Effects of extremely low-frequency electromagnetic fields on B16F10 cancer cells

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ABSTRACT

This paper presents a method to inhibit B16F10 cancer cells using extremely low-frequency electromagnetic fields (ELF-EMFs) and to evaluate cell viability using MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide) assay. The study examined the effect of a natural EMF resonance frequency (7.83 Hz) and a power line frequency (60 Hz) on B16F10 cancer cells for 24 and 48 h. The B16F10 cancer cells were also exposed to sweep frequencies in several sweep intervals to quantitatively analyze the viability of cancer cells. The results yielded a 17% inhibition rate under 7.83 Hz compared with that of the control group. Moreover, sweep frequencies in narrow intervals (7.83 ± 0.1 Hz for the step 0.05 Hz) caused an inhibition rate of 26.4%, and inhibitory effects decreased as frequency sweep intervals increased. These results indicate that a Schumann resonance frequency of 7.83 Hz can inhibit the growth of cancer cells and that using a specific frequency type can lead to more effective growth inhibition.

Introduction

With advances in technology, various frequencies of electromagnetic fields (EMFs) have become omnipresent in our lives – from the radio frequency of cell phones to the low frequency of power lines and even the earth’s magnetic field nature frequency (i.e., Schumann resonance frequency). Extremely low-frequency (ELF) EMFs are present in the geomagnetic field. Resonant oscillations in the ionosphere of the earth and oscillations in the plasma sphere and magnetosphere are caused by solar wind (Čosić et al., 2006). The peaks of the resonant characteristics of the earth’s EMF system are called Schumann resonances and reside at approximately 100, 21, 14.1, 7.83, 5.7, 4, 1, 0.1 and 0.001 Hz (Zhadin, 2001). The most common geomagnetic frequency is 7.83 Hz, and plants, animals and humans benefit from living in environments with this geomagnetic frequency (Füllekrug, 1995; Zhadin, 2001). Therefore, the effects of EMFs on the human body have generated much attention. More and more studies have focused on determining the effects of EMFs on biological processes, such as cell proliferation, changes in cell membrane potential, cell ion transport, activation of several enzymes and DNA expression (Tiwari, 2015). Some of these studies have indicated that EMFs can promote the proliferation of stem cells and bone cells (Berg, 1999; Brighton et al., 2001; Li et al., 2012; Ross et al., 2015). Others have demonstrated that EMFs can inhibit the growth of specific cancer cells under low-frequency ranges (<300 Hz) and low EMF intensities (Li et al., 2012; Yan et al., 2010; Buckner et al., 2015; Chen et al., 2010; Nie et al., 2013; Ming et al., 2015; Wang et al., 2011; Novikov et al., 2009). These findings suggest that EMF exposure can be used as a non-thermal cancer treatment.

According to previous studies, the effects of EMFs are associated with cell metabolism and ion voltage-gated channel effects. Several studies have proposed that non-specific processes, such as changes in mitochondrial activity, the formation of free radicals, and the promotion of DNA damage, are involved in EMF effects (Roderick and Cook, 2008; Simko et al., 1998; Tsai et al., 2009). Furthermore, research has shown that the mechanisms of EMF effects are related to the ion voltage-gated channels on the cell membrane (Berg, 1999; Desteﬂanis et al., 2015; Lyle et al., 1991; Pevarskaya et al., 2014). These studies consider that EMF exposure can promote ion influx through voltage-gated channels. EMF exposure can increase the concentration of some important ions, such as Ca2+, in the cytosolic, which then changes the metabolic rate of biological functions. Although EMFs have been found
to generally affect biological functions, they have also been shown to generate different effects on specific cells and tissues, especially in ELF ranges (Tiwari, 2015).

Recently, many studies have focused on the effects of ELF-EMFs on cancer cells. Yan et al. (2010) showed that cancer cell lines are more sensitive than non-malignant cells and present inhibitory effects under special frequencies in low intensities of field exposure because of the T-type Ca\textsuperscript{2+} channel. Therefore, EMFs promote ion influx, which can be blocked by the inhibitors of voltage-gated channels and thus prevent ion uptake. Inhibitors also block the EMF-dependent inhibition of cell proliferation. Chen et al. (2010) demonstrated that 60 Hz in 0.1 mT can also inhibit the growth of HeLa and PC-12 cancer cells after 48 and 72 h of exposure. Martirosyan et al. (2013) showed that 8 Hz EMF has a pronounced inhibitory effect on bacterial growth rate and development. Moreover, Wang et al. (2011) and Tsai et al. (2009) found that 7.5 Hz had inhibitory effects on BGC-823 and B16F10 cancer cells.

The results of all these studies suggest that ELF-EMFs can inhibit cancer cell growth. However, most of these studies use a constant single frequency to determine the effect of ELF-EMFs on biological processes. Few utilize special frequency types, such as sweep frequency, to explore the effects of EMFs on biological processes. Thus, the current study examines if and how the use of sweep frequency, compared with constant frequency, produces different effects on biological processes.

The inhibitory effects of different frequency types on B16F10 cancer cells are investigated. The environmental ELF-EMF includes natural ELF-EMFs and man-made ELF-EMFs whose frequencies are 7.83 and 60 Hz. The Schumann resonance frequency of 7.83 Hz was set as the basic frequency that affects tumor cells. Additionally, different sweep intervals around 7.83 Hz were used to explore different biological responses. A low-intensity magnetic field of 0.3 mT was chosen for this study. The EMF device was composed of a Schumann frequency generator, a drive circuit, a switch power supply, and multi-turning coils.

The viability of cancer cells was detected using 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT). This study aims to provide a basis for future studies regarding the clinical treatment of cancer through suppression.

Materials and methods

Experimental setup

The device used in this study was designed to produce a time-varying magnetic field environment to stimulate tumor cells (Melanoma, B16F10). Therefore, we designed the experiment to determine the effect of ELF-EMF on B16F10 cells. A block diagram of how environmental ELF-EMFs affect B16F10 cells is shown in Figure 1. This figure shows that the experimental procedure involved the following eight steps: (1) produce a time-varying ELF-EMF device, (2) generate a square ELF-EMF, (3) seed B16F10 into a 96-well culture plate, (4) culture B16F10 in a cell culture incubator, (5) place the coil in a cell culture incubator, (6) stimulate B16F10 by ELF-EMF, (7) conduct the cell viability assay and (8) analyze the data.

First, the ELF-EMF device contained a signal generator and coils. The microprocessor control unit (10F222, Microchip, Chandler, Arizona, U.S.A) generated a square wave. The experimental frequency square wave triggered the driving circuit to drive the coil, thus generating a magnetic field. The microprocessor control unit generated a 5 V square waveform to n-mos (2N7002, Willas Corp., Taipei, Taiwan) and then switched to DC 12 V for the coils (300 turns of a 0.1 mm wire), thus producing a magnetic field. Because non-thermal EMF effects have some degree of influence on cancer cells, a low-intensity magnetic field magnitude was chosen. The input current through the coil was 21 mA. The field magnitude, measured by a Gauss/Tesla meter (Model 5180, F.W. Bell Inc., Orlando, Florida, U.S.A) magnetic field average value, was 0.3 ± 0.05 mT inside the coil. This low-intensity magnetic field parameter was used in the entire experiment.

Figure 1. Block diagram of the experimental setup to determine how environmental ELF-EMFs affect B16F10.
Second, the ELF-EMF device generator square waveform was controlled by a program that changed the output frequency of the square wave signal. The square wave had a duty cycle of 50% in every cycle. The two types of frequencies used in this study were constant frequency and sweep frequency. Table 1 shows all the experiment parameters used in this study. A constant frequency repeats continuously throughout each cycle. In this study, the constant frequency repeated at rates of 7.83, 60 and 7.83 Hz with 60 Hz (the whole waveform cycle was 7.83 Hz per one pulse and then continued to 60 Hz per one pulse waveform, as shown in Supplementary Figure 1(a). Conversely, a sweep frequency continuously changes the frequency in every cycle. This type of frequency changes stepwise in a certain range. For example, 7.83 Hz was set as a fundamental frequency, and the frequency systematically swept within specific sweep intervals, such as 7.83 ± 0.3 and 7.83 ± 2 Hz. Several sweep frequencies, including 7.83 ± 0.3 Hz, 7.83 ± 0.1 Hz, as shown in Supplementary Figure (b)–(e), 7.83 ± 0.5 Hz, 7.83 ± 1 Hz, and 7.83 ± 2 Hz in two different sweep steps (0.1 and 0.05 Hz), were also performed in the study. The procedure was implemented at least four times to obtain the average results for each frequency group. The magnitude was about 0.3 ± 0.05 mT inside the coil.

Third, the tumor cells were cultured in a 96-well plate, and there were 2000 cells in a single well. Figure 2(a) shows how a multi-turning coil was put under the 96-well plate, and both ELF-EMF devices were put into cell culture CO₂ incubators (Forma™ 310; Thermo Scientific, Waltham, Massachusetts, U.S.A.). Moreover, because of the cell growth rate and the numbers of B16F10 cells in this study, the durations of the experiments were 24 and 48 h, as shown in Supplementary Figure 2. Finally, MTT assay was used to assess the viability of the cancer cells, which was caused by the EMF.

Table 1. Parameters of the EMF experiment.

| Frequency          | Sweep step     | Field magnitude | Duration |
|--------------------|----------------|-----------------|----------|
| 7.83 Hz            | –              | 0.3 ± 0.05 mT   | 24 h/48 h|
| 7.83 Hz with 60 Hz | –              | 0.3 ± 0.05 mT   | 48 h     |
| 7.83 ± 0.1 Hz      | 0.1 Hz/0.05 Hz | 0.3 ± 0.05 mT   | 48 h     |
| 7.83 ± 0.3 Hz      | 0.1 Hz/0.05 Hz | 0.3 ± 0.05 mT   | 48 h     |
| 7.83 ± 0.5 Hz      | 0.1 Hz/0.05 Hz | 0.3 ± 0.05 mT   | 48 h     |
| 7.83 ± 1 Hz        | 0.1 Hz/0.05 Hz | 0.3 ± 0.05 mT   | 48 h     |
| 7.83 ± 2 Hz        | 0.1 Hz/0.05 Hz | 0.3 ± 0.05 mT   | 48 h     |

Simulation of the magnetic field

The actual magnetic field distribution of the ELF-EMF device generator was simulated using modeling.

Figure 2. (a) Illustration of the experimental setup to determine how ELF-EMFs affect B16F10; (b) a 96-well culture plate divided into five positions based on the magnitude of the magnetic field; (c) simulation of magnetic field distribution within the coil.
software (COMSOL Multiphysics 4.3b, COMSOL Inc., Burlington, New Jersey, U.S.A). The multi-turning coil was placed directly under a 96-well plate, as shown in Figure 2(a). The 96-well plates were divided into several groups for field magnitude and field uniformity, as shown in Figure 2(b). Each group was composed of four wells. The results of each separate group were averaged from four different wells to observe the average inhibitory effects. Figure 2(c) shows that groups 3, 4 and 5, regarded as the uniform magnetic field groups, were in a symmetrical position inside the coil, and the field magnitude was about 0.3 mT. Group 2 was right above the coil current pathway. Group 1 was a relatively weak magnetic field group compared with the other groups outside the coil because its field magnitude was ±0.01 mT. All experimental and control cells in this study were seeded in the same position described in Figure 2(b).

**Cancer cells**

The cancer cells in this study were melanoma (B16F10) cells. The B16F10 cells have been identified as those of skin cancer, which is the most malignant type of cancer in people. Although melanoma usually occurs in Western countries, cases of melanoma have been rising in Taiwan and Japan in recent years. Therefore, B16F10 was used as the object of study for this experiment.

The B16F10 cells were cultured in a humidified incubator of 37°C and 5% CO₂. The culture medium was Dulbecco’s Modified Eagle’s Medium, which consisted of l-glutamine, 4500 mg/L glucose and 3.7 gm/L of sodium bicarbonate. It was formulated at 13.4 g of powder per liter of the medium.

**MTT assay**

The MTT assay is used to quantitatively analyze which B16F10 cytostatic activity is affected by the EMF. This is a colorimetric assay that measures the reduction of yellow MTT by mitochondrial succinate dehydrogenase. The MTT enters the cells and passes into the mitochondria, where it is reduced to an insoluble colored (dark purple) formazan product. The cells are then solubilized with an organic solvent (eq. isopropanol), and the released, solubilized formazan reagent is measured spectrophotometrically. Because the reduction in MTT can only occur in metabolically active cells, the level of activity is a measure of the cells’ viability. Therefore, we can measure the optical density (OD) value using an enzyme-linked immunosorbent assay reader (TECAN Sunrise, TECAN, Salzburg, Austria).

To compare the cell generation after each subculture, the cell viability was obtained using the following formula:

\[
\text{Cell viability(\%)} = \frac{\text{experiment OD}}{\text{control OD}} \times 100\%
\]

Formula (1) refers to the viability of the experiment group compared with the control group. All experiments were conducted at least thrice, and the data were represented as the mean ± standard error of the mean. Statistical analysis (t-test) significance levels were used (*p < 0.05).

**Results and discussion**

**Constant frequency**

The first stage of the experiment involved evaluating the effect of an ELF of 7.83 Hz on cell functions to establish the experimental basis for the next stage. In the 24 h experiment results, which are shown in Figure 3(a), the cell viability was 95.4%, 94.3%, 89.3%, 87.2% and 87.6%. The experimental group was inhibited by the 7.83 Hz EMF exposure, so the OD values and the viability were lower than those of the control group. According to cell viability, groups 3, 4 and 5 had a low viability relative to experiment groups 1 and 2. The uniform magnetic field region had a better inhibitory effect than the non-uniform magnetic field region. Although the cell viability of group 2 was 5% higher than that in groups 3, 4 and 5, the non-uniform region also had an inhibitory effect. However, inhibitory effects were not obvious in the 24 h experiments. A higher inhibition rate was also observed in the 48 h experiments than in the 24 h ones, as shown in Figure 3(b). The cell viability for the five different groups was 96.1%, 87.8%, 84.5%, 84.8% and 82.7%, respectively. The best inhibitory effect was found in group 5. Group 1 had an inconspicuous inhibitory effect compared with any other case. Except for the relatively low field amplitude of group 1, the cell viability values of the four other groups demonstrated a decreasing trend. The uniform field region (groups 3, 4, 5) retained a rate of at least 15% inhibition under our experiment conditions. Moreover, the error bars of these three groups were lower than those of the two other groups. Cells stimulated in the uniform magnetic field may have been relatively stable, which then led to similar OD values. A low frequency of 7.83 Hz combined with an extremely low EMF can inhibit the growth of B16F10 cancer cells. Because of these results, other frequency parameters were tested. The
48 h results of group 5 showed the best inhibition rate (17%) among all the groups, so we observed the 48 h results of group 5 in the next stage of the study.

Mixed-single frequency

In the mixed-frequency experiment, the treatment effect on cancer cells was similar to that of the single-frequency experiment. Unlike the treatment in the single-frequency experiment, that in the mixed-frequency one focused on supplying a constantly changing frequency effect on the cancer cells. Figure 4 shows the cell viability of B16F10 cells under 7.83, 60 and 7.83 Hz with 60 Hz EMF environments at 48 h in position 5. The treatment of 7.83 Hz can inhibit cell proliferation. The cell survival rate of the cells under 7.83 Hz was the minimum of the entire experiment. In contrast to the treatment frequency having an inhibitory effect, 60 Hz was unable to suppress cell survival rate viability. The cell viabilities of the two single frequencies (7.83 and 60 Hz) were 84.7% and 98.1%, respectively.

The cell viability of the mixed-single frequency treatment (7.83 with 60 Hz) was 90.9%. The treatments demonstrated an inhibitory effect on B16F10, but this effect was 7.6% lower than that of the treatment of 7.83 Hz. Binding two frequencies means that the cells are exposed to half times period of whole pulse waveforms. Based on fast Fourier transform (FFT) analysis, the spectrum of combining frequencies generates other characteristic frequencies, and the amplitude of 7.83 Hz decreased by about 6 dB compared with the combination frequency treatment of 7.83 Hz. The decrease in resonance time causes the inhibition rate to drop. The mean of the cells’ viability signal of 7.83 Hz with 60 Hz was between that of 7.83 and 60 Hz. This increasing trend was also observed in the signal that consisted of 7.83 and 60 Hz. In comparing single frequency and mixed frequency, the mean of the mixed-frequency cells’ viability was situated between that of two single-frequency cells’ viability, which was combined into the mixed frequency. The cells’ viability of 7.83 Hz with 60 Hz was between that of the signal frequency 7.83 and 60 Hz cells’ viability rate.

In Figure 5(a) and (b), the amplitude of the characteristic frequency of 7.83 Hz in the 7.83 Hz treatment is 25.2 dB, which is 6.3 dB larger than that in 7.83 Hz with 60 Hz. The amplitude can be an indicator of frequencies’ components. As the dB value of 7.83 Hz increased, the effect of resonance frequency on the melanoma cells’ ELF-EMF stimulated time increased. The addition of maxima efficiency affected the calcium ion’s frequency and led to an increase in cell inhibition rate.

The results demonstrate that EMFs affect cell viability, but the mechanism of how EMFs affect cells remains
unclear. The EMF affected several biological processes whose functions are closely related to cell membrane properties. The EMF acts on membrane potential through hyperpolarization or depolarization (Brighton et al., 2001) ELF-EMFs also modify the transmembrane ion channels and reorient some molecules, which causes the deformation of ion channels and alters ion flow, especially that of Ca\textsuperscript{2+}. Ca\textsuperscript{2+} is well known to play a pivotal role in signal transduction pathways that include cell growth and division, metabolic function, apoptosis, synaptic transmission and gene expression (Bootman et al., 2001; Vijayalaxmi and Prihoda, 2009). While ELF-EMFs affect cells, changes in intracellular Ca\textsuperscript{2+} concentration have already been found (Lindström et al., 1995; Mellstrom et al., 2008; Yan et al., 2010) to inhibit the proliferation of malignant cells (Novikov et al., 2009; Panagopoulos et al., 2002). In our results, the treatment of 7.83 Hz demonstrated the most significant inhibition of B16F10 cells’ viability. This may be caused by Ca\textsuperscript{2+} ion cyclotron energy resonance. The Ca\textsuperscript{2+} ion resonance frequency is reported as 7 Hz (Panagopoulos et al., 2002; Lisi et al. 2008a; Lisi et al. 2008b). While supplying the resonance frequency, the efficiency of transmission energy is highest. With the frequency deviating from the resonance frequency, the efficiency of energy transmission decreases. Compared to the results, the natural EMF frequency was close to the Ca\textsuperscript{2+} ion resonance frequency; therefore, the natural EMF frequency has the most influence on cancer cells.

**Sweep frequency**

Figure 6(a) shows the cell viability of all frequency parameters for group 5 in 48 h, and the related cell viability is shown in Table 2. The cell viability of 7.83 ± 0.1 Hz for the 48 h experiment was 74.54% for the 0.1 Hz sweep step and 74.58% for the 0.05 Hz sweep step. For B16F10 cancer cells, 7.83 ± 0.1 and 7.83 ± 0.3 Hz caused a similar inhibitory effect. A frequency sweep in narrow intervals obtains a better inhibition rate than the constant. The inhibitory effects of the sweep frequencies of 7.83 ± 0.1 and 7.83 ± 0.3 Hz at both steps were 8% better than the constant frequency of 7.83 Hz in the 48 h experiment. When increasing the sweep intervals to 7.83 ± 0.5 Hz, the cell viability of 7.83 ± 0.5 Hz for the 48 h experiment was 78.32% for the 0.1 Hz sweep step and 77.71% for the 0.05 Hz sweep step. The inhibition rate of 7.83 ± 0.5 Hz was lower than 7.83 ± 0.1 and 7.83 ± 0.3 Hz; however, the inhibitory effect was still better than the constant frequency of 7.83 Hz, as no difference between both sweep steps was observed.

The sweep experimental results indicated that the inhibitory effect gradually decreased as the sweep intervals increased. The next step was to determine whether different sweep intervals could cause specific inhibitory effects when sweep ranges are continuously added; therefore, the sweep intervals were increased to 7.83 ± 1 Hz. The cell viability of 7.83 ± 1 Hz for the 48 h experiment was 85.69% for the 0.1 Hz sweep step and 80.67% for the 0.05 Hz sweep step. These results suggest that the inhibitory effect gradually worsens with the increase in sweep intervals. In the narrow sweep intervals (7.83 ± 0.1, 7.83 ± 0.3 and 7.83 ± 0.5 Hz), the cell viability was lower than 80%. Conversely, the inhibition rate of the wide sweep intervals (7.83 ± 1 Hz) gradually declined and approached a constant frequency 7.83 Hz. Moreover, the cell viability between the two sweep steps had a 5% difference, and the inhibition rate of step 0.1 Hz was better than that of step 0.05 Hz. Finally, the sweep ranges were increased to 7.83 ± 2 Hz. The cell viability of 7.83 ± 2 Hz for the 48 h experiment was 86.86% for the 0.1 Hz sweep step and 83.77% for the 0.05 Hz sweep step. As we expected, the inhibition rate of
7.83 ± 2 Hz was lower than 7.83 ± 1 Hz, and the inhibitory effect of step 0.1 Hz was lower than that of step 0.05 Hz in 7.83 ± 2 Hz. Therefore, sweep intervals and sweep steps cause different phenomena in B16F10 cancer cells.

**Discussion**

The results of this study must be clarified by more experiments and studies. Similar to our results, those of other studies have shown that low-frequency EMF can effectively inhibit the growth of cancer cells (Li et al., 2012; Yan et al., 2010; Buckner et al., 2015; Chen et al., 2010; Nie et al., 2013; Ming et al., 2015; Wang et al., 2011; Novikov et al., 2009). Research suggests that possible EMF mechanisms are related to intra- and extra-cellular Ca²⁺. Free Ca²⁺ in cytosolic represents a ubiquitous signaling mechanism that controls a variety of cellular processes, including proliferation, metabolism and gene transcription. However, under certain conditions, increases in intracellular Ca²⁺ are cytotoxic (Pall, 2013; Prevarskaya et al., 2014). Buckner et al. (2015) and Huang et al. (2006) demonstrate that exposure under EMF

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**Figure 6.** (a) Cell viability of all frequency experiments in group 5 (all results \( n \geq 3 \), mean ± SD, \(*p < 0.05\)); (b) cell viability of 7.83 Hz in 0.1 and 0.05 Hz sweep frequency intervals.
Table 2. Cell viabilities of all frequency experiments in group 5.

| Frequency      | Steps | Cell viability | Inhibition rate |
|----------------|-------|----------------|-----------------|
| 7.83 Hz        | –     | 82.75%         | 17.25%          |
| 7.83 Hz with 0.1 Hz | –   | 90.90%         | 9.10%           |
| 7.83 ± 0.1 Hz  | 0.1 Hz| 75.35%         | 24.65%          |
| 7.83 ± 0.3 Hz  | 0.1 Hz| 74.54%         | 25.46%          |
| 7.83 ± 0.5 Hz  | 0.05 Hz| 74.58%         | 25.42%          |
| 7.83 ± 1 Hz    | 0.05 Hz| 78.32%         | 21.68%          |
| 7.83 ± 2 Hz    | 0.1 Hz| 85.69%         | 14.31%          |
|                | 0.05 Hz| 80.67%         | 19.33%          |

promotes Ca\(^{2+}\) influx through the Ca\(^{2+}\) voltage-gate channel, so EMF can increase the concentration of Ca\(^{2+}\) in the cytosolic and then change biological functions. One reason is that increasing Ca\(^{2+}\) in the cytosolic changes the mitochondrial membrane’s potential to influence mitochondrial activity, such as increasing respiration and altering mitochondrial protein expression, which inhibit the growth of cancer cells (Roderick and Cook, 2008).

Compared with a constant frequency, sweep frequency is a special frequency parameter, so the exact mechanisms behind how ELF-EMFs suppress cancer cells are not yet clear. The FFT analysis of sweep frequency 7.83 Hz ±1 Hz was shown in Supplementary Figure 3. The FFT analysis spectrogram of 7.83 ± 1 Hz in 0.05-Hz-step have more characteristic frequency spectrum than that of 0.1 Hz-step near major frequency 7.83 Hz. We considered that the gradually decreasing sweep intervals step caused more exposure at the Schumann resonance frequency (7.83 Hz) in the fixed time. That would change the probability of ion-channel on/off switching events by membrane magneto mechanical, stress, suppression of cell growth by magnetic pressure (Zablotskii et al., 2016). Thus, the probability of ion-channel on/off switching events could increase by the narrow interval frequency (step 0.05 Hz). Xi et al. (2003) and Foletti et al. (2010) indicated that ions in the ion resonance frequency lead to ion movement, so sweep frequency has greater chances of reaching the ion resonance frequency than constant frequency has. Therefore, sweep frequencies in narrow intervals (7.83 ± 0.1, 7.83 ± 0.3 and 7.83 ± 0.5 Hz) produce a better cell inhibitory effect than the single-frequency 7.83 Hz. However, when the number of sweep intervals is progressively increased to 7.83 ± 1 and 7.83 ± 2 Hz, the number of frequencies sweeping at the same time will gradually increase. This may lower the total resonance time of the possible resonance frequency and thus decrease the inhibition rate. Finally, sweep frequencies in wide intervals produce different inhibitory effects among different sweep steps. In this study, because step 0.05 Hz had a smaller frequency range than did step 0.1 Hz, step 0.05 Hz could easily sweep to the resonance frequency, and the total resonance time was higher; therefore, step 0.05 Hz led to a better cell inhibitory effect than the step 0.1 Hz.

Conclusions

This study has shown that a Schumann resonance frequency of 7.83 Hz combined with a low-intensity EMF can inhibit the growth of B16F10 cancer cells. Sweep frequencies in narrow intervals can produce better inhibitory effects than constant frequencies can. Cell viability gradually decreases as sweep intervals increase. Furthermore, the cell viability of different steps gradually has a disparity between steps 0.1 and 0.05 Hz as the sweep intervals reach 1 and 2 Hz. Finally, the best inhibitory effect happens in 7.83 ± 0.1 in step 0.1 Hz. In conclusion, our results reveal that ELF-EMF potentially affects the cell viability of cancer cells by supplying different signals, such as single frequencies and mixed frequencies.

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Declaration of interest

The authors report no conflicts of interests. The authors alone are responsible for the content and writing of this article.

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