PEMF/Magnetic Fields, Cancer

https://pubmed.ncbi.nlm.nih.gov/39201657/
Cellular and Molecular Effects of Magnetic Fields 2024
Recently, magnetic fields (MFs) have received major attention due to their potential therapeutic applications and biological effects.
Molecular insights are offered into how MFs modulate oxidative stress and inflammatory responses, which are pivotal in various pathological conditions. Furthermore, we explore the therapeutic potential of MFs in regenerative medicine, cancer treatment, and neurodegenerative diseases.

https://pubmed.ncbi.nlm.nih.gov/32331350/
Low-Frequency Magnetic Fields (LF-MFs) Inhibit Proliferation by Triggering Apoptosis and Altering Cell Cycle Distribution in Breast Cancer Cells 2020
Magnetic fields, as a non-invasive therapy, have shown anti-tumor effects in vitro and in vivo; however, the detailed mechanisms involved are still not clear. In this study, we found that in exposure to low-frequency magnetic fields (LF-MFs) with an intensity of 1 mT and frequencies of 50, 125, 200, and 275 Hz, separately, the proliferation of breast cancer cells was inhibited and LF-MF with 200 Hz reached the optimum inhibition effect, on exposure time-dependently. Notably, we found that exposure to LF-MF led to MCF-7 and ZR-75-1 cell apoptosis and cell cycle arrest. Moreover, we also discovered that LF-MF effectively increased the level of reactive oxygen species (ROS), suppressed the PI3K/AKT signaling pathway, and activated glycogen synthase kinase-3β (GSK-3β). We demonstrated that the GSK3β activity contributed to LF-MF-induced cell proliferation inhibition and apoptosis, while the underlying mechanism was associated with the inhibition of PI3K/AKT through increasing the intracellular ROS accumulation. These results indicate that LF-MF with a specific frequency may be an attractive therapy to treat breast cancers.

https://pubmed.ncbi.nlm.nih.gov/27748048/
Mechanisms and therapeutic effectiveness of pulsed electromagnetic field therapy in oncology 2016

https://pubmed.ncbi.nlm.nih.gov
Changes in cell death of peripheral blood lymphocytes isolated from children with acute lymphoblastic leukemia upon stimulation with 7 Hz, 30 mT pulsed electromagnetic field 2015

https://pubmed.ncbi.nlm.nih.gov/36172744/
In Vitro and in Vivo Study of the Effect of Osteogenic Pulsed Electromagnetic Fields on Breast and Lung Cancer Cells 2022
Pulsed electromagnetic field (PEMF), a newly emerged therapeutic strategy, has been highly regarded as less invasive and almost safe to patients, is now a clinically accepted form to treat diseases including cancer.
Conclusion: Together, our data suggested that clinically used osteogenic PEMF signals moderately suppressed cancer cell growth and proliferation both in vitro and in vivo.

https://pubmed.ncbi.nlm.nih.gov/37869515/
System-level biological effects of extremely low-frequency electromagnetic fields: an in vivo experimental review 2023
This present article intends to systematically review the in vivo experimental outcome and the corresponding mechanisms to shed some light on the safety considerations of ELF-EMFs. This will further advance the subsequent application of electrotherapy in human health.

https://pubmed.ncbi.nlm.nih.gov/20731873/
Stimulation of osteogenic differentiation in human osteoprogenitor cells by pulsed electromagnetic fields: an in vitro study 2010
BMSCs derived from four different donors were cultured in osteogenic medium, with the PEMF treated group being continuously exposed to a 15 Hz, 1 Gauss EM field, consisting of 5-millisecond bursts with 5-microsecond pulses. GDH: 0.1mT/2.5us= 40T/s
Conclusions: PEMF exposure of differentiating human BMSCs enhanced mineralization and seemed to induce differentiation at the expense of proliferation. The osteogenic stimulus of PEMF was confirmed by the up-regulation of several osteogenic marker genes in the PEMF treated group, which preceded the deposition of mineral itself. These findings indicate that PEMF can directly stimulate osteoprogenitor cells towards osteogenic differentiation. This supports the theory that PEMF treatment may recruit these cells to facilitate an osteogenic response in vivo.

https://pubmed.ncbi.nlm.nih.gov/33675261/
The Effect of Pulsed Electromagnetic Fields on Angiogenesis 2021
A pulsed electromagnetic field (PEMF) has been used to treat inflammation-based diseases such as osteoporosis, neurological injury, and osteoarthritis. Numerous animal experiments and in vitro studies have shown that PEMF may affect angiogenesis. For ischemic diseases, in theory, blood flow may be richer by increasing the number of blood vessels which supply blood to ischemic tissue. PEMF plays a role in enhancing angiogenesis, and their clinical application may go far beyond the current scope. In this review, we analyzed and summarized the effects and possible mechanisms of PEMF on angiogenesis. Most studies have shown that PEMF with specific parameters can promote angiogenesis, which is manifested by an increased vascular growth rate and increased capillary density.

https://pubmed.ncbi.nlm.nih.gov/34574442/
Anti-Oxidative and Immune Regulatory Responses of THP-1 and PBMC to Pulsed EMF Are Field-Strength Dependent 2021
Taken together, our results emphasize an altered susceptibility of immune cells of different origin and associate EMF-related effects with anti-inflammatory signaling and lipid metabolism.

https://www.researchgate.net/figure/Clinical-studies-of-PEMF-therapy-in-oncology_tbl3_309218771

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5354149/
Pulsed Electromagnetic Field Stimulation Promotes Anti-cell Proliferative Activity in Doxorubicin-treated Mouse Osteosarcoma Cells

2017

effects of PEMF (5 mT, 200 Hz) of different durations and doxorubicin on the proliferative activity of LM8 cells were measured by the MTT assay

Conclusion: Our results indicate that combination of PEMF and doxorubicin could be a novel chemotherapeutic strategy.

https://aacrjournals.org/cancerres/article/65/9_Supplement/287/519343/Daily-Pulsed-Electromagnetic-Field-PEMF-therapy

Daily Pulsed Electromagnetic Field (PEMF) therapy inhibits tumor angiogenesis via the hypoxia driven pathway: therapeutic implications 2005

This leads to the conclusion that PEMF is an effective adjunct therapy following IR therapy but that the continued daily PEMF therapy should be stopped sometime (perhaps 2-4 days) prior to a second round of IR therapy. The temporary cessation of PEMF prior to the second round of IR is necessary for resumption of angiogenesis, decrease of hypoxic areas and increase in proliferative active and well oxygenated areas within the tumor

https://www.nature.com/articles/s41598-023-34144-5

Effects of extremely low frequency electromagnetic fields on the tumor cell inhibition and the possible mechanism 2023

Magnetic field exposure has the potential to serve as an advanced strategy in cancer management. ROS produced by cells using this method appear to be the key to tumor growth inhibition3. We proved that the main mechanism was not only related to ROS but also closely related to the contact between cells. We speculated that the magnetic field exposure changed the secretion of certain substrates, leading to the changes in signaling and thus restoring tumor cell contact inhibition. Based on the experimental results and previous experiments, four properties of magnetic field suppression were summarized.

The intracellular calcium signal and the membrane potential with the change in the magnetic field were relatively synchronized (except A549). We hypothesized that the calcium ion concentration was associated with the membrane potential on magnetic field exposure. In addition, only 293 T cells showed significant differences in the calcium ion concentration when exposed to the magnetic field.

A549 cells have been cultured at 37 ± 0.18 °C in presence of an extremely low-frequency magnetic field of 20 Hz, 5-mT.

https://www.nature.com/articles/s41598-023-35767-4

Synergistic cytotoxic effects of an extremely low-frequency electromagnetic field with doxorubicin on MCF-7 cell line 2023

Breast cancer is one of the leading causes of cancer deaths in women worldwide. Magnetic fields have shown anti-tumor effects in vitro and in vivo as a non-invasive therapy method that can affect cellular metabolism remotely. Doxorubicin (DOX) is one of the most commonly used drugs for treating breast cancer patients. It can be assumed that combining chemotherapy and magnetotherapy is one of the most effective treatments for breast cancer. This study aimed to investigate the potential cytotoxic effect of DOX at low concentrations in combination with extremely low-frequency electromagnetic fields (ELF–EMF; 50 Hz; 20 mT). The breast cancer cell line MCF-7 was examined for oxidative stress, cell cycle, and apoptosis. MCF-7 cells were treated with various concentrations of DOX as an apoptosis-inducing agent and ELF–EMF. Cytotoxicity was examined using the MTT colorimetric assay at 12, 24, and 48 h. Consequently, concentration- and time-dependent cytotoxicity was observed in MCF-7 cells for DOX within 24 h. The MTT assay results used showed that a 2 µM concentration of DOX reduced cell viability to 50% compared with control, and as well, the combination of ELF–EMF and DOX reduced cell viability to 50% compared with control at > 0.25 µM doses for 24 h. In MCF-7 cells, combining 0.25 µM DOX with ELF–EMF resulted in increased ROS levels and DOX-induced apoptosis. Flow cytometry analysis, on the other hand, revealed enhanced arrest of MCF-7 cells in the G0-G1 phase of the cell cycle, as well as inducing apoptotic cell death in MCF-7 cells, implying that the synergistic effects of 0.25 µM DOX and ELF–EMF may represent a novel and effective agent against breast cancer.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9939155/

Is extremely low frequency pulsed electromagnetic fields applicable to gliomas? A literature review of the underlying mechanisms and application of extremely low frequency pulsed electromagnetic fields 2023

7.1. Bio-energy transport

Pang 84 made an attempt to discover the mechanism of energy transport in protein molecules under EMF. After analyzing Davydov's theory on energy transport, they changed the Hamiltonian and the wave function of systems simultaneously and built a Pang's soliton model on the basis of Davydov's model. They confirmed that Pang's soliton could transport hundreds of amino acid residues and that it varied with the external EMF. That is, EMF could target amino acid residues in protein molecules and influence soliton energy transport, thus affecting bio-energy. In the article, the term “bio-energy transport” indicates bio-energy flows along protein molecules, a process that sustains life activities. Physical models 84 have been employed to explain this biological process. Such an approach may be a new trend of studies on ELF-PEMF mechanisms. In addition, the variation in the biological effects of EMFs with strength and direction points out a feasible direction for follow-up research.

7.2. Epigenetic modulation

ELF-PEMF could mediate the level of miR-30a to affect autophagy by targeting specific genes. 48 In 2016, Pasi 85 used the same ELF-PEMF (75 Hz, 2 mT) on the chemo- and radioresistant human GBM cell line T98G. Their results showed that ELF-PEMF could decrease miR-421, miR-21, and miR-17 levels, which were found to be overexpressed in tumor cells and to lead to apoptosis resistance in an epigenetic manner. 86 , 87 , 88 , 89 They also showed that a combination of TMZ and ELF-PEMF could decelerate tumor proliferation epigenetically. 85

In conclusion, ELF-PEMF influenced ARs and augmented their anti-tumor effects.

https://pubmed.ncbi.nlm.nih.gov/32159242/

Effects and Mechanisms of Exogenous Electromagnetic Field on Bone Cells: A Review 2020

Osteoporosis, fractures, and other bone diseases or injuries represent serious health problems in modern society. A variety of treatments including drugs, surgeries, physical therapies, etc. have been used to prevent or delay the progression of these diseases/injuries with limited effects. Electromagnetic field (EMF) has been used to non-invasively treat bone diseases, such as fracture and osteoporosis, for many years. However, because a variety of cellular and molecular events can be affected by EMF with various parameters, the precise bioeffects and underlying mechanisms of specific EMF on bone cells are still obscure. Here, we summarize the common therapeutic parameters (frequency and intensity) of major types of EMF used to treat bone cells taken from 32 papers we selected from the PubMed database published in English from 1991 to 2018. Briefly, pulse EMF promotes the proliferation of osteoblasts when its frequency is 7.5-15 Hz or 50-75 Hz and the intensity is 0.40-1.55 mT or 3.8-4 mT. Sinusoidal EMF, with 0.9-4.8 mT and 45-60 Hz, and static magnetic field with 0.1-0.4 mT or 400 mT, can promote osteoblast differentiation and maturation. Finally, we summarize the latest advances on the molecular signaling pathways influenced by EMF in osteoblasts and osteoclasts. A variety of molecules such as adenosine receptors, calcium channels, BMP2, Notch, Wnt1, etc., can be influenced by EMF in osteoblasts. For osteoclasts, EMF affects RANK, NF-κB, MAPK, etc. We speculate that EMF with different frequencies and intensities exert distinct bioeffects on specific bone cells. More high-quality work is required to explore the detailed effects and underlying mechanisms of EMF on bone cells/skeleton to optimize the application of EMF on bone diseases/injuries. Bioelectromagnetics. 2020;41:263-278 © 2020 Bioelectromagnetics Society.

https://pubmed.ncbi.nlm.nih.gov/23589052/
Effect of 1 mT sinusoidal electromagnetic fields on proliferation and osteogenic differentiation of rat bone marrow mesenchymal stromal cells 2013
Electromagnetic field (EMF) stimulation is clinically beneficial for fracture nonunion and a wide range of bone disorders. However, no consensus has been reached on the optimal parameters of the EMF. The exact mechanism by which EMFs enhance osteogenesis has also not been defined. In the present study, a sinusoidal 1 mT EMF at frequencies of 10, 30, 50, and 70 Hz were administered to rat bone marrow mesenchymal stromal cells (rBMSCs) in the cyclic mode of 2 h exposures followed by 4 h of culture without exposure. The cell viability, proliferation, expression of some osteogenic genes, and mineralization of the extracellular matrix were investigated. It was found that the cell viability was decreased by EMF exposures of 50 and 70 Hz. The proliferation of rBMSCs was elevated significantly in the 10 Hz EMF-treated group during the culture periods. The expression of alkaline phosphatase (ALP) and osteocalcin (OC), two early-phase osteogenic differentiation markers, was up-regulated by the 1 mT, 10 Hz EMF after 1 week. However, the expression of genes that marked the later-phase osteogenic differentiation and maturation of osteoblasts was elevated by the stimulation of 50 Hz EMFs after 2 weeks. In addition, it was observed that the mineralization of the extracellular matrix was enhanced by 50 Hz EMF exposure. These results indicated that the 1 mT EMF at different frequencies had disparate effects on the viability, proliferation and osteogenic differentiation of rBMSCs, and may be beneficial for developing novel therapeutic approaches in bone regenerative medicine.

https://pubmed.ncbi.nlm.nih.gov/34622330/
Osteogenesis Modulation: Induction of Mandibular Bone Growth in Adults by Electrical Field for Aesthetic Purposes 2022
Background: A new technique in plastic surgery termed Osteogenesis Modulation is described. This technique uses a surgically implanted, battery-operated medical device to deliver customized electrical pulses to produce mandibular bone growth. This device was designed to be a temporary, nonpermanent implant. The purpose of this study was to review both the safety and efficacy of Osteogenesis Modulation.
Methods: This study comprises two phases. Phase I involved experimental technology development and animal experiments. Phase II included technology development for clinical use and a clinical trial. In Phase II, four patients with a diagnosis of mandibular hypoplasia and microgenia underwent surgical implantation of the novel medical device over the chin bone. Once a satisfactory change of contour of mandibular bone was achieved, the devices were removed. In all patients, the devices were left in place for 12 months, then surgically removed under local anesthesia. Preoperative and long-term postoperative cephalometric controls were done.

Results: In all patients, symmetrical mandibular bone growth was observed with good-to-excellent aesthetic results. The overall follow-up period was 39 months. Cephalometric controls taken 3 to 6 months after the device removal showed an average increase in mandible length of 5.26mm (range, 2.83-7.60mm)
CONCLUSIONS: Preliminary clinical results suggest that Osteogenesis Modulation is a safe, minimally invasive, and effective alternative treatment for the correction of mandibular hypoplasia in selected cases.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7298453/
Role of pulsed electromagnetic fields after joint replacements 2020
Pulsed Electro Magnetic Fields (PEMFs) treatment, although initially recommended after total joint replacement to promote bone ingrowth and to reduce inflammation and pain, is not currently part of usual clinical practice. The purpose of this review was to analyze existing literature on PEMFs effects in joint replacement surgery and to report results of clinical studies and current indications. We selected all currently available prospective studies or RCT on the use of PEMFs in total joint replacement with the purpose of investigating effects of PEMFs on recovery, pain relief and patients' satisfaction following hip, knee or shoulder arthroplasty. All the studies analyzed reported no adverse effects, and good patient compliance to the treatment. The available literature shows that early control of joint inflammation process in the first days after surgery through the use of PEMFs should be considered an effective completion of the surgical procedure to improve the patient's functional recovery.
At first, the main focus has been on stimulation regimes using 100 Hz PEMF pulses with very low intensities, around 0.2 mT[13]. Today, the clinical protocols with most scientific evidence are: (1) 75 Hz and 1.5-2.5 mT (PEMF with square and trapezoidal waves)[3]; and (2) 15 Hz and 0.3-1.8 mT (PRF-PEMF with about 4 kHz carrier frequency)[9].
The stem used was a Wagner SL revision stem of titanium-aluminum-niobium alloy. Treated patients were stimulated from day 7 to day 90 post-operatively. The device was used 6 h per day. The peak amplitude of the magnetic field produced by the device was 2 mT at 75 Hz.

https://pubmed.ncbi.nlm.nih.gov/1932623/
Effect of a 9 mT pulsed magnetic field on C3H/Bi female mice with mammary carcinoma. A comparison between the 12 Hz and the 460 Hz frequencies 1991
In a previous experiment, the exposure of tumoral C3H/Bi female mice to a 9 mT, 460 Hz pulsed magnetic field led to an increase in the length of survival in the late period of the disease; this might be due to a hampered metastatic process. In the present study 27 controls and 52 exposed mice were treated with the same protocol (a 10-minute exposure, 3 non-consecutive days a week, from 2-3 weeks after the tumors appeared until death) but with a 12 Hz PMF. In this experiment the 12 Hz PMF appeared to increase length of survival times in the early period of the disease

https://pubmed.ncbi.nlm.nih.gov/25530714/
Optimization of a therapeutic electromagnetic field (EMF) to retard breast cancer tumor growth and vascularity 2014
Methods: The therapeutic EMF device generated a defined 120 Hz semi sine wave pulse signal of variable intensity. Murine 16/C mammary adenocarcinoma tumor fragments were implanted subcutaneously between the scapulae of syngeneic C3H mice. Once the tumor grew to 100 mm(3), daily EMF treatments were started by placing the cage of mice within the EMF field. Treatment ranged from 10 to 20 milli-Tesla (mT) and was given for 3 to 80 minutes either once or twice a day for 12 days. Tumors were measured and volumes calculated each 3-4 days.
Results: Therapeutic EMF treatment significantly suppressed tumor growth in all 7 EMF treated groups. Exposure to 20mT for 10 minutes twice a day was the most effective tumor growth suppressor. The effect of EMF treatment on extent of tumor vascularization, necrosis and viable area was determined after euthanasia. The EMF reduced the vascular (CD31 immunohistochemically positive) volume fraction and increased the necrotic volume of the tumor. Treatment with 15 mT for 10 min/d gave the maximum anti-angiogenic effect. Lack of a significant correlation between tumor CD 31 positive area and tumor growth rate indicates a mechanism for suppression of tumor growth in addition to suppression of tumor vascularization.
Conclusion: It is proposed that EMF therapy aimed at suppression of tumor growth and vascularization may prove a safe alternative for patients whether they are or are not candidates for conventional cancer therapy.

https://pubmed.ncbi.nlm.nih.gov/38473720/
Pulsed Electromagnetic Fields (PEMFs) Trigger Cell Death and Senescence in Cancer Cells 2024

The currently available anti-cancer therapies, such as gamma-radiation and chemotherapeutic agents, induce cell death and cellular senescence not only in cancer cells but also in the adjacent normal tissue. New anti-tumor approaches focus on limiting the side effects on normal cells. In this frame, the potential anti-tumor properties of Pulsed Electromagnetic Fields (PEMFs) through the irradiation of breast cancer epithelial cells (MCF-7 and MDA-MB-231) and normal fibroblasts (FF95) were investigated. PEMFs had a frequency of 8 Hz, full-square wave type and magnetic flux density of 0.011 T and were applied twice daily for 5 days. The data collected showcase that PEMF application decreases the proliferation rate and viability of breast cancer cells while having the opposite effect on normal fibroblasts. Moreover, PEMF irradiation induces cell death and cellular senescence only in breast cancer cells without any effect in the non-cancerous cells. These findings suggest PEMF irradiation as a novel, non-invasive anti-cancer strategy that, when combined with senolytic drugs, may eliminate both cancer and the remaining senescent cells, while simultaneously avoiding the side effects of the current treatments.

https://pubmed.ncbi.nlm.nih.gov/29125193/
Exposure to a specific time-varying electromagnetic field inhibits cell proliferation via cAMP and ERK signaling in cancer cells 2018
Exposure to specific electromagnetic field (EMF) patterns can affect a variety of biological systems. We have shown that exposure to Thomas-EMF, a low-intensity, frequency-modulated (25-6 Hz) EMF pattern, inhibited growth and altered cell signaling in malignant cells. Exposure to Thomas-EMF for 1 h/day inhibited the growth of malignant cells including B16-BL6 mouse melanoma cells, MDA-MB-231, MDA-MB-468, BT-20, and MCF-7 human breast cancer and HeLa cervical cancer cells but did not affect non-malignant cells. The Thomas-EMF-dependent changes in cell proliferation were mediated by adenosine 3',5'-cyclic monophosphate (cAMP) and extracellular-signal-regulated kinase (ERK) signaling pathways. Exposure of malignant cells to Thomas-EMF transiently changed the level of cellular cAMP and promoted ERK phosphorylation. Pharmacologic inhibitors (SQ22536) and activators (forskolin) of cAMP production both blocked the ability of Thomas-EMF to inhibit cell proliferation, and an inhibitor of the MAP kinase pathway (PD98059) was able to partially block Thomas-EMF-dependent inhibition of cell proliferation. Genetic modulation of protein kinase A (PKA) in B16-BL6 cells also altered the effect of Thomas-EMF on cell proliferation. Cells transfected with the constitutively active form of PKA (PKA-CA), which interfered with ERK phosphorylation, also interfered with the Thomas-EMF effect on cell proliferation. The non-malignant cells did not show any EMF-dependent changes in cAMP levels, ERK phosphorylation, or cell growth. These data indicate that exposure to the specific Thomas-EMF pattern can inhibit the growth of malignant cells in a manner dependent on contributions from the cAMP and MAP kinase pathways. Bioelectromagnetics. 39;217-230, 2018

https://pubmed.ncbi.nlm.nih.gov/11911264/
Therapeutic electromagnetic field effects on angiogenesis and tumor growth 2001
Materials and methods: Implanted tumors were allowed to grow for seven days until the tumor volume reached 100 mm3 before treatment was started. Mice (20 per control, 10 per EMF exposed group) received treatment (10 minutes per day with 0, 10 mT, 15 mT or 20 mT) with a 120 pulses per second pulsating magnetic field. Tumor growth was assessed throughout the treatment period. The extent of tumor vascularization was evaluated by immunohistochemical staining for CD31.
Results: Exposure to TEMF significantly reduced tumor growth, significantly reduced the percentage of area stained for CD31 indicating a reduction in the extent of vascularization and there was a concomitant increase in the extent of tumor necrosis.
Conclusion: A novel TEMF treatment safely reduced growth and vascularization of implanted breast cancers in mice.

https://pubmed.ncbi.nlm.nih.gov/37117238/
Effects of extremely low frequency electromagnetic fields on the tumor cell inhibition and the possible mechanism 2023
Low-frequency magnetic fields exert a significant inhibitory effect on tumor growth and have been developed as a therapeutic modality. However, the effect of a low-frequency magnetic field on the interaction between cells is still poorly understood. This study aimed to preliminarily evaluate the direct effect of magnetic field ditectely on cultured cells and indirect effect mediated by cell-environment (conditioned medium). 293 T cells, Hepg2 cells, A549 cells have been cultured at 37 ± 0.18 °C in presence of an extremely low-frequency magnetic field of 20 Hz, 5-mT. The adherent tumor cells were more sensitive to magnetic field inhibition in the original environment (conditioned medium) with adherence inhibition rate for Hepg2 and A549 estimated at 18% and 30% respectively. The inhibition effect was suppressed when the suspended cells separated or clump density at a low density. The nontumor cell lines showed no inhibitory effect on exposure to a low-frequency magnetic field. The intracellular ion fluorescence (IIF) showed that the magnetic field significantly altered the membrane potential, indicating hyperpolarization of the adherent cells (ΔIIF 293 T cells: - 25%, ΔIIF Hepg2 cells: - 20% and ΔIIF A549 cells: - 13%) and depolarization of the suspended cells (ΔIIF Raji cells: + 9%). In addition, the conditioned media collected after magnetic field exposure acted on unexposed tumor cells and caused inhibition. Our findings might provide a basis for the mechanism of magnetic field interaction between cells and cell environment in the future

https://pubmed.ncbi.nlm.nih.gov/32142642/
Pulsed Low-Frequency Magnetic Fields Induce Tumor Membrane Disruption and Altered Cell Viability 2020
Tumor cells express a unique cell surface glycocalyx with upregulation of sulfated glycosaminoglycans and charged glycoproteins. Little is known about how electromagnetic fields interact with this layer, particularly with regard to harnessing unique properties for therapeutic benefit. We applied a pulsed 20-millitesla (mT) magnetic field with rate of rise (dB/dt) in the msec range to cultured tumor cells to assess whether this affects membrane integrity as measured using cytolytic assays. A 10-min exposure of A549 human lung cancer cells to sequential 50- and 385-Hz oscillating magnetic fields was sufficient to induce intracellular protease release, suggesting altered membrane integrity after the field exposure. Heparinase treatment, which digests anionic sulfated glycan polymers, before exposure rendered cells insensitive to this effect. We further examined a non-neoplastic human primary cell line (lung lymphatic endothelial cells) as a typical normal host cell from the lung cancer microenvironment and found no effect of field exposure on membrane integrity. The field exposure was also sufficient to alter proliferation of tumor cells in culture, but not that of normal lymphatic cells. Pulsed magnetic field exposure of human breast cancer cells that express a sialic-acid rich glycocalyx also induced protease release, and this was partially abrogated by sialidase pretreatment, which removes cell surface anionic sialic acid. Scanning electron microscopy showed that field exposure may induce unique membrane "rippling" along with nanoscale pores on A549 cells. These effects were caused by a short exposure to pulsed 20-mT magnetic fields, and future work may examine greater magnitude effects. The proof of concept herein points to a mechanistic basis for possible applications of pulsed magnetic fields in novel anticancer strategies

https://pubmed.ncbi.nlm.nih.gov/37992690/
Glycocalyx transduces membrane leak in brain tumor cells exposed to sharp magnetic pulsing 2023
In testing glioblastoma and neuroblastoma cells known to overexpress glycoproteins rich in modifications by the anionic glycan sialic acid (Sia), exposure of brain tumor cells on the same platform to a pulse train that included a 5 min 50Hz Lf-PMF (dB/dt ∼ 2 T/s at 10 ms pulse widths) induced a very modest but significant protease leak above that of control nonexposed cells (with modest but significant reductions in long-term tumor cell viability after the 5 min exposure). Using a markedly higher dB/dt system (80 T/s pulses, 70 μs pulse-width at 5.9 cm from a MagVenture coil source) induced markedly greater leak by the same cells, and eliminating Sia by treating cells with AUS sialidase immediately preexposure abrogated the effect entirely in SH-SY5Y neuroblastoma cells, and partially in T98G glioblastoma cells. The system demonstrated significant leak (including inward leak of propidium iodide), with reduced leak at lower dB/dt in a variety of tumor cells. The ability to abrogate Lf-PMF protease leak by pretreatment with sialidase in SH-SY5Y brain tumor cells or with heparin lyase in A549 lung tumor cells indicated the importance of heavy Sia or heparan sulfate glycosaminoglycan glycocalyx modifications as dominant glycan species mediating Lf-PMF membrane

leak in respective tumor cells. This "first-physical" Lf-PMF tumor glycocalyx event, with downstream cell stress, may represent a critical and "tunable" transduction mechanism that depends on characteristic anionic glycans overexpressed by distinct malignant tumors.

https://pubmed.ncbi.nlm.nih.gov/39117725/
Anti-tumor effect of innovative tumor treatment device OM-100 through enhancing anti-PD-1 immunotherapy in glioblastoma growth 2024
Glioblastoma (GBM) is associated with a median survival rate of less than 15 months, necessitating innovative treatment approaches. This study investigates the safety and efficacy of the low-frequency magnetic field (LFMF) OM-100 instrument in GBM therapy. In vitro experiments utilized normal astrocyte and GBM cell lines, determining that OM-100 at 100 kHz for 72 h selectively targeted GBM cells without harming normal cells. Subsequent analyses revealed OM-100's impact on cell viability, apoptosis, migration, invasion, reactive oxide species levels, and PD-L1 expression. In vivo studies on mice with U87-induced GBM demonstrated OM-100's synergy with anti-PD-1 therapy, leading to significant tumor volume reduction and increased apoptosis. Notably, OM-100 exhibited safety in healthy mice. Overall, OM-100 could enhance anti-PD-1 immunotherapy effectiveness probably by directly inhibiting tumor proliferation and migration as well as promoting PD-L1 expression, offering a promising therapeutic strategy for GBM treatment.

https://pubmed.ncbi.nlm.nih.gov/16045802/
Therapeutic Electromagnetic Field (TEMF) and gamma irradiation on human breast cancer xenograft growth, angiogenesis and metastasis 2005
Background: The effects of a rectified semi-sinewave signal (15 mT amplitude, 120 pulses per second, EMF Therapeutics, Inc.) (TEMF) alone and in combination with gamma irradiation (IR) therapy in nude mice bearing a human MDA MB231 breast cancer xenograft were tested. Green fluorescence protein transfected cancer cells were injected into the mammary fat pad of young female mice. Six weeks later, mice were randomly divided into four treatment groups: untreated controls; 10 minute daily TEMF; 200 cGy of IR every other day (total 800 cGy); IR plus daily TEMF. Some mice in each group were euthanized 24 hours after the end of IR. TEMF treatment continued for 3 additional weeks. Tumor sections were stained for: endothelial cells with CD31 and PAS or hypoxia inducible factor 1alpha (HIF).
Results: Most tumors <35 mm3 were white but tumors >35 mm3 were pink and had a vascularized capsule. The cortex within 100 microns of the capsule had little vascularization. Blood vessels, capillaries, and endothelial pseudopods were found at >100 microns from the capsule (subcortex). Tumors >35 mm3 treated with IR 24 hours previously or with TEMF had decreased blood vessels in the subcortex and more endothelial pseudopods projecting into hypoxic, HIF positive areas than tumors from the control group. Mice that received either IR or TEMF had significantly fewer lung metastatic sites and slower tumor growth than did untreated mice. No harmful side effects were attributed to TEMF.
Conclusion: TEMF therapy provided a safe means for retarding tumor vascularization, growth and metastasis

https://pubmed.ncbi.nlm.nih.gov/27748048/
Mechanisms and therapeutic effectiveness of pulsed electromagnetic field therapy in oncology 2016
Cancer is one of the most common causes of death worldwide. Available treatments are associated with numerous side effects and only a low percentage of patients achieve complete remission. Therefore, there is a strong need for new therapeutic strategies. In this regard, pulsed electromagnetic field (PEMF) therapy presents several potential advantages including non-invasiveness, safety, lack of toxicity for non-cancerous cells, and the possibility of being combined with other available therapies. Indeed, PEMF stimulation has already been used in the context of various cancer types including skin, breast, prostate, hepatocellular, lung, ovarian, pancreatic, bladder, thyroid, and colon cancer in vitro and in vivo. At present, only limited application of PEMF in cancer has been documented in humans. In this article, we review the experimental and clinical evidence of PEMF therapy discussing future perspectives in its use in oncology

https://pubmed.ncbi.nlm.nih.gov/27223425/
Moderate and strong static magnetic fields directly affect EGFR kinase domain orientation to inhibit cancer cell proliferation 2016
Static magnetic fields (SMFs) can affect cell proliferation in a cell-type and intensity-dependent way but the mechanism remains unclear.

https://pubmed.ncbi.nlm.nih.gov/20582429/
Effects of 50-Hz magnetic field exposure on superoxide radical anion formation and HSP70 induction in human K562 cells 2010
Here, we report on the influence of MF exposure (50-Hz sine wave; 1 h; 0.025-0.10 mT; vertical or horizontal MF exposure direction) on different cellular parameters (proliferation, cell cycle distribution, superoxide radical anion, and HSP70 protein levels) in the human leukaemia cell line K562.
Both vertical and horizontal MF exposures for 1 h caused significantly and transiently increased HSP70 levels (>twofold), at several flux densities, compared to sham controls and also compared to heat treatment. This exposure also increased (30-40%) the levels of the superoxide radical anion, comparable to the positive control PMA. Addition of free radical scavengers (melatonin or 1,10-phenantroline) inhibited the MF-induced increase in HSP70. In conclusion, an early response to ELF MF in K562 cells seems to be an increased amount of oxygen radicals, leading to HSP70 induction. Furthermore, the results suggest that there is a flux density threshold where 50-Hz MF exerts its effects on K562 cells, at or below 0.025 mT, and also that it is the MF, and not the induced electric field, which is the active parameter.

https://pubmed.ncbi.nlm.nih.gov/26850078/
Exposure to a 50-Hz magnetic field induced mitochondrial permeability transition through the ROS/GSK-3β signaling pathway 2016
Exposure to the MF at 0.4 mT for 60 min transiently induced mitochondrial permeability transition (MPT) and Cyt-c release, although there was no significant effect on mitochondrial membrane potential (ΔΨm).
In addition, cells exposed to the MF showed increased intracellular reactive oxidative species (ROS) levels and glycogen synthase kinase-3β (GSK-3β) dephosphorylation at 9 serine residue (Ser(9)).

https://pubmed.ncbi.nlm.nih.gov/24314291/
Effect of low frequency magnetic fields on melanoma: tumor inhibition and immune modulation 2013
We previously found that the low frequency magnetic fields (LF-MF) inhibited gastric and lung cancer cell growth. We suppose that exposure to LF-MF may modulate immune function so as to inhibit tumor. We here investigated whether LF-MF can inhibit the proliferation and metastasis of melanoma and influence immune function.
Lung metastasis mice were prepared by injection of 2 × 105 B16-F10 melanoma cells into the tail vein in C57BL/6 mice. The mice were then exposed to an LF-MF (0.4 T, 7.5 Hz) for 43 days. Survival rate, tumor markers and the innate and adaptive immune parameters were measured.
Conclusion: LF-MF inhibited the growth and metastasis of melanoma cancer cells and improved immune function of tumor-bearing mice. This suggests that the inhibition may be attributed to modulation of LF-MF on immune function and LF-MF may be a potential therapy for treatment of melanoma.

https://pubmed.ncbi.nlm.nih.gov/33816280/
Progressive Study on the Non-thermal Effects of Magnetic Field Therapy in Oncology 2021
Previous studies reported that static magnetic fields (SMFs) and low-frequency magnetic fields (LF-MFs, frequency below 300 Hz) exert anti-tumor function, independent of thermal effects. Magnetic fields (MFs) could inhibit cell growth and proliferation; induce cell cycle arrest, apoptosis, autophagy, and differentiation; regulate the immune system; and suppress angiogenesis and metastasis *via* various signaling pathways. In addition, they are effective in combination therapies: MFs not only promote the absorption of chemotherapy drugs by producing small holes on the surface of cell membrane but also enhance the inhibitory effects by regulating apoptosis and cell cycle related proteins.

https://pubmed.ncbi.nlm.nih.gov/39117725/
Anti-tumor effect of innovative tumor treatment device OM-100 through enhancing anti-PD-1 immunotherapy in glioblastoma growth 2024
In vitro experiments utilized normal astrocyte and GBM cell lines, determining that OM-100 at 100 kHz for 72 h selectively targeted GBM cells without harming normal cells. Subsequent analyses revealed OM-100's impact on cell viability, apoptosis, migration, invasion, reactive oxide species levels, and PD-L1 expression. In vivo studies on mice with U87-induced GBM demonstrated OM-100's synergy with anti-PD-1 therapy, leading to significant tumor volume reduction and increased apoptosis. Notably, OM-100 exhibited safety in healthy mice. Overall, OM-100 could enhance anti-PD-1 immunotherapy effectiveness probably by directly inhibiting tumor proliferation and migration as well as promoting PD-L1 expression, offering a promising therapeutic strategy for GBM treatment.

https://pubmed.ncbi.nlm.nih.gov/38524191/
Design and characterisation of a cell exposure system with high magnetic field homogeneity: RILZ coils 2024
This study highlights the importance of the homogeneity of the magnetic field intensity generated by the exposure systems used and offers an effective solution to control the magnetic field exposure parameters *in vitro* assays.

https://pubmed.ncbi.nlm.nih.gov/35919980/
Magnetic field effects in biology from the perspective of the radical pair mechanism 2022
Hundreds of studies have found that weak magnetic fields can significantly influence various biological systems. However, the underlying mechanisms behind these phenomena remain elusive. Remarkably, the magnetic energies implicated in these effects are much smaller than thermal energies. Here, we review these observations, and we suggest an explanation based on the radical pair mechanism, which involves the quantum dynamics of the electron and nuclear spins of transient radical molecules.
ROS are the collection of derivatives of molecular oxygen that occur in biology, which can be categorized into two types, free radicals and non-radical species. The non-radical species are hydrogen peroxide (H_2O_2), organic hydroperoxides (ROOH), singlet molecular oxygen ($^1O_2$), electronically excited carbonyl, ozone (O_3), hypochlorous acid (HOCl, and hypobromous acid HOBr). Free radical species are super-oxide anion radical ($O_2^{\bullet-}$), hydroxyl radical (•OH), peroxyl radical (ROO•) and alkoxyl radical (RO•) [130]. Any imbalance of ROS can lead to adverse effects. H_2O_2 and $O_2^{\bullet-}$ are the main redox signalling agents.
In a considerable number of studies, magnetic field effects in biology are accompanied with oxidative stress [15,135,136], which is an imbalance between oxidants and antioxidants in favour of the oxidants, leading to a disruption of redox signalling and control and/or molecular damage. [137–139]
Huizen and co-workers showed that weak magnetic fields (less than 1 mT) changed stem cell-mediated growth, where changes in ROS were implicated [81]
2.3. Oscillating magnetic field
2.3.1. Low-frequency
The effects of oscillating magnetic fields on biological functions are abundant [207–215], and are often correlated with modulation of ROS levels [216–218]. In this section, we review several studies on extremely low-frequency (less than 3 kHz) magnetic fields on various biological functions.
Sherrard and co-workers showed that exposure of the cerebellum to low-intensity repetitive transcranial magnetic stimulation (LI-rTMS) (10 mT) modulated behaviour and Purkinje cell morphology [219,220]. Recently, the same group reported that LI-rTMS (2 mT) induced axon growth and synapse formation providing olivocerebellar reinnervation in the cerebellum [221]. The authors concluded that cryptochrome was required for the magnetosensitivity of the neurons, which was consistent with ROS production by activated cryptochrome [222]. In a recent study, the team showed that LI-rTMS (10 mT and 10 Hz) evoked neuronal firing during the stimulation period and induced durable attenuation of synaptic activity and spontaneous firing in cortical neurons of rats in vivo [223].
Contalbrigo et al. showed that magnetic fields (less than 1 mT, 50 Hz) influenced some haematochemical parameters of circadian rhythms in Sprague–Dawley rats [224]. Further, Fedele et al. reported that a 300 μT magnetic field (3–50 Hz) induced changes in two locomotor phenotypes, circadian period and activity levels via modulating cryptochrome in Drosophila [225]. Moreover, it has been shown that exposure to a magnetic field of an 0.1 mT and 50 Hz alters clock gene expressions [226].
Manikonda et al. applied magnetic fields (50 and 100 μT, 50 Hz) to the cerebellum, hippocampus and cortex of rat brains. They observed that H_2O_2 increased in the descending order of cerebellum, hippocampus and cortex. In that work, 100 μT induced more oxidative stress compared to 50 μT [227]. Furthermore, Özgün et al. reported that exposure to a magnetic field (1 mT, 50 Hz) in vitro induced human neuronal differentiation through N-methyl- D -aspartate (NMDA) recep-
tor activation [228]. They observed that the magnetic field enhanced intracellular Ca^{2+} levels. The authors concluded that NMDA receptors (NMDARs) are essential for magnetosensitivity in such phenomena. It is also known that a combination of static (27–37 μT) and time varying (13/114 μT, 7/72 Hz) magnetic fields directly interact with the Ca^{2+} channel protein in the cell membrane [229]. It has also been reported that exposure to greater than 5 mT (50 Hz) magnetic fields may promote X-ray-induced mutations in hamster ovary K1 cells [230]. Koyama et al. showed that exposure to a magnetic field of 5 mT (60 Hz) promoted damage induced by H_2O_2, resulting in an increase in the number of mutations in plasmids in E. coli [231]. Studies of extremely low-frequency magnetic field effects (less than 1000 Hz) on various biological functions are shown in tables 3 and 4.
Radicals are molecules with an odd number of electrons in the outer shell [393,394]. A pair of radicals can be formed by breaking a chemical bond or electron transfer between two molecules

https://pubmed.ncbi.nlm.nih.gov/31779223/
Remote Actuation of Apoptosis in Liver Cancer Cells via Magneto-Mechanical Modulation of Iron Oxide Nanoparticles 2019
We show that liver cancer cells can be loaded with superparamagnetic iron oxide nanoparticles (SPIONs). SPIONs retained in lysosomal compartments can be effectively actuated with a high intensity (up to 8 T), short pulse width (~15 μs), pulsed magnetic field (PMF), resulting in lysosomal membrane permeabilization (LMP) in cancer cells.

https://www.mdpi.com/2079-7737/13/9/734
Low Magnetic Field Exposure Alters Prostate Cancer Cell Properties 2024
Our findings suggest that LMF exposure may promote a more aggressive cancer phenotype by modulating key molecular and cellular pathways, highlighting the potential therapeutic implications of magnetic field modulation in cancer treatment.

https://pubmed.ncbi.nlm.nih.gov/24241907/
Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort 2014
Methods: 120,852 men and women aged 55-69 years at time of enrollment in 1986 were followed up (17.3 years) for incident lung, breast and brain cancer, and hemato-lymphoproliferative malignancies.
Results: None of the exposure metrics showed an effect on incidence for lung, breast, and brain cancer, nor any of the assessed subtypes in men and women. Of the hemato-lymphoproliferative malignancies in men, ever high exposed to ELF-MF showed a significant association with acute myeloid leukemia (AML) [hazard ratio (HR) 2.15; 95 % confidence interval (CI) 1.06-4.35] and follicular lymphoma (FL) (HR 2.78; 95 % CI 1.00-5.77). Cumulative exposure to ELF-MF showed a significant, positive association with FL but not AML among men.

https://www.nature.com/articles/s41598-017-10407-w
Low Frequency Magnetic Fields Induce Autophagy-associated Cell Death in Lung Cancer through miR-486-mediated Inhibition of Akt/mTOR Signaling Pathway 2017
Taken together, this study proved that LF-MFs can inhibit lung cancers through miR-486 induced autophagic cell death, which suggest a clinical application of LF-MFs in cancer treatment.

https://pubmed.ncbi.nlm.nih.gov/35994829/
Extremely low-frequency magnetic fields significantly enhance the cytotoxicity of methotrexate and can reduce migration of cancer cell lines via transiently induced plasma membrane damage 2022
Extra Low-frequency Magnetic Fields (ELF-MFs) significantly enhance cellular uptake of methotrexate by inducing transient plasma membrane pores/damage. This enhanced 'dose loading' of methotrexate via the electromagnetically induced membrane pores leads to similar outcomes as the normal control while using significantly smaller therapeutic doses in vitro when compared to non-ELF-MF treated control. Approximately 10% of the typical therapeutic dose yielded similar results when used with ELF-MF. ELF-MFs increase PC12, THP-1 and HeLa proliferation in vitro (120% of the control).
The cells were cultured in 24 well plate (Corstar) at 1 # 10 6/mL supplemented with 10 mM methotrexate and subjected to 6V 10Hz ELF-MF field densities ranging between 0.1 and 0.6 mT.

https://pubmed.ncbi.nlm.nih.gov/24244477/
Inhibition of angiogenesis mediated by extremely low-frequency magnetic fields (ELF-MFs) 2013
The formation of new blood vessels is an essential therapeutic target in many diseases such as cancer, ischemic diseases, and chronic inflammation. In this regard, extremely low-frequency (ELF) electromagnetic fields (EMFs) seem able to inhibit vessel growth when used in a specific window of amplitude. To investigate the mechanism of anti-angiogenic action of ELF-EMFs we tested the effect of a sinusoidal magnetic field (MF) of 2 mT intensity and frequency of 50 Hz on endothelial cell models HUVEC and MS-1 measuring cell status and proliferation, motility and tubule formation ability.
These findings could not only explain the mechanism of anti-angiogenic action exerted by MFs, but also promote the possible development of new therapeutic applications for treatment of those diseases where excessive angiogenesis is involved.

https://pubmed.ncbi.nlm.nih.gov/18512694/
Extremely low frequency electromagnetic fields (ELF-EMFs) induce in vitro angiogenesis process in human endothelial cells 2008
Effects of extremely low frequency (ELF) electromagnetic fields (EMFs) on activation of angiogenesis were analysed using cultured umbilical human vein endothelial cells (HUVECs). The cultures were exposed to a sinusoidal EMF to intensity of 1 mT, 50 Hz for up to 12 h. EMFs increased the degree of endothelial cell proliferation and tubule formation, coupled by an acceleration in the process of wound healing.

https://pubmed.ncbi.nlm.nih.gov/25025060/
Extremely low frequency magnetic fields induce spermatogenic germ cell apoptosis: possible mechanism 2014
The energy generated by an extremely low frequency electromagnetic field (ELF-EMF) is too weak to directly induce genotoxicity. However, it is reported that an extremely low frequency magnetic field (ELF-MF) is related to DNA strand breakage and apoptosis. The testes that conduct spermatogenesis through a dynamic cellular process involving meiosis and mitosis seem vulnerable to external stress such as heat, MF exposure, and chemical or physical agents. Nevertheless the results regarding adverse effects of ELF-EMF on human or animal reproductive functions are inconclusive. According to the guideline of the International Commission on Non-Ionizing Radiation Protection (ICNIRP; 2010) for limiting exposure to time-varying MF (1 Hz to 100 kHz), overall conclusion of epidemiologic studies has not consistently shown an association between human adverse reproductive outcomes and maternal or paternal exposure to low frequency fields. In animal studies there is no compelling evidence of causal relationship between prenatal development and ELF-MF exposure. However there is increasing evidence that EL-EMF exposure is involved with germ cell apoptosis in testes. Biophysical mechanism by which ELF-MF induces germ cell apoptosis has not been established. This review proposes the possible mechanism of germ cell apoptosis in testes induced by ELF-MF.

https://pubmed.ncbi.nlm.nih.gov/39152229/
Pulsed electromagnetic fields regulate metabolic reprogramming and mitochondrial fission in endothelial cells for angiogenesis 2024
Pulsed electromagnetic field (PEMF) therapy has been extensively investigated in clinical studies for the treatment of angiogenesis-related diseases. However, there is a lack of research on the impact of PEMFs on energy metabolism and mitochondrial dynamics during angiogenesis. The present study included tube formation and CCK-8 assays. A Seahorse assay was conducted to analyze energy metabolism, and mitochondrial membrane potential assays, mitochondrial imaging, and reactive oxygen species assays were used to measure changes in mitochondrial structure and function in human umbilical vein endothelial cells (HUVECs) exposed to PEMFs. Real-time polymerase chain reaction was used to analyze the mRNA expression levels of antioxidants, glycolytic pathway-related genes, and genes associated with mitochondrial fission and fusion. The tube formation assay demonstrated a significantly greater tube network in the PEMF group compared to the control group. The glycolysis and mitochondrial stress tests revealed that PEMFs promoted a shift in the energy metabolism pattern of HUVECs from oxidative phosphorylation to aerobic glycolysis. Mitochondrial imaging revealed a wire-like mitochondrial morphology in the control group, and treatment with PEMFs led to shorter and more granular mitochondria. Our major findings indicate that exposure to PEMFs accelerates angiogenesis in HUVECs, likely by inducing energy metabolism reprogramming and mitochondrial fission.

https://pubmed.ncbi.nlm.nih.gov/37144743/
A mechanistically approached review upon assorted cell lines stimulated by athermal electromagnetic irradiation 2023
The probable influence of electromagnetic irradiation on cancer treatment has been deduced from the interaction of artificial electromagnetic emissions with biological organisms.
As a result, subcellular structures such as aberrant Ca^{2+} channels, rich glycocalyx charge, or high water content in cancerous cells, which have attracted a great deal of attention, can explain their higher susceptibility compared with healthy cells under irradiation.

https://pubmed.ncbi.nlm.nih.gov/25875081/

Inhibition of cancer cell growth by exposure to a specific time-varying electromagnetic field involves T-type calcium channels 2015

In vitro studies showed that exposure of malignant cells to Thomas-EMF for > 15 min promoted Ca(2+) influx which could be blocked by inhibitors of voltage-gated T-type Ca(2+) channels. Blocking Ca(2+) uptake also blocked Thomas-EMF-dependent inhibition of cell proliferation. Exposure to Thomas-EMF delayed cell cycle progression and altered cyclin expression consistent with the decrease in cell proliferation. Non-malignant cells did not show any EMF-dependent changes in Ca(2+) influx or cell growth. These data confirm that exposure to a specific EMF pattern can affect cellular processes and that exposure to Thomas-EMF may provide a potential anti-cancer therapy.

https://pubmed.ncbi.nlm.nih.gov/37755661/

The Application of Electromagnetic Fields in Cancer 2024

Some epidemiological studies suggest that there may be a link between exposure to EMF and developing malignancies (such as leukemia and gliomas) or neurodegenerative diseases since EMF has a variety of biological effects such as altering reactive oxygen species (ROS)-regulated pathways. EMF exposure, however, has the potential to cause cancer cells to undergo a period of regulated cell death.

https://karger.com/cpb/article-pdf/46/1/389/2449782/000488473.pdf

Effects of Fifty-Hertz Electromagnetic Fields on Granulocytic Differentiation of ATRA-Treated Acute Promyelocytic Leukemia NB4 Cells 2018

Our results indicate that ELF-EMFs promote ATRA-induced NB4 cells differentiation that varies with the dose. After 96 h of exposure at 2 mT the number of cells is about one third lower compared to cells treated with ATRA alone without detectable signs of cell death. Most importantly, the lower cell number count was paralleled by an increase in known granulocytic differentiation markers, such as NBT reduction activity and CD11b surface marker expression.
ROS have been tentatively proposed to mediate the effects of ELF-EMF [36, 37]. Thus, while investigating mechanisms underlying the effects observed in NB4 cells, we monitored ROS levels in ELF-EMF-irradiated and ATRA-treated cells. Interestingly, a significant increase in ROS levels was observed shortly after exposure to ELF-EMF. However, the precise mechanisms through which ELF-EMF increases cellular ROS production remain unknown.

https://pubmed.ncbi.nlm.nih.gov/38565404/

Low-frequency magnetic field therapy for glioblastoma: Current advances, mechanisms, challenges and future perspectives 2024

In this review, we shed the light on the current status of applying LF-MFs in the treatment of GBM. We specifically emphasize our current understanding of the mechanisms by which LF-MFs mediate anticancer effects and the challenges faced by LF-MFs in treating GBM cells. Furthermore, we discuss the prospective applications of magnetic field therapy in the future treatment of GBM.

https://www.sciencedirect.com/science/article/pii/S2090123224001255?via%3Dihub

Low-frequency magnetic field therapy for glioblastoma: Current advances, mechanisms, challenges and future perspectives 2024

The specific mechanism of LF-MF therapy may be that it can exert corresponding biological effects by inducing extracellular Ca^{2+} influx into GBM cells [19], [20], [40], while changes of the Ca^{2+} signalling pathway have been widely proven to affect the proliferation, differentiation, apoptosis, angiogenesis and gene transcription of tumour cells [38], [43] (Fig. 3). In addition, the increase of cytoplasmic Ca^{2+} concentration will lead to the increase of reactive oxygen species(ROS) and lipid peroxidation, while the increase of ROS will in turn stimulate the increase of intracellular Ca^{2+} concentration, the interaction between ROS and Ca^{2+} signaling pathway is bi-directional. ROS can regulate the Ca^{2+} signalling pathway, and the Ca^{2+} signalling pathway is very important for ROS production [44]. Therefore, the production of ROS and activation of the Ca^{2+} signalling pathway may be initial inducible effects induced by LF-MFs in living organisms [19], [20].

https://www.nature.com/articles/s42003-024-06866-3

Low frequency sinusoidal electromagnetic fields promote the osteogenic differentiation of rat bone marrow mesenchymal stem cells by modulating miR-34b-5p/STAC2 2024

Electromagnetic fields (EMFs) have emerged as an effective treatment for osteoporosis. However, the specific mechanism underlying their therapeutic efficacy remains controversial. Herein, we confirm the pro-osteogenic effects of 15 Hz and 0.4-1 mT low-frequency sinusoidal EMFs (SEMFs) on rat bone marrow mesenchymal stem cells (BMSCs).

https://pubmed.ncbi.nlm.nih.gov/23162666/

A pilot study of extremely low-frequency magnetic fields in advanced non-small cell lung cancer: Effects on survival and palliation of general symptoms 2012

We investigated the effects of 420 r/min, 0.4-T extremely low-frequency MFs (ELF-MFs) on the survival and palliation of general symptoms in 13 advanced non-small cell lung cancer (NSCLC) patients.
Additionally, the patients were treated 2 h per day, 5 days per week for 6-10 weeks.
Our results demonstrated that decreased pleural effusion, remission of shortness of breath, relief of cancer pain, increased appetite, improved physical strength, regular bowel movement and better sleep quality was detected in 2 (15.4%), 5 (38.5%), 5 (38.5%), 6 (46.2%), 9 (69.2%), 1 (7.7%) and 2 (15.4%) patients, respectively. However, the palliation of symptoms in 2 (15.4%) patients was observed during therapy and disappeared at treatment termination. No severe toxicity or side-effects were detected in our trial. The median survival was 6.0 months (95% CI, 1.0-11.0). The 1- and 2-year survival rates were 31.7 and 15.9%, respectively. This study is the first to describe survival and palliation of general symptoms in advanced NSCLC patients treated with ELF-MFs. As an effective, well-tolerated and safe treatment choice, ELF-MFs may prolong survival and improve general symptoms of advanced NSCLC patients. However, this treatment strategy requires further research.

https://pubmed.ncbi.nlm.nih.gov/30074140/

6-mT 0-120-Hz magnetic fields differentially affect cellular ATP levels 2018

We found that the 6-mT static magnetic field (SMF) either does not affect or increase cellular ATP levels, while 6-mT 50-Hz MF either does not affect or decrease cellular ATP levels. In contrast, 6-mT 120-Hz MF has variable effects. We examined the mitochondrial membrane potential (MMP) as well as reactive oxygen species (ROS) in four different cell lines, but did not find their direct correlation with ATP levels. Although none of the ATP level changes induced by these three different frequencies of 6-mT MFs are dramatic, these results may be used to explain some differential cellular responses of various cell lines to different frequency MFs.

https://pubmed.ncbi.nlm.nih.gov/36378418/
A 50 Hz magnetic field influences the viability of breast cancer cells 96 h after exposure 2023
The breast cell lines were exposed to 50 Hz ELF-MF at flux densities of 0.1 mT and 1.0 mT and were examined 96 h after the beginning of ELF-MF exposure. The duration of 50 Hz ELF-MF exposure influenced the cell viability and proliferation of both the tumor and nontumorigenic breast cell lines. In particular, short-term exposure (4-8 h, 0.1 mT and 1.0 mT) led to an increase in viability in breast cancer cells, while long and high exposure (24 h, 1.0 mT) led to a decrease in viability and proliferation in all cell lines.

https://pubmed.ncbi.nlm.nih.gov/36805133/
Effects of extremely low-frequency magnetic fields on human MDA-MB-231 breast cancer cells: proteomic characterization 2023
This study analyzed the changes in the cell viability, cellular morphology, oxidative stress response and alteration of proteomic profile in breast cancer cells (MDA-MB-231) exposed to ELF-MF (50 Hz, 1 mT for 4 h). Non-tumorigenic human breast cells (MCF-10A) were used as control cells. Exposed MDA-MB-231 breast cancer cells increased their viability and live cell number and showed a higher density and length of filopodia compared with the unexposed cells. In addition, ELF-MF induced an increase of the mitochondrial ROS levels and an alteration of mitochondrial morphology.

https://pubmed.ncbi.nlm.nih.gov/33632057/
Effect of extremely low frequency electromagnetic field parameters on the proliferation of human breast cancer 2021
The following four important parameters of ELF-EMF were examined: frequencies (7.83 ± 0.3, 23.49 ± 0.3, and 39.15 ± 0.3 Hz), flux density (0.5 and 1 mT), exposure duration (12, 24, and 48 h), and the exposure methodology (continuous exposure versus switching exposure). The viability of MDA-MB-231 cells exposed to the optimized ELF-EMF pattern (7.83 ± 0.3 Hz, 1 mT, and 6 h switching exposure) was 40.1%. By contrast, the optimized ELF-EMF parameters that were most cytotoxic to breast cancer MDA-MB-231 cells were not damaging to normal M10 cells. In vitro studies also showed that exposure of MDA-MB-231 cells to the optimized ELF-EMF pattern promoted Ca^{2+} influx and resulted in apoptosis. These data confirm that exposure to this specific ELF-EMF pattern can influence cellular processes and inhibit cancer cell growth. The specific ELF-EMF pattern determined in this study may provide a potential anti-cancer treatment in the future.

https://pubmed.ncbi.nlm.nih.gov/39048853/
Electromagnetic Fields Trigger Cell Death in Glioblastoma Cells through Increasing miR-126-5p and Intracellular Ca2+ Levels 2024
In summary, our investigation underscores that electromagnetic fields at a 2.4 GHz frequency may adversely affect certain cancer cell lines, notably triggering apoptosis in the glioblastoma cancer cell line.

https://pubmed.ncbi.nlm.nih.gov/38448548/
Comparison of pulsed and continuous electromagnetic field generated by WPT system on human dermal and neural cells 2024
In this study, we tested the effect of exposure EMF generated by a new prototype wireless charging system on four human cell lines (normal cell lines-HDFa, NHA; tumor cell lines-SH-SY5Y, T98G). We tested different operating parameters of the wireless power transfer (WPT) device (87-207 kHz, 1.01-1.05 kW, 1.3-1.7 mT) at different exposure times (pulsed 6 × 10 min; continuous 1 × 60 min).
The results of our study did not show any negative effect of the generated EMF on either normal cells or tumor cell lines.

https://pubmed.ncbi.nlm.nih.gov/39165679/
Integrating electromagnetic cancer stress with immunotherapy: a therapeutic paradigm 2024
An array of published cell-based and small animal studies have demonstrated a variety of exposures of cancer cells or experimental carcinomas to electromagnetic (EM) wave platforms that are non-ionizing and non-thermal. Overall effects appear to be inhibitory, inducing cancer cell stress or death as well as inhibition in tumor growth in experimental models.
Nevertheless, outputs such as tumor cytotoxicity, apoptosis, tumor membrane electroporation and leak, and reactive oxygen species generation are intriguing. Unlike the use of chemo/radiation and/or targeted therapies in cancer, EM platforms may allow for the survival of tumor-associated immunologic cells, including naïve and sensitized anti-tumor T cells. Moreover, EM-induced cancer cell stress and apoptosis may potentiate endogenous tumor antigen-specific anti-tumor immunity.

https://www.sciencedirect.com/science/article/pii/S0167488919300941
The extremely low frequency electromagnetic stimulation selective for cancer cells elicits growth arrest through a metabolic shift
The efficacy of the very low frequency electromagnetic field in cancer treatment remains elusive due to a lack of explanatory mechanisms for its effect. We developed a novel thermodynamic model that calculates for every cell type the frequency capable of inhibiting proliferation. When this frequency was applied to two human cancer cell lines, it reduced their growth while not affecting healthy cells. The effect was abolished by the inhibition of calcium fluxes.

https://www.researchgate.net/publication/324815806_Electrical_Characterization_of_Normal_and_Cancer_Cells
Electrical Characterization of Normal and Cancer Cells 2018
Empirically, normal cells were observed to exhibit higher dielectric constants when compared to cancer cells from the same tissue.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3609927/
Pulsed Magnetic Field Improves the Transport of Iron Oxide Nanoparticles through Cell Barriers 2013
Understanding how a magnetic field affects the interaction of magnetic nanoparticles (MNPs) with cells is fundamental to any potential downstream applications of MNPs as gene and drug delivery vehicles. Here, we present a quantitative analysis of how a pulsed magnetic field influences the manner in which MNPs interact with, and penetrate across a cell monolayer. Relative to a constant magnetic field, the rate of MNP uptake and transport across cell monolayers was enhanced by a pulsed magnetic field.