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Effects of Electromagnetic Fields on Mammalian Cells

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ABSTRACT

The characteristics of mammalian cells can be influenced by electromagnetic fields (EMFs). The electromagnetic fields have a number of physiological effects on cells and tissues such as alteration of gene expression, cells viability, proliferation, apoptosis, number of mammospheres, cells cycle phase, and invasion. The existing literature proves that the impact of EMFs on mammalian cells depends on the density and uniformity of the field, frequency range, exposure time, cell types, culture environment, and culcure medium. This paper presents a review of the impacts of EMFs on mammalian cells in vitro culture. In this article, we reviewed the contemporary understanding of the various form of electromagnetic radiation effect on cultured mammalian cells in vitro, EMF exposing systems, and internal field mechanism in the cells.

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1. INTRODUCTION

Cell culture means to keep living cells in artificial media providing sufficient nutrients for cells to grow for days or weeks to obtain sufficient numbers of cells for analysis. Usually culture medium is supplemented with antibiotics and fungicides to control contamination. Cells are often cultured in petri plates or flasks [1]. Mammalian cells refer to cells which are collected from tissue of a mammal. Cell culture can be used in cytogenetic, biochemical, and molecular laboratories for diagnostic [2] as well as research studies [1]. It can also be used for experiments in controlling diseases, and study of the reaction to drugs or agents. Furthermore cells culture helps us to analyze gene expression, motility, cells viability, proliferation, apoptosis, cells cycle phase, and invasion [3, 4].

In the recent years, there has been a sharp increase in electrical and communication devices that radiate EMFs. In addition, epidermiology studies have showed that there is a correlation between EMFs and biological cells[5]. There is also a strong rationale to well establish the biological effect of EMFs so that it gives us insight of etiology of cancer, tumour formation, and drug resistance. Thus, the concern about the impact of EMFs on mammals is increasing. The characteristics of cultured cells are influenced by not only the culture medium and environment, but also the properties of exposing electromagnetic radiation [4]. The impact of EMFs on mammalian cells depends on the frequency, density and uniformity of the fields, exposure time, cell types, culture environment and medium. EMFs have some negative influences on mammalian cells such as it damage cells, modify cells viability, motility and proliferation, and lead tumorigenesis[3].

This paper comprehensively reviews the mechanism of actions of electromagnetic fields in cells, EMF exposing systems, and low frequency, high frequency and pulsed electromagnetic wave radiation effect on gene expression, cells cycle phase, invasion, motility, cells viability, apoptosis, and proliferation for cultured mammal cells in vitro.

2. MECHANISMS OF ACTION OF EMF ON CELLS

The effect of EMFs on mammalian cells varies with the spectrum of the field. Electric and magnetic fields alter different factors of cells such as orientation of molecules, the lifetimes of free radicals, ionic and molecular currents, [6] and temperature of the biological system. The change of these factors is the function of frequency, amplitude, wave shape, and exposure time. Due to these modifications, chemical reaction rates, signalling between cells, molecular bindings, cell functions, and growth rates are altered. In addition environmental factors such as temperature, carbon dioxide concentration, oxygen concentration, and humidity control the EMF effect in the biological system [6]. The insight of the influence of EM fields in molecular and cellular biology is discussed under two section such as electric and magnetic fields effects.

2.1 Electric field

The force created by electric fields is given by

$$\vec{F} = q\vec{E} \tag{1}$$

where, $\vec{F}$ is the force in Newtons, q is the charge in Coulombs, and $\vec{E}$ is the electric field in V/m. This force results in creation of ion currents and modifies in the orientation of dipoles in molecules. The force could also direct to shift between energy levels, and induce dipole moments $\vec{M}$ in C-m. The current density, $\vec{J_i}$ in molecules or ions [6] per second per meter squared has both drift and diffusion components is given by

$$\vec{J}_i = N_i \mu \vec{F} + qD\vec{\nabla}N_i \tag{2}$$

where, μ is the mobility in s/kg, D is the diffusion constant in m^2/s, N_i is the ion concentration [7], [8] in molecules per cubic meter, and $\vec{\nabla}$ is the gradient of the concentration. The force for the charged particle is

$$\vec{F} = q\vec{E} + (\vec{M} \cdot \vec{\nabla})\vec{E} \tag{3}$$

The drift part of the ion current density is given by

$$\vec{J} = \sigma\vec{E} + \Sigma N_i \mu_i (\vec{M_i} \cdot \vec{\nabla})\vec{E} \tag{4}$$

where, σ is the conductivity. The equation (4) can be written as

$$\vec{J} = \Sigma q_i N_i \mu_i \vec{E} + \Sigma N_i \mu_i (\vec{M_i} \cdot \vec{\nabla})\vec{E} \tag{5}$$

where, N_i is the ion concentration, $\vec{M_i}$ is the dipole moment and μ is the mobility. Index i indicates each of the ion. These ion currents can change the distance of the two components of the chemical reaction to react. Hence, it changes chemical reaction rates, and the possibility that charged molecules bind to receptor molecules [9]. Furthermore, large electric field may change the orientation of molecules, and the energy with which two molecules come together. It also induces electric dipole moments. If the induced dipole moment reverses sign with the applied field, particles might have a net displacement along electric field with a large gradient. The chemical reaction rate is also influenced by the orientation of two colliding molecules.

Biological systems are nonlinear. The gradient of the applied field can causes currents for both neutral and charged particles with induces dipole moments. In addition electric fields could modify the chemical reaction by means of Stark effect. Therefore, the change in the physical mechanism such as ion currents and molecular currents lead to chemical change as a result influence the biological activities [6].

2.2 Magnetic fields

Magnetic fields have consequences on biological systems as it changes the energy separating various atomic and molecular states, apply a force to move charged particles, orients magnetic dipoles. Time varying magnetic fields [6] which are responsible for electric field induction exert forces to molecules and ions that directs to current flows, changes in the orientation and changes in the occupation and values of various energy levels. The force created by electric and magnetic fields is given by

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \quad (6)$$

where, q is the charge on the particle, $\vec{F}$ is the force vector, $\vec{E}$ is the electric field, $\vec{v}$ is the velocity, and $\vec{B}$ is the magnetic field [6]. A torque exerted by dc magnetic field on magnetic dipoles orient them along field lines. The torque, $\vec{\tau}$ is written as

$$\vec{\tau} = \vec{M}_b \times \vec{B} \quad (7)$$

where, $\vec{M}_b$ is the magnetic dipole moment which is a vector perpendicular to the plane of the current. The translational force for an inhomogeneous magnetic field is

$$\vec{F} = \vec{M}_b \vec{\nabla} \vec{B} . \quad (8)$$

The influence of static magnetic fields on ions and molecules is depending on the alteration of the energy level, the nuclear spins, and the electron spins. This transfer in the energy levels changes the lifetime of free radicals and chemical reaction rates [6], [10]. An AC magnetic field excites particles, therefore it moves from one energy level to another. The concentration of free radical in an energy level varies with the frequency of the applied magnetic fields. Thus, the current density is the main cause of biological effect of magnetic fields[6] [10].

3. LOW FREQUENCY (LF) EMFs

The well defined and characterized exposure conditions are important to analyze the EMF effect on mammal cells. The World Health Organization provided some guidelines with this regards in 1996. The choice of the exposure systems is depend on the type of the experiment (in vivo or in vitro) and the biological sample.

3.1 LF-EMFs generating systems

The LF-EMF exposure systems radiate EMFs in frequency range of below 300 Hz. The LF system as indicated in Figure 1 consists of a signal generator, amplifier, and radiating coils incubated in an incubator to study biological effect of cells in vitro. R. M. Ansari and T. K. Hei have used the MC-2XC concentric coil exposure system [11]. The Helmoltz device with a custom made variable magnetic field generator is also used to expose 50 Hz electromagnetic field on neuroblastoma cells in [12]. A low frequency (0-100 Hz) sinusoidal EMFs exposure system includes precision signal generator, amplifier and Merritt coil. The output of the precision signal generator is connected to the audio amplifier. The signal from the amplifier is used to feed double wound square Merritt coil systems [13].

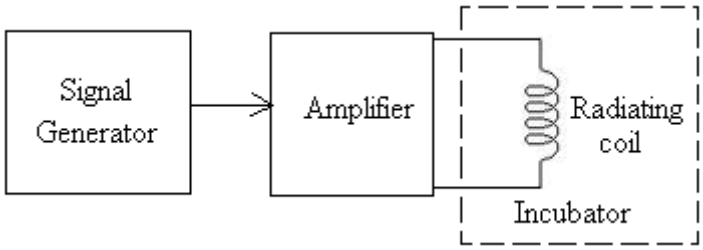

Figure 1. Block diagram of a LF exposure system.

3.2 LF-EMFs Effects

The LF-EMFs (<300 Hz) have not only some negative impacts on specific cells with certain intensity, but also it can be used to treat some pathological conditions with a range of densities and wave shapes. LF-EMF can be used for therapeutic applications of various medical conditions because it influence

the growth rate of cells. The short term (24hr) or the long term (7days) exposure of extremely low frequency (60 Hz) alternating magnetic fields (100 μT) does not affect the survival of human hamster hybrid AL cells and not increases the mutagenic potency of carcinogens. Therefore, the exposure of A_L cells to EMF is non-cytotoxic and non-mutagenic [11].

Two hours exposure is the peak stimulation condition for human fibroblasts cell proliferation where the cells are influenced by any of the three kinds of fields as constant electromagnetic field, alternating electromagnetic field (50 Hz) and cyclotron electromagnetic. The cyclotron electromagnetic field (80 mcTl) increases the growth rate of live cells (up to 206 ± 22 %) and declines the number of dead cells (down to 31 ± 6 %) [14]. Extremly LF-EMFs (1 mT, 50 Hz, 24–72 hours exposure) raise the proteasome functionality of human colon carcinoma cell line due to the enhancement of intracellular free radicals. This fields increase cell growth and protein oxidation and it has no effect in cell viability [15].

The extremely low frequency (25 Hz) magnetic fields at 2.4 mT flux densities with lipopolysaccharide stimulation decline the cells viability of murine J7774.2 macrophages for 24 hours expose though this field density enhances chemiluminescence and it has antitumoricidal effect [16]. Extremely LF-MF (50 Hz, 0.4 mT) alternates the protein profile of human breast cancer cell line MCF7 and may change many physiological functions of normal cells [17]. The power frequency magnetic field (50 Hz, 15 mT peak values) persuades stress like responses in human lymphocytes similar to heat shock. This frequency alters in chromatin conformation and reduced of 53BP1 foci level [18]. Therefore, low frequency EMFs can bring advantages as well as adverse effects on cells.

4. HIGH FREQUENCY (HF) EMFs

4.1 HF-EMFs generating systems

RF exposure system is the most important device to investigate the effects of EMFs on biological cells because this is the most usable frequency range in human life. This device is complex in structure due to maintaining uniformity of fields and constant temperature. D. T. Pooley et al. have designed a well controlled and well characterised waveguide cavity cell culture expose system to study the biological effect of millimetre wave radiation in the frequency range of 27.5-35GHz. This exposure system minimizes local heating effect, 'hot spot' convection phenomena and shows well propagation characteristics [19]. L Ardoina et al. have reported a wire patch cell (WPC) in vitro exposure device to investigate the biological effect of GSM1800 MHz electromagnetic radiation from mobile phone. This system maintains homogenous specific absorption rate distribution and avoids thermal increase inside the cultured dishes. Figure 2 demonstrates the WPC system [20]. This WPC can be inserted into a commercial incubator.

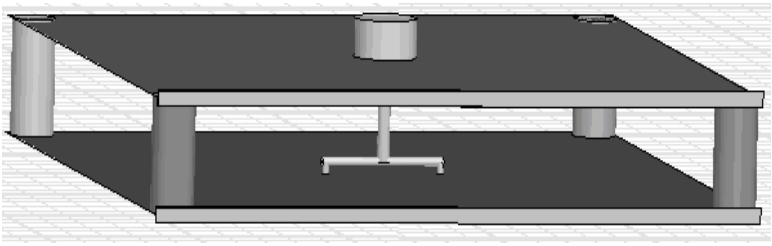

Figure 2. A 20 × 20 × 2 cm^3 empty exposure cell. The cell consists of two planes, four props, one coaxial probe located at the cell centre and soldered at the cell ground plane. The roof plane is connected to external conductor of the connector [20] is capable to exposure four 35 mm petri dishes.

Paffi et al. have also described a WPC operating at 2.45 GHz which shows good efficiency and homogeneity of SAR [21]. An electromagnetic system consisting of computer controlled microwave source to feed four transmission lines can be used to analyze the effect MW radiation on lens epithelium cells [3]. Y. Zhu et al. have used microwave exposure system comprising microwave generator, power amplifier and horn antenna [22]. The transversal electromagnetic mode cell with signal generator and signal amplifier is used as 864 MHz continuous wave electromagnetic radiation system in in-vitro experiment of V79 cells line [23]. A RF EMFs exposure system using the radial transmission line is described in [24].

4.2 HF-EMFs Effects

With the advances in technology, the concerns about the biological effects of RF EMFs on cells are increasing. There is no well established document on this topic. HF radiation can have harmful impact or not depending on the exposure length and intensity. The short time (1hr) radiation in mobile phone frequency band decreases the number of normal human astrocytes (NHA) cells in vitro experiment though the one hour exposure of NHA cells with 24 hours post exposure incubation does not change cell genetics such as mRNA expression [25]. The EMF from cellular phones increases the human DNA rewinding rate by 40% in vitro. This conformational change in human DNA can be reduced by 95% by using neutralizer shielding disk [26].

The high frequency microwave electromagnetic radiation (1.1 GHz, 2.22 mW) has different effects than conductive heat on the lens epithelium. This high frequency radiation can damage lens which is irreversible and long term radiation can cause cataract [3]. The 915 MHz microwave with SAR of 37 mW/kg of GSM mobile phone persuades stress like responses in human lymphocytes similar to heat shock. This frequency makes significant condensation of chromatin and reduces of 53BP1 foci level [18]. The microwave emitted by a transmitter in the mobile phone frequency range also lead to the significant cell death in vitro cultured cortical neuronal cells. This radiation has harmful effect on brain neuronal cells in vivo as well [22].

The 864 MHz continuous wave EMF at SAR of 0.66 W/k does not have a significant impact on the growth kinetics of Chinese hamster lung cells of line V79, whereas it decreases the cells proliferation on the third day following exposure. The field does not change the colony forming ability and viability of irradiated cells [23]. The low dose ionizing radiation on breast cells, generated a neoplastic phenotype. This phenotype boost up mammosphere numbers, invasion and motility, and altered cell cycle phases. It also increases ABC transporters and modifies gene expression. Therefore, low dose ionization increases drug resistance and possibility of breast cancer formation [27]. The tumor initiating cells such as MCF-7 have more resistance to ionizing radiation/chemotherapy than the general MCF-7 cells [28].

The frequency modulated continuous wave (SAR = 0.6 W/kg, 100 hrs) at the frequency of 835.62 MHz does not have any effect on cell progression of mouse fibroblasts C3H/1OT1/2 and human glioma U87MG cells in vitro [29]. The resonant low intensity radiofrequency EMF at frequencies between 10 kHz to 120 kHz has anticancer effect on leiomyosarcoma bearing wistar rats is shown in [30]. MERT-Nylon electromagnetic shielding polymer can decrease the negative effect of microwave radiation on biological cells as it increase the cell viability and resistivity to EM radiation [25]. Therefore, RF EMFs usually have some harmful impacts on cells. The harmful effects can be reduced by using differenet shieldings.

5. PULSE EMFs

5.1 PEMFs generating systems

The existence of PEMFs is increasing due to the raise in use of digital communication devices. The design performances of PEMF exposure systems depend on the control of pulse frequency and duration. A. Úbeda et al. have reported a waveguide RF exposure system in the 'Radio Frequency Biological Effect' project. The configuration of the system is presented in Figure 3[31].

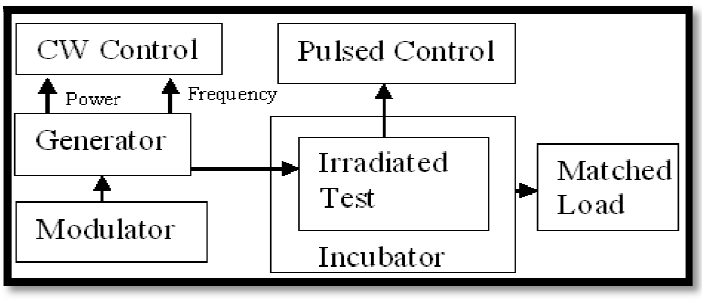

Figure 3. Block diagram of a pulse exposure system. The frequency of generator signal is 2.0-2.5 GHz and maximum power 35 W. The pulse modulator regulates duration and frequency of pulses (minimum duration of pulse is 5 μs). Double waveguide applicator (90 x 45 mm section, 500 mm in length) with matched load is used for irradiated and test sample. External devices control frequency, power and pulse shape [31] .

J. Zhen, et al. have simulated and modelled a gigahertz transverse electromagnetic (GTEM) transmission cells using FDTD method to study the effect of biological cells to ultra wideband (UWB),

monopolar, electromagnetic pulses [32]. The UWB radiation exposure system designed at Louisiana Tech University, Ruston, LA, is shows in Figure 4 [33]. V. V. Rostov et al. have used MI-505 magnetron as repetitive pulsed microwaves (RPM) radiating source [34].

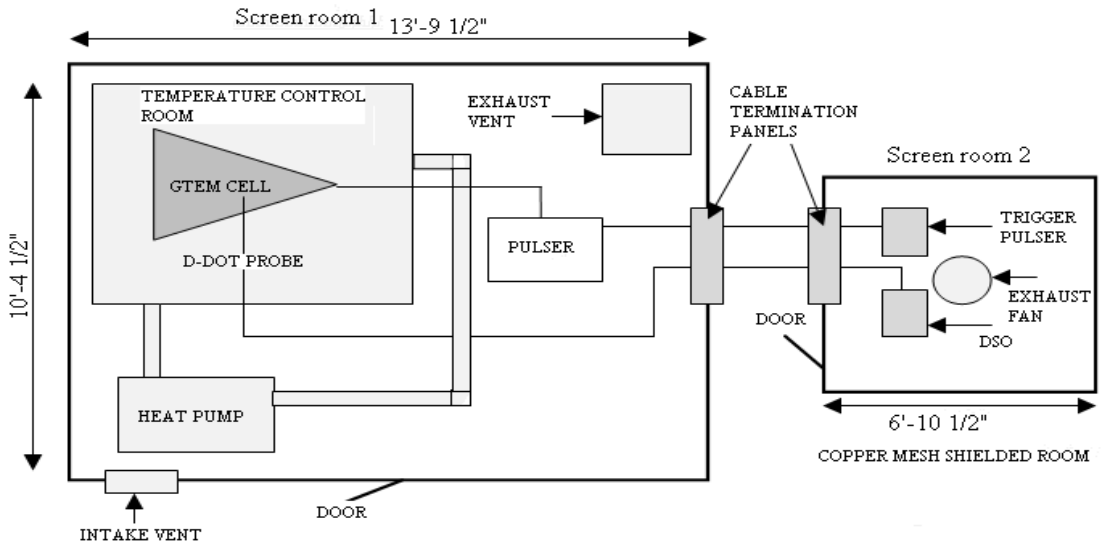

Figure 4. UWBR exposure system. The large room which contains a GTEM cell and pulser is shielded with copper and steel plating. A dot probe is used to characteristics the pulse in the GTEM cell. The pulse is controlled from a second copper mesh, RF shielded enclosure. A digital storage oscilloscope (6 GHz bandwidth) is used to monitor pulse experiments. Termination panels on both rooms permit room-to-room electrical connections [33].

5.2 PEMFs effects

There is no established mechanism about PEMFs effects on mammalian cells.The effects of PEMF also depend on the cell density. Low energy, low frequency PEMFs can stimulate cell proliferation of low density human articular chondrocyte cultures for a long time (6 days). On the other hand, in high density cultures, the PEMF induces cell proliferation for only the first three days of exposure. The PEMFs (75 Hz, 2.3 mT) with pulse duration 1.3 ms can be used in the treatment of orthopaedic pathology such as articular cartilage defect with autologous chondrocyte implantation [35].

The effects of PEMF are dose depenednet.The 24 hrs intermittent exposures of 1.8 GHz radiofrequency fields which is amplitude modulated signal by a rectangular pulse with repetition frequency of 217 Hz, and SAR of 4 W/kg has significant effects on lens epithelial cells (hLECs). It increases DNA damage at 3 W/kg SAR and the double strand breaks (DSBs) at above 3W/kg SAR. The 3 W/kg and 4 W/kg exposures significantly elevated intracellular ROS levels. The hLECs exhibited significant G0/G1 arrest ($P < 0.05$) when 4 W/kg radiation for 24 hours is used but there was no detectable effect on cell apoptosis. Whereas, superposing of electromagnetic noise with amplitude of 2μT can blocked the effects induced by RF [36]. A dose dependent increase in cell viability was confirmed in HGM treated hepatocytes during the post exposure period of 8-24 h. Low dose UWBR motives 1.5-fold increase in cell viability in HGM-treated AML-12 hepatocytes. This implies that UWBR has a role in hepatocarcinoma. Low dose UWB electromagnetic radiation has also a mitogenic effect on AML-12 mouse hepatocytes in vitro. UWBR induces cyclin *A* protein which causes cell proliferation and increase MTT activity. [33].

The effects also depend on the exposure duration. The short time exposure of RPM (10 GHz, 100–300 ns pulse duration, 4–25 s^{-1} pulse repetition rate, 0.7–17.4 kW/cm^2 peak power density) has significant effects on malignant cells. The 5 min irradiation of RPM on malignant cells such as mastocytoma P815 and Ehrlich carcinoma cells inhibits their proliferation though it can significantly modify the level of lipid peroxidation and carbonylized proteins and disturbing the structures and functions of mitochondrion [34].

The code division multiple access RF EMF centered on 847.74 MHz does not have any effect on cell progression of mouse fibroblasts C3H/1OT1/2 and human glioma U87MG cells [29]. A European collaborative multidisciplinary study from the 'Radio Frequency Biological Effect' project investigated the biological effect of PEMF on two human cancer cells lines. They showed that PEMFs inside the waveguide have not impact on cell growth or cell viability [31].

Therefore, promote investigations are required to establish a conclusion about the pulse EMF effect of mammalian. Moreover, detrimental effect of pulse EMFs can be reduced by using shielding and superposing of electromagnetic noise.

6. DISCUSSION

The effects of EMFs on cultured mammal cells are influenced by many parameters such as intensity, frequency, exposure length, and biological parameters. An additional factor such as infected cells or normal cells is also related to effect. Table1 summarizes effects of EMFs on mammalian culture cells. Several authors have emphasized the important of cellular mechanism and exposure system to confine the definite biological effects on mammalian cells. The choice of the exposure system for in vitro study is an important issue because it ensures SAR level and homogeneity of the dose.

The Helmoltz device, Merritt coil, and concentric coil with MF generator can act as LF-MF exposure system [11], [12], [13]. The WPC, transverse electromagnetic cell, waveguide cavity, and horn antenna can be used as HF exposure system in vitro study of culture cells [19], [20], [22]. The MI-505 magnetron is a good candidate for a RPM radiating source [34]. Therefore, EM wave generator with amplifier and TEM cell or waveguide is the effective exposure system because of its simplicity and homogeneity of field distribution.

EMFs effects vary with cell type, intensity, frequency and duration of field application. EMFs can initiate cancer and increase mammosphere [27]. Microwave EMF damages lens cells [3] and leads to significant cells death in vitro culture [22]. On the other, EMFs in some frequency range can be used to treat diseases by proliferating cells. The PEMF is the effective treatment for osteoarthritis which is the most common disorder of musculoskeletal system and it can proliferate articular chondrocyte [26, 37]. Low frequency fields are non-cytotoxic and non-mutagenic and can increase cell growth and protein [11, 15]

Though, EMFs have some negative impacts on mammal cells, it can be used for beneficial purposes such as disease analysis, diagnosis, disease treatment etc. Moreover, negative impacts of EMFs can be mitigated with electromagnetic noise, MRET-Nylon, and other shielding materials [25, 36]. Thus, it is essential to know the definite mechanism of EMFs on mammalian cells.

Table 1. Summarization of the Effects of EMFs on Cells

Type of EMFs	Cell Types	EMF Characteristics	Effects on Cells	Refer-ences
Low Frequency EMFs	Human hamster hybrid A_L cells	Alternating magnetic fields (100μT, 60 Hz, 24 hr/7 days)	Non-cytotoxic and non-mutagenic.	[11]
	Human fibroblasts cell	Cyclotron electromagnetic field (80 mcTl, 2 hrs)	Increased the growth rate of live cells and declined the number of dead cells	[14]
	Human colon carcinoma cell	ELF EMFs (1 mT, 50 Hz, 24–72 hrs)	Iincreased cell growth and protein oxidation and no effect in cell viability	[15]
	Murine J7774.2 macrophages	Extremely low frequency magnetic fields (25 Hz, 2.4 mT, 24 hrs) with lipopolysaccharide stimulation	Declined cells viability, and it has antitumoricidal effect	[16]
	Human breast cancer cell line MCF7	ELF MF (50 Hz, 0.4 mT)	Alternated the protein profile	[17]
	Human lymphocytes	Magnetic field (50 Hz, 15 mT peak values)	Altered chromatin conformation and reduced 53BP1 foci level	[18]
	Normal human astrocytes (NHA) cells	Mobile phone radiation (1hr)	Decreased the number of NHA, did not change mRNA expression	[25]
	Serum nocturnal melatonin	900 MHz and 1800 MHz EMF radiation (SAR = 2 W/kg, average power density 1 ± 04mW/cm^2)	Insignificant effects	[38]
High Frequency EMFs	Lens epithelium cells	Microwave electromagnetic radiation (1.1GHz, 2.22 mW)	Damaged lens and long term radiation can cause cataract	[3]
	Cortical neuronal cells	Microwave (mobile phone frequency)	Significant cell death	[22]
	Chinese hamster lung cells of line V79	Continuous wave electromagnetic field (864 MHz, SAR of 0.66 W/kg)	Decreased cells proliferation, did not change the colony forming ability and viability	[23]
	Breast cells (MCF 10A)	Low dose ionizing radiation	Boosted up mammosphere numbers, invasion and motility, and altered cell cycle phases, modified gene expression, increased drug resistance and possibility of breast cancer	[27]

			formation	
	Human lymphocytes	915 MHz microwave (SAR of 37 mW/kg)	Significant condensation of chromatin and reduced of 53BP1 foci level	[18]
	Mouse fibroblasts C3H 1OTl/2 and human glioma U87MG cells	Frequency modulated continuous wave (SAR = 0.6 W/kg, 100 hrs, 835.62 MH)	Did not have any effect on cell progression	[29]
	Leiomyosarcoma bearing wistar rats	Low intensity radio frequency (10 kHz to 120 kHz)	Anticancer effect	[30]
	Human articular chondrocyte cells	PEMFs (75 Hz, 2.3 mT, pulse duration 1.3 ms)	Stimulated cell proliferation	[35]
	Mastocytoma P815 and Ehrlich carcinoma cells	RPM (10 GHz, 100–300 ns pulse duration, 4–25 s^{-1} pulse repetition rate, 0.7–17.4 kW/cm^2 peak power density)	Inhibited proliferation.	[34]
Pulse EMFs	Mouse fibroblasts C3H 1OTl/2 and human glioma U87MG cells	CDMA RF EMF centered on 847.74 MHz (SAR = 0.6 W/kg, 100 hrs)	No effect on cell progression	[29]
	Human cancer cells lines	Pulsed RF EM field	Had not impact on cell growth or viability	[31]
	Lens epithelial cells (hLECs)	Amplitude modulated RF fields (1.8 GHz pulse repetition frequency of 217 Hz, duty cycle of 1:8, and SAR of 4 W/kg)	Increased DNA damage, no effect on cell apoptosis	[36]
	AML-12 mouse hepatocytes cells	UWBR (2hrs, 23°C, pulse width of 10 ns, repetition rate of 1 kHz, and field strength of 5-20 kV/m)	Increased cell proliferation and MTT activity, roled in hepatocarcinoma	[33]

7. CONCLUSION

The impact of electromagnetic radiations on mammal cells has been investigated by a large number of researchers and scientists in vitro cell culture. With the advances of molecular and cellular biology, majority of experiments are conducted on mammal cells, and very few on human cells. Since various frequencies and field intensities, and different types of cells have been used in experiments, inconsistent and contradictory effects have been reported. On the whole, very modest numbers of influences of EMFs on cells are well established. To establish the exact effects of EMFs on cells, and eliminate the contradiction, rigorous experiments are required in this field.

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