

Induction of apoptosis by 900 MHz radiofrequency radiation emitted from a GSM mobile phone simulator in bystander Jurkat cells

S.M.J. Mortazavi^{1,2}, N. Erfani^{3*}, H. Mozdarani⁴, R. Azmoonfar⁵,
N. Shokrpour⁶

¹Department of Medical Physics and Medical Engineering, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran

²Ionizing and Non-ionizing Radiation Protection Research Center (INIRPRC), School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

³Shiraz Institute for Cancer Research, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran

⁴Department of Medical Genetics, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran

⁵Radiology Department, School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

⁶School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

► Short report

* Corresponding author:

Dr. N. Erfani,

Fax: +98 71 32304952

E-mail: erfani@sums.ac.ir

Revised: May 2014

Accepted: June 2014

Int. J. Radiat. Res., April 2015;
13(2): 181-186

DOI: 10.7508/ijrr.2015.02.009

Background: Radiation-induced bystander effect is a response which results in damage in non-irradiated cells in response to signals from the irradiated cells. The aim of the present study was to investigate microwave-induced bystander effect from a GSM mobile phone simulator on induction of apoptosis in Jurkat cell line. **Materials and Methods:** Jurkat cells were divided into three groups of non-irradiated, exposed and bystander (medium transfer from the irradiated cells). The exposed group was subjected to irradiation from GSM mobile simulator for 2h and 12h; the medium from irradiated cells was then transferred to the bystander cells. Apoptosis rate was measured 12 and 24 hours after treatment by Annexin V 7-AAD kit using flow cytometry. **Results:** Apoptosis was observed in both exposed and bystander cells of Jurkat cell line. The difference among non-irradiated, exposed and bystander cell groups was significant ($p < 0.05$). **Conclusion:** From the obtained results it can be concluded that microwave radiation exposure in Jurkat cells leads to a significant increase in the apoptosis rate not only in the exposed cells but also in the bystander cells.

Keywords: Apoptosis, bystander effect, microwave, radiofrequency (RF), Jurkat cell line.

INTRODUCTION

The levels of electromagnetic radiation in the microwave range are rapidly increasing in our environment ⁽¹⁾. Nowadays, the use of mobile phones has increased exponentially ^(2, 3). Electromagnetic radiation, emitted by mobile phones and base stations, has raised the concern of possible health hazards related to exposure to these sources of electromagnetic fields ^(3, 4).

There are several controversial reports regarding the capability of radiofrequency electromagnetic fields (RF EMFs) to induce apoptosis ⁽⁵⁻⁷⁾. Investigation of apoptosis rate in the rat's cortical neurons exposed to a 900-MHz global system for mobile communication (GSM) RF field for 24h has shown no statistically significant difference between controls and 24h GSM-exposed neurons ⁽⁸⁾. Apoptosis, the programmed cell death, plays a significant role

in the improvement and regulation of the immune system ⁽⁹⁾. Microwave significantly inhibits the metabolic activity, leads to the induction of apoptosis in A549 cells ⁽¹⁰⁾, and enhances caspase dependent pathways of apoptosis ⁽⁵⁾. Exposure of cells to ionizing radiation results in significant biological effects occurring in both irradiated and non-irradiated cells called bystander effect. Gap junctional intercellular communication and existence of diffusible factors play an important role in this phenomenon but the mechanism is not clearly known ^(11, 12). In previous investigations, bystander effect induced by gamma and alpha radiations has been studied in different cell lines ⁽¹³⁻¹⁵⁾. In 1992, Nagasawa and Little for the first time investigated the bystander effect of radiation using low doses of alpha particles from a source of plutonium238 in Chinese hamster ovary cells by measuring the frequency of sister chromatid exchange ⁽¹⁶⁾. Early studies have shown that transmission of the medium from irradiated cells can induce biological effects in non-irradiated cells ⁽¹⁴⁾. Cell communication via Gap Junction ^(11, 15, 17) and the release of soluble factors in medium ^(14, 18) have been reported as two basic mechanisms of bystander effect. Over the past years our laboratory has focused on studying the health effects of exposure of laboratory animals and humans to some common and/or occupational sources of electromagnetic fields such as mobile phones ⁽¹⁹⁻²⁶⁾, laptop computers ⁽²⁷⁾, radar ⁽²⁸⁾ and MRI ⁽²⁹⁾. All previous studies on bystander effect have been performed using ionizing radiation. The aim of this study was to determine whether 900MHz GSM radiation can induce apoptosis in Jurkat cell line. Also, there was an attempt to investigate the bystander effect of RF as a non-ionizing radiation in Jurkat cells.

MATERIALS AND METHODS

Cell culture conditions

Human T-cell line (Jurkat) purchased from Pastor Institute in Iran was used in this experiment. Jurkat cells were grown in suspension in RPMI-1640 (Sigma) with 10%

fetal bovine serum (Gibco) at a density of 10^5 cells/mL. Cultures were exposed to MW for 2h at incubator temperature and then suspended in fresh medium at 37°C. Thereafter, analyses were made by a flow cytometry device manufactured by BD Company, USA. Jurkat cells were cultured in laboratory condition (incubator 5% CO₂ at 37° C, RPMI 1640 and 10% FBS and 1% penicillin) in three groups of non-irradiated, exposed and bystander. There were 2×10^5 cells / ml in each well. According to the protocol, the cells were washed twice with cold PBS and then re-suspended in 1X binding buffer at a concentration of 1×10^6 cells/ml. Then, 100µl of the solution was transferred (1×10^5 cells) to a 5 ml culture tube; thereafter, 5µl of PE Annexin V and 5 µl 7-AAD were added to the tube. The cells were gently vortexed and incubated for 15 min at room temperature (25°C) in the dark. 400 µl of 1X binding buffer was added to each tube and analyzed by flow cytometry.

Exposure system

A GSM mobile phone simulator (designed and produced at the school of electrical and computer engineering, Shiraz University in collaboration with the Center for Research in Radiation Sciences (CRRS), Shiraz University of Medical Sciences (SUMS) was used for microwave irradiation. It was used as a coherent EMF source. The frequency was adjustable from 800 to 1800 MHz but in this experiment 900 MHz radiation (a wavelength of about 33.4 cm) that is similar to GSM mobile phone was used. Amplitude was digitally modulated with 217Hz frequency and duty cycle was 0.125 (the signal was switched on for 463 micro seconds periodically with a rate of 217 Hz. The power was adjustable from zero to 3 Watts but we fixed it at 2 W during exposure. The signal bandwidth was 200 kHz (similar to GSM mobile phone channels). The waves were transmitted by a co-axial wire to a waveguide. The cells were in 6 well plates. They were exposed to electromagnetic field of GSM mobile system simulator for 2 hours. After 12 hours, the medium was separated and added to the bystander cell groups. Group A, 12 hours after transferring the medium and Group B 24 hours

after it were tested. In this study, apoptosis was determined by apoptosis kit Annexin V-PE 7-AAD using flow cytometry method after exposure of the cells to microwave radiation emitted from GSM mobile simulator. Using this method, apoptosis in the early and late stages, as well as necrosis in each group, was determined and analyzed by non-parametric statistical tests, such as Mann-Whitney U and Kruskal Wallis tests. P value less than 0.05 was considered as significant.

RESULTS

The finding of this study showed a statistically significant difference between the non-irradiated and exposed and also between

non-irradiated and bystander cells in group A (12h) while the difference between cell groups in group B (24h) was not significant. Figure 1 displays the result of irradiation of Jurkat cells under 2h exposure and 12h after the medium transfer. MW irradiation was found to affect the apoptosis of the Jurkat cells in both exposed and bystander cells in comparison with the non-irradiated cells. The differences found among all the three groups are shown in table 1. (Group A, Means \pm SE: 2.72 ± 0.17 , 6.84 ± 1.64 , 5.75 ± 0.58 respectively). In figure 2, the percentage of apoptosis which was analyzed 24h after the medium transfer is shown in the three groups (Group B, Means \pm SE: 1.48 ± 0.15 , 2.77 ± 0.56 , 1.14 ± 0.35 , respectively). No significant differences were seen in the total number of cells in group B with Annexin V 7AAD.

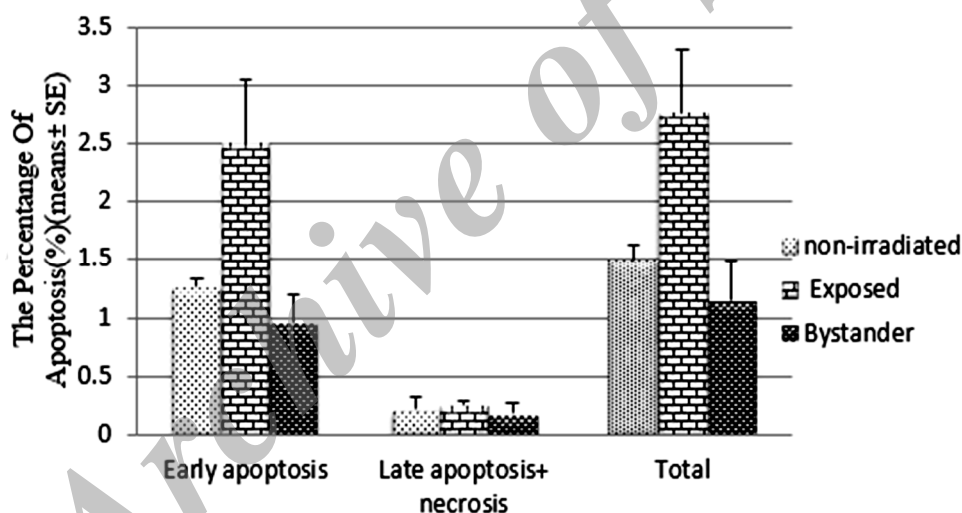


Figure 2. Comparison of apoptosis rate in 3 subgroups of non-irradiated, exposed and bystander T-cell line (Jurkat), (2h exposure to 900 MHz field; 24h later medium transfer was performed and after 12h analysis was conducted by flow cytometry method and Annexin V-AAD kit).

Table 1. Apoptosis rate in different subgroups. The significance level was considered at $p < 0.05$.

Groups	Non-irradiated Cells	Exposed Cells	Bystander Cells	Significance (P-Value)
Group A	2.72 ± 0.17	6.84 ± 1.64	5.75 ± 0.58	$P=0.049$
	2.72 ± 0.17	6.84 ± 1.64	5.75 ± 0.58	$P=0.049$ $P=0.827$ (NS)
Group B	1.48 ± 0.15	2.77 ± 0.56	1.14 ± 0.35	$P=0.089$ (NS)
	1.48 ± 0.15	2.77 ± 0.56	1.14 ± 0.35	$P=0.42$ (NS) $P=0.069$ (NS)

NS: not significant

*p-value shows the results obtained by performing Mann-Whitney test (a non-parametric test for comparing two means)

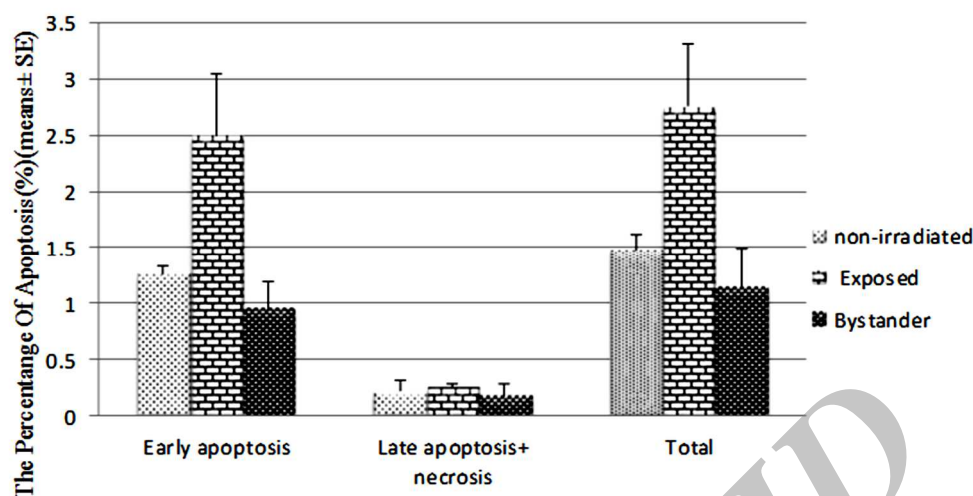


Figure 2. Comparison of apoptosis rate in 3 subgroups of non-irradiated, exposed and bystander T-cell line (Jurkat), (2h exposure to 900 MHz field; 24h later medium transfer was performed and after 12h analysis was conducted by flow cytometry method and Annexin V-AAD kit).

DISCUSSION

Our findings in this study showed that when the cells were exposed to RF radiation for two hours, programmed cell death in group A among non-irradiated, exposed and bystander cells was statistically significant while in group B it was not. To the best of our knowledge, this study is the first investigation on MW-induced bystander effect. Mortazavi *et al.* have previously indicated that laboratory animals pre-irradiated with radiofrequency radiation were less susceptible to subsequent lethal effects of high doses of ionizing radiation (22, 30). These findings were later confirmed by our subsequent reports (22, 24) as well as the few published reports that investigated the induction of adaptive response after pre-treatment with microwave radiation (31-35).

The use of mobile phones has increased drastically over the past years. This growth has generated concerns regarding the safety of these phones. Apoptosis is the process of programmed cell death (PCD) that may occur in multicellular organisms. On the other hand, bystander effect is a radiobiological phenomenon which occurs at low doses of radiation and results in damage to the non-irradiated cells in response to the signals from irradiated cells. There are several

controversial reports regarding the ability of RF EMFs to induce apoptosis (5-7). Previous research showed that with continuous exposure to 2.45-GHz microwave in a Jurkat *T-cell* line, significant non-thermal effects regarding Fas-induced apoptosis occur. On the other hand, our results revealed that under the conditions of the present experiment, RF exposure (GSM-900 MHz) does significantly increase the apoptosis rate in the Jurkat cell line.

Different results have been reported on the effect of RF on the apoptosis. Capri *et al.* had previously indicated that when an apoptotic agent was used in peripheral blood mononuclear cells, radiofrequency at a frequency of 1800 MHz could not induce apoptotic phenomenon in this in-vitro system(4). Many studies have also shown that microwave radiation can induce apoptosis and cause cell death, but many others could not reveal such an effect. Previous studies reported the use of RF exposure as a therapeutic tool for inducing apoptosis in tumor cells (36).

CONCLUSION

To the best of our knowledge, our study is the first investigation on the MW-induced bystander effect. Based on the finding of this study, it can

be concluded that microwave radiation exposure in Jurkat cell line leads to a significant increase in the apoptosis rate not only in the exposed cells but also in the bystander cells. This finding may have important implications for radiotherapy.

Conflicts of interest: none to declare.

ACKNOWLEDGEMENTS

This study was supported by the Institute of Cancer Research (ICR) and the Center for Research in Radiation Sciences (CRRS), Shiraz University of Medical Sciences (SUMS).

REFERENCES

1. Peinnequin A, Piriou A, Mathieu J, Dabouis V, Sebbah C, Malabiau R, et al. (2000) Non-thermal effects of continuous 2.45 GHz microwaves on Fas-induced apoptosis in human Jurkat T-cell line. *Bioelectrochemistry*, **51(2)**:157-61.
2. Sommer AM, Streckert J, Bitz AK, Hansen VW, Lerchl A. (2004) No effects of GSM-modulated 900 MHz electromagnetic fields on survival rate and spontaneous development of lymphoma in female AKR/J mice. *BMC cancer*, **4(1)**: 77.
3. Sukhotina I, Streckert JR, Bitz AK, Hansen VW, Lerchl A. (2006) 1800 MHz electromagnetic field effects on melatonin release from isolated pineal glands. *Journal of pineal research*, **40(1)**: 86-91.
4. Capri M, Scarcella E, Bianchi E, Fumelli C, Mesirca P, Agostini C, et al. (2004) 1800 MHz radiofrequency (mobile phones, different Global System for Mobile communication modulations) does not affect apoptosis and heat shock protein 70 level in peripheral blood mononuclear cells from young and old donors. *Int J Radiat Biol*, **80(6)**: 389-97.
5. Esmekaya MA, Seyhan N, Ömeroglu S(2010) Pulse modulated 900 MHz radiation induces hypothyroidism and apoptosis in thyroid cells: a light, electron microscopy and immunohistochemical study. *Int J Radiat Biol*, **86(12)**:1106-16.
6. Joubert V, Lévêque P, Rametti A, Collin A, Bourthoumieu S, Yardin C. (2006) Microwave exposure of neuronal cells *in-vitro*: Study of apoptosis. *Int J Radiat Biol*, **82(4)**: 267-75.
7. Dasdag S, Akdag MZ, Ulukaya E, Uzunlar AK, Yegin D (2008) Mobile phone exposure does not induce apoptosis on spermatogenesis in rats. *Archives of Medical Research*, **39(1)**: 40-4.
8. Joubert V, Leveque P, Cueille M, Bourthoumieu S, Yardin C (2007) No apoptosis is induced in rat cortical neurons exposed to GSM phone fields. *Bioelectromagnetics*, **28(2)**: 115-21.
9. Rastogi RP and Sinha RP (2010) Apoptosis: molecular mechanisms and pathogenicity. *EXCLI Journal*, **8**: 155-181.
10. Song X-l, Wang C-h, Hu H-y, Yu C, Bai C (2011) Microwave induces apoptosis in A549 human lung carcinoma cell line. *Chinese Medical Journal-Beijing*, **124(8)**:1193.
11. Azzam EI, De Toledo SM, Little JB (2001) Direct evidence for the participation of gap junction-mediated intercellular communication in the transmission of damage signals from α -particle irradiated to nonirradiated cells. *Proceedings of the National Academy of Sciences*, **98(2)**: 473-8.
12. Hei TK, Zhou H, Ivanov VN, Hong M, Lieberman HB, Brenner DJ, et al. (2008) Mechanism of radiation-induced bystander effects: a unifying model. *Journal of Pharmacy and Pharmacology*, **60(8)**:943-50.
13. Lorimore S, Kadhim M, Pocock D, Papworth D, Stevens D, Goodhead D, et al. (1998) Chromosomal instability in the descendants of unirradiated surviving cells after α -particle irradiation. *Proceedings of the National Academy of Sciences*, **95(10)**: 5730-3.
14. Seymour CM (1997) Medium from irradiated human epithelial cells but not human fibroblasts reduces the clonogenic survival of unirradiated cells. *Int J Radiat Biol*, **71(4)**:421-7.
15. Azzam EI, de Toledo SM, Gooding T, Little JB (1998) Intercellular communication is involved in the bystander regulation of gene expression in human cells exposed to very low fluences of alpha particles. *Radiation Research*, **150(5)**:497-504.
16. Nagasawa H and Little JB (1992) Induction of sister chromatid exchanges by extremely low doses of α -particles. *Cancer Research*, **52(22)**:6394-6.
17. Nagasawa H and Little JB (1999) Unexpected sensitivity to the induction of mutations by very low doses of alpha-particle radiation: evidence for a bystander effect. *Radiation Research*, **152(5)**:552-7.
18. Mothersill C and Seymour C (1998) Cell-cell contact during gamma irradiation is not required to induce a bystander effect in normal human keratinocytes: evidence for release during irradiation of a signal controlling survival into the medium. *Radiation Research*, **149(3)**:256-62.
19. Mortazavi SMJ, Ahmadi J, Shariati M (2007) Prevalence of subjective poor health symptoms associated with exposure to electromagnetic fields among University students. *Bioelectromagnetics*, **28(4)**: 326-30.
20. Mortazavi SM, Mahbudi A, Atefi M, Bagheri S, Bahaadini N, Besharati A (2011) An old issue and a new look: electromagnetic hypersensitivity caused by radiations emitted by GSM mobile phones. *Technol Health Care*, **19(6)**: 435-43.
21. Mortazavi SMJ, Rouintan MS, Taeb S, Dehghan N, Ghaffarpanah AA, Sadeghi Z, et al. (2012) Human

- short-term exposure to electromagnetic fields emitted by mobile phones decreases computer-assisted visual reaction time. *Acta Neurol Belg*. 2012 Feb 10. PubMed PMID: 22426673. Epub 2012/03/20. Eng. **112(2)**: 171-5.
22. Mortazavi SMJ, Mosleh-Shirazi MA, Tavassoli AR, Taheri M, Mehdizadeh AR, Namazi SAS, et al. (2012) Increased Radioresistance to Lethal Doses of Gamma Rays in Mice and Rats after Exposure to Microwave Radiation Emitted by a GSM Mobile Phone Simulator. *Dose Response*, **11(2)**: 281-92.
 23. Mortazavi SM, Vazife-Doost S, Yaghooti M, Mehdizadeh S, Rajaie-Far A(2012) Occupational exposure of dentists to electromagnetic fields produced by magnetostrictive cavitrons alters the serum cortisol level. *J Nat Sci Biol Med*, **3(1)**:60-4.
 24. Mortazavi SMJ, Mosleh-Shirazi MA, Tavassoli AR, Taheri M, Bagheri Z, Ghalandari R, et al. (2011) A comparative study on the increased radioresistance to lethal doses of gamma rays after exposure to microwave radiation and oral intake of flaxseed oil. *Int J Radiat Res*, **9(1)**:9-14.
 25. Mortazavi SMJ, Rouintan MS, Taeb S, Dehghan N, Ghaffarpanah AA, Sadeghi Z, et al. (2012) Human short-term exposure to electromagnetic fields emitted by mobile phones decreases computer-assisted visual reaction time. *Acta Neurologica Belgica*, **112(2)**:171-5.
 26. Mortazavi SMJ, Motamedifar M, Namdari G, Taheri M, Mortazavi AR (2013) Counterbalancing immunosuppression-induced infections during long-term stay of humans in space. *Journal of Medical Hypotheses and Ideas*, **7**: 8–10.
 27. Mortazavi SMJ, Tavassoli A, Ranjbari F, Moammaiee P (2010) Effects of Laptop Computers' Electromagnetic Field on Sperm Quality. *J Reprod Infertil*, **11(4)**: 251-8.
 28. Mortazavi SMJ, Taeb S, Dehghan N (2013) Alterations of visual reaction time and short term memory in military radar personnel. *Iranian J Publ Health*, **42(4)**: 428-35.
 29. Mortazavi SMJ, Daiee E, Yazdi A, Khiabani K, Kavousi A, Vazirinejad R, et al. (2008) Mercury release from dental amalgam restorations after magnetic resonance imaging and following mobile phone use. *Pakistan Journal of Biological Sciences*, **11(8)**:1142-6.
 30. Mortazavi S, Mosleh-Shirazi M, Tavassoli A, Taheri M, Bagheri Z, Ghalandari R, et al. (2011) A comparative study on the increased radioresistance to lethal doses of gamma rays after exposure to microwave radiation and oral intake of flaxseed oil. *Int J Radiat Res*, **9(1)**: 9-14.
 31. Sannino A, Sarti M, Reddy SB, Prihoda TJ, Vijayalaxmi, Scarfi MR (2009) Induction of adaptive response in human blood lymphocytes exposed to radiofrequency radiation. *Radiat Res*, **171(6)**: 735-42.
 32. Sannino A, Zeni O, Sarti M, Romeo S, Reddy SB, Belisario MA, et al. (2011) Induction of adaptive response in human blood lymphocytes exposed to 900 MHz radiofrequency fields: Influence of cell cycle. *Int J Radiat Biol*, **87(9)**: 993-9.
 33. Cao Y, Xu Q, Jin ZD, Zhou Z, Nie JH, Tong J (2011) Induction of adaptive response: pre-exposure of mice to 900 MHz radiofrequency fields reduces hematopoietic damage caused by subsequent exposure to ionising radiation. *Int J Radiat Biol*, **87(7)**:720-8.
 34. Jiang B, Nie J, Zhou Z, Zhang J, Tong J, Cao Y (2012) Adaptive response in mice exposed to 900 MHz radiofrequency fields: primary DNA damage. *PLoS One*, **7(2)**: e32040.
 35. Zeni O, Sannino A, Romeo S, Massa R, Sarti M, Reddy AB, et al. 2012 Induction of an adaptive response in human blood lymphocytes exposed to radiofrequency fields: Influence of the universal mobile telecommunication system (UMTS) signal and the specific absorption rate. *Mutat Res. PubMed PMID: 22525361. Epub 2012/04/25. Eng.* **747(1)**: 29-35.
 36. Maeda K, Maeda T, Yunlong Q (2004) *In-vitro* and *in-vivo* induction of human LoVo cells into apoptotic process by non-invasive microwave treatment: A potentially novel approach for physical therapy of human colorectal cancer. *Oncology Reports*, **11(4)**:771-5.