 49-63.

Belyaev, I.Y., Alipov, Y.D., Scheglov, V.S and Lystsov, V.N. (1992). Resonance effect of microwaves on the genome conformational state of *E.coli* cells. Z. Naturforsch, 47, 621-627.

Betskii, O.V., Devyatkov, N.D. and Kislov, W. (2000). Low intensity millimeter waves in medicine and biology. Crit .Rev. Biomed. Eng, 28.217-268.

Blenkinsopp, S.A., Khouiy, A.E. and Coslerton, I.W. (1992). Electrical enhancement of biocide efficacy against *Pseudomonas aeruginosa* biofiims. Appl. Environ. Microbiol. 58,3770-3773.

Bookwalter, G.N., Shukla,T.P. and Kwolek, W.F. (1982). Microwave processing to destroy Salmonellae in corn–soy–milk blends and effect on product quality. J. Food Sci. 47:1683–1686.

Bulgakova, V.G., Grushina, V.A., Orlova, T.I., Petrykina, Z.M., Polin , A.N., Noks, P.P,. Kononenko, A.A. and Rubin, A.B. (1996). The effect of millimeter-band radiation of nonthermal intensity on sensitivity of Staphylococcus to various antibiotics. Biofizika, 41.1289-1293.

Bush, K.1., Courvalin, P., Dantas, G., Davies, J., Eisenstein, B., Huovinen, P., Jacoby, G.A., Kishony, R., Kreiswirth, B.N., Kutter, E., Lerner, S.A., Levy, S., Lewis, K., Lomovskaya, O., Miller, J.H., Mobashery, S., Piddock, L.J., Projan, S., Thomas, C.M., Tomasz, A., Tulkens, P.M., Walsh, T.R, Watson, J.D., Witkowski, J., Witte, W., Wright, G., Yeh, P. and Zgurskaya, H.I. (2011).Tackling antibiotic resistance. Nature Revi Micro. 9(12): 894–896.

Cambau, E. and Guunann, L. (1993). Mechanisms of resistance to quinolones. Drugs, (45) 3.15-23.

Caubet, R., Pedarros-Caubet, E., Chu, M., Freye, E., de Belem Rodrigues, M., Moreau, I.M. and Ellison, W.J. (2004). A radio frequency electric current enhances antibiotic efficacy against bacterial biofilms. Antimkrob. Agents Chemo. 48.4662-4664.

Cellini, L., Grande, R. and Di Campli, E. (2008). Bacterial response to the exposure of 50Hz electromagnetic fields. Bioelectrom. 29 (4): 302–311.

Chang, S.K., Choi, J.S., Gil, H.W., Yang, J.O., Lee, E.Y., Jeon, Y.S., Lee, Z.W., Lee, M., Hong, M.Y., Ho Son, T. and Hong, S.Y. (2005). Genotoxicity evaluation of electromagnetic fields generated by 835-MHz mobile phone frequency band. Eur. J.Cancer. Prev. 14:175-179.

Chow, K. and Tung, W. (2000). Magnetic field exposure stimulates transposition through the induction of DnaK/J synthesis. Biochem. Biophys. Res. Commun. 270: 745–748.

Del Re, B., Garoia, F., Mesirca, P., Agostini, C., Bersani, F. and Giorgi, G. (2003). Extremely low frequency magnetic fields affect transposition activity in Escherichia coli. Radi. Envir. Biophy. 42: 113- 118.

Farber, J.M., Aoust, J.D., Diotte, M., Sewell, A. and Daley, E. (1998). Survival of Listeria spp. on raw whole chickens cooked in microwave ovens. J. Food Protect. 61:1465–1469.

FCC, (1999). Questions and answers about biological effects and potential hazards of radio-frequency electromagnetic fields. OET Bulletin 56, 4th Edition. http://www.fcc.gov/encyclopedia/oet-bulletins-line.

Fesenko, E.E., Gefelyuk, V.I., Kazachenko, V.N. and Chemeris, N.k. (1995). Preliminary microwave irradiation of water solutions changes their channel-modifying activity. FEBS Lett, 366.49-52.

Fojt, L., Klapetek, P., Strasak, L. and Vetterl, V. (2009). 50Hz magnetic field effect on the morphology of bacteria. Micron, 40(8) 918–922.

Fojt, L., Strasak, L. and Vetterl, V. (2007). Effect of electromagnetic fields on the denitrification activity of *Paracoccus denitrificans*. Bioelectrochem.70 (1) 91–95.

Fojt, L., Strasak, L.,Vetterl, V. and Smarda, J. (2004). Comparison of the lowfrequency magnetic field effects on bacteria *Escherichia coli*, *Leclercia adecarboxylata* and *Staphylococcus aureus*. Bioelectrochem. 63: 337-41.

Fujikawa, H., Ushioda, H. and Kudo, Y. (1992). Kinetics of *Escherichia coli* destruction by microwave irradiation. Appl. Environ. Microbiol. 58:920–924.

Gaafar, A., Hanafy, S., Tohamy, T. and Ibrahim, H. (2006). Stimulation and control of E. coli by using an extremely low frequency magnetic field. Rom. J. of Biophysics.16(4): 283–296.

Gaafar, A., Hanafy, S., Tohamy, T. and Ibrahim, H. (2008). The effect of electromagnetic field on protein molecular structure of *E. coli* and its pathogenesis. Roman. J. of Biophysics.18 (2).145–169.

Grosman, Z. Kol´ar, M. and Tesar´ıkov´a, E. (1992). Effects of static magnetic field on some pathogenic microorganisms," Acta Universitatis Palackianae Olomucensis Facultatis Medicae. 134: 7–9.

Guofen, Yu., Coln, E., Schoenbach, K., Gellerman, M., Fox, P., Rec, L., Stephen J. B. and Shenggang, L. (2002). A study on biological effects of low intensity millimeter waves. IEEE Trans. on Plasma Sci, 30, 1489–1496.

Heddleson, R.A. and Doores, S. (1994). Factors affecting microwave heating of foods and microwave induced destruction of foodborne pathogens- a review. J. Food Protect. 57:1025–1037.

Hungate, F., Fujihara, P. and Strankman, S. (1979). Proceedings of the 18th Annual Handford Life Science Symposium. In: Philips PD, Gillis MF, Kaune WT, Mahlom DD (editors): Biological Effects of Low Frequency Electro-Magnetic Fields Richland, WA: pp. 530–537.

Isakhanyan, V. and Trchounian, A. (2005).Indirect and repeated electromagnetic irradiation with extremely high frequency of bacteria *Escherichia coli*. Biophys, 50,604-606.

Justo, R., Perez, H., Alvarez, C. and Alegre, M. (2006). Growth of *Escherichia coli* under extremely low-frequency electromagnetic fields," Appl. Biochem. and Biotech. 134 (2):155–163.

Kolter, K. (2010). Biofilms in lab and nature: a molecular geneticist's voyage to microbial ecology. Int. Microbiol. 13,1-7.

Levy, B. (2001). Antibiotic resistance: consequences of inaction, Clinical Infectious Diseases, vol. 33 (3):124–129.

McCann, J,. Dietrich, F. and Rafferty, C. (1998). The genotoxic potential of electric and magnetic fields: an update. Mutat. Res. 411: 45–86.

Murphy, J.C, Kaden, D.A, Warren, J. and Sivak, A. (1993). International commission for protection against environmental mutagens and carcinogens. Power frequency electric and magnetic fields: a review of genetic toxicology. Mutat. Res. 296: 221–240.

Potenza, L., Cucchiarini, L.; Piatti, E., Angelini, U. and Dacha, M. (2004). Effects of high static magnetic field exposure on different DNAs. Bioelectrom. 25:352–355.

Ruediger, W. (2009). Genotoxic effects of radiofrequency electromagnetic fields. Pathophy. 16, 89–102.

Schreiber, W.G., Teichmann, E.M., Schiffer, I, Hast, J., Akbari, W., Georgi, H., Graf, R., Hehn, M., Spiebeta, H.W, Thelen ,M., Oesch, F. and Hengstler, J. (2001). Lack of mutagenic and comutagenic effects of magnetic fields during magnetic resonance imaging. J. Magn .Reson .Imaging. 14: 779–788.

Segatore, B., Setacci, D., Bennato, F.,Cardigno, R., Amicosante, G and Iorio, R. (2012). Evaluations of the Effects of Extremely Low-Frequency Electromagnetic Fields on Growth and Antibiotic Susceptibility of Escherichia coli and Pseudomonas aeruginosa. Inter. J. Microb.1-7.

Shamis, Y., Patel, S., Taube , A., Morsi, Y., Sbarski, I., Shramkov, Y., Croft, R., Crawford, R.J. and Ivanova, E.P. (2009). A new sterilization technique of bovine pericardial biomaterial using microwave radiation. Tissue Eng. Meth. 15:445–454.

Shamis, Y., Taube, A., Mitik-Dineva, N., Croft, R., Crawford, R.J. and Ivanova, E.P. (2011). A study of the specific electromagnetic effects of microwave radiation on *Escherichia coli*. Appl. Environ. Microbiol. 77:3017–3022.

Shcheglov, V. S., Alipov, E. D. and Beryaev, I. Y. (2002). Cell-to-cell communication in response of *E. coli* cells at different phases of growth to low-intensity microwaves. Biochim. Biophys .Acta, 1572, 101-106.

Sinitsyn, N.I., Petrosyan, V.I., Yolkin, V.A., Devyatkov, N.D., Gulyaev, Y.V. and Betskii, O.V. (2000). Special function of the "millimeter wavelength waves-aqueous medium" system in nature. Crit. Rev. Biomed. Eng, 28.269-305.

Soghomonyan, D. and Trchounian, A. (2013). Comparable Effects of Low-intensity Electromagnetic Irradiationat the Frequency of 51.8 and 53 GHz and Antibiotic

Ceftazidime on Lactobacillus acidophilus Growth and Survival. Cell Biochem. Biophys. 1-7.

Tabrahm, F., Mower, H., Batkin, S. and Greenwood, P. (1994). Enhanced mutagenic effect of a 60 Hz time-varying magnetic field onnumbers of azide-induced TA100 revertant colonies. Bioelectrom. 15: 85–93.

Tadevosyan, H., Kalantaryan, V. and Trchounian, A. (2007). The effects of electromagnetic radiation of extremely high frequency and low intensity on the growth rate of *Escherichia coli* and the role of medium pH. Biophys., 52,893-898.

Tadevosyan, H., Kalantaryan, V. and Trchounian, A. (2006). Direct and mediated effects of the extremely high frequency coherent electromagnetic radiation (millimeter waves) with low intensity on bacteria. In: Biological Effects of Electromagnetic Fields. Proc. 4th Intern. Workshop, Crete, Greece. 1307-1314.

Tadevosyan, H., Kalantaryan, V. and Trchounian, A. (2008). Extremely high frequency electromagnetic radiation enforces bacterial effects of inhibitors and antibiotics. Cell Biochem. Biophys. 51,97-103.

Torgomyan, H. and Trchounian, A. (2011). Low-intensity electromagnetic irradiation of 70.6 and 73 GHz frequencies enhances the effects of disulfide bonds reducer on Escherichia coli growth and affects the bacterial surface oxidation-reduction state. Biochem. Biophys. Res. Conunun. 414,265-269.

Torgomyan, H. and Trchounian, A. (2012). *Escherichia coli* membrane-associated energy-dependent processes and sensitivity toward antibiotics changes as responses to low-intensity electromagnetic irradiation of 70.6 and 73 GHz frequencies. Cell Biochem. Biophys. 62,451-461.

Torgomyan, H., Kalantaryan, V. and Trchounian , A. (2011). Law intensity electromagnetic irradiation with 70.6 and 73 GHz frequencies affects *Escherichia coli* growth and changes water properties. Cell Biochem. Biophys. 60.275-281.

Torgomyan, H., Ohanyan, V., BIbuIyan, S., Kalantaryan, V. and Trchounian, A. (2012). Electromagnetic irradiation of *Enterococcus hirae* at low-intensity 51.8- and 53.0-GHz frequencies: changes in bacterial cell membrane properties and enhanced antibiotics effects. FEMS Microbiol. Lett., 329.131-137.

Trchounian, A. (2004). *Escherichia coli* proton-translocating FOF1-ATP synthase and its association with solute secondary transporters and/or enzymes of anaerobic oxidation-reduction under fermentation. Biochem. Biophys. Res. Commun. 315.1051-1057.

Woo, I.S., Rhee, I.K. and Park, H.D. (2000). Differential damage in bacterial cells by microwave radiation on the basis of cell wall structure. Appl. Environ. Microbiol. 66:2243–2247.

Xu, C., Lin, X., Ren, H., Zhang, Y., Wang,S. and Peng, X. (2006). Analysis of outer bacterial communication. J.MicrobioIImmunol. Infect, 36,153-160.

Yumoto, H., Tominaga, T., Hirao, K., Kimura, T., Takahashi1, K.,Sumitomo, T., Bando, N. and Matsuo, T. (2012). Bactericidal activity and oral pathogen inactivation by electromagnetic wave irradiation. J. Applied Microb. 113, 181–191.

Zielinski, M., Ciesielski, S., Cydzik-kwiatkowska, A, Turek, J., and Debowski, M. (2007). Influence of microwave radiation on bacterial activity and community structure in biofilm. Pro. Biochem., 42: 1250–1253.