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A REVIEW ON THE EFFECT OF EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELD ON BONE HEALING

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Abstract

Extremely low-frequency electromagnetic fields (ELF-EMF) have been studied for their potential effects on bone healing. Bone healing is a complex process involving the regeneration and repair of bone tissue, and the application of ELF-EMF has been explored as a noninvasive and potentially beneficial therapeutic approach. The mechanisms underlying the effects of ELF-EMF on bone healing are not fully understood but may involve cellular stimulation, electrochemical effects, calcium ion signaling, modulation of growth factors and cytokines, and activation of signal transduction pathways. These mechanisms could influence cellular activity, gene expression, and tissue regeneration, potentially enhancing the healing process. Studies investigating the effects of ELF-EMF on bone healing have produced mixed results. Some studies have reported positive effects, such as increased cellular activity, accelerated bone formation, and improved healing outcomes. However, other studies have shown no significant effects or even negative outcomes. The clinical application of ELF-EMF in bone healing has been explored in various contexts, including nonunion fractures, delayed union fractures, orthopedic surgeries, and dental implant procedures. However, the optimal parameters for ELF-EMF therapy and its overall efficacy remain subjects of ongoing research and debate. Factors such as intensity, frequency, waveform, duration of exposure, and individual patient characteristics need to be carefully considered. Further research, including well-designed studies and large-scale clinical trials, is needed to establish clear guidelines and recommendations for the application of ELF-EMF in bone healing. Healthcare professionals should approach the use of ELF-EMF cautiously, taking into account individual patient factors and the current state of evidence.

Overall, while ELF-EMF shows promise as a potential therapeutic modality for bone healing, more research is necessary to fully understand its mechanisms of action, optimize treatment protocols, and determine its clinical effectiveness and safety.

INTRODUCTION

The study of the effects of extremely low electric and magnetic fields (ELF-EMF) on bone healing is a field of research within the broader discipline of bio electromagnetics. It explores the potential influence of these fields on the process of bone repair and regeneration and the interactions between living organisms and electromagnetic fields at various frequencies and intensities. It has been reported that low frequency static, electric and electromagnetic fields had certain biological effects on bone cells. Zhang et. al., (2010) and Aslan et. al., (2012).

Bone healing is a complex biological process that involves a series of cellular and molecular events the regeneration and repair of bone tissue following a fracture or injury. It relies on the coordinated activity of various cellular and molecular mechanisms. It is well-established that various physical and chemical factors play crucial roles in bone healing, including mechanical forces, growth factors, and the local microenvironment. In recent years, there has been increasing interest in understanding the potential effects of ELF-EMF on bone healing.

ELF-EMF refers to electromagnetic fields with frequencies below 300 Hz, which are typically encountered in everyday environments. These fields are generated by various sources, such as power lines, household appliances, and electronic devices. While the biological effects of higher-frequency electromagnetic fields, such as those used in medical imaging (e.g., X-rays), have been extensively studied, the impact of ELF-EMF on biological systems, including bone healing, is still an area of active investigation.

The study of the effects of ELF-EMF on bone healing gained momentum in the 1970s when it was observed that astronauts who spent extended periods in space experienced bone loss and decreased bone healing rates. Since then, numerous laboratory and clinical studies have been conducted to investigate the potential benefits or adverse effects of ELF-EMF on bone healing.

Research in this field has primarily focused on investigating whether ELF-EMF exposure can enhance or inhibit bone healing processes. Some studies have suggested that exposure to specific ELF-EMF parameters may accelerate bone healing and improve fracture repair in both animal models and human subjects. These effects are believed to be mediated through various cellular mechanisms, including increased cell proliferation, enhanced synthesis of extracellular matrix proteins, and modulation of growth factors involved in bone regeneration.

The underlying mechanisms by which ELF-EMF may influence bone healing are still not fully understood. However, several hypotheses have been proposed. One theory suggests that the electromagnetic fields could stimulate bone cells, such as osteoblasts (cells responsible for bone formation) and osteoclasts (cells responsible for bone resorption), promoting their activity and accelerating the healing process. Another hypothesis suggests that ELF-EMF may influence cellular signaling pathways and gene expression, leading to enhanced tissue regeneration.

Research in this field has involved both in vitro experiments, using cell cultures exposed to controlled electromagnetic fields, and in vivo studies, involving animals or human subjects. Various experimental parameters, such as field intensity, frequency, waveform, and exposure duration, have been investigated to determine their influence on bone healing outcomes.

However, it is important to note that the results of studies investigating the effects of ELF-EMF on bone healing have been mixed, with some studies reporting no significant effects or even conflicting results. The lack of consistency in results may be attributed to differences in study designs, variations in experimental conditions, and the complexity of the biological systems involved. The complexity of bone healing, combined with the wide range of ELF-EMF parameters used in different studies, makes it challenging to draw definitive conclusions. There are many local and systemic, positive and negative factors that affect fracture recovery Aslan et al (2014) and Einhorn et al (2015).

Due to the potential implications for clinical applications, further research is needed to better understand the underlying mechanisms and optimize the parameters of ELF-EMF exposure for potential therapeutic use. Additionally, standardization of experimental protocols and rigorous study designs are essential to ensure reliable and reproducible results in this field, the study of the effects of extremely low electric and magnetic fields on bone healing is an area of ongoing research. While some studies suggest potential benefits of ELF-EMF exposure for bone repair, further investigation is necessary to determine the optimal parameters and clarify the underlying mechanisms involved.

LITERATURE REVIEW

Aaron and Ciombor (1996) investigated the effects of electromagnetic fields on bone formation in a rat model. The researchers found that exposure to ELF-EMF enhanced endochondral ossification, the process by which cartilage is replaced by bone, leading to accelerated bone healing.

Pilla et. al., (2002) investigated the effects of low-intensity pulsed ultrasound (LIPUS) on bone healing. LIPUS is a form of biophysical stimulation that involves the use of acoustic waves. The researchers found that LIPUS treatment accelerated fracture healing in rabbits.

Chang K & Chang WH., (2006) their study explores the effects of ELF-EMF exposure on the differentiation of human bone marrow-derived mesenchymal stem cells into chondrocytes (cartilage cells). It provides insights into the potential cellular mechanisms involved in bone healing and tissue regeneration.

Sollazzo et. al., (2007) also investigated the effects of ELF-EMF on human osteoblast-like cells in vitro. The researchers observed an increase in cell proliferation and osteoblastic differentiation in response to ELF-EMF exposure. They concluded that ELF-EMF had a positive effect on bone cell activity

Griffin et. al., (2011) Cochrane systematic review evaluates the efficacy of electromagnetic field stimulation in promoting bone healing in adults with delayed union or nonunion fractures. It provides an analysis of randomized controlled trials and offers insights into the overall effectiveness of ELF-EMF therapy.

Iorio et. al., (2012) clinical study focused on the effects of ELF-EMF in patients with knee osteoarthritis. The results showed that ELF-EMF treatment reduced pain and improved physical function in the study participants, suggesting a positive impact on osteoarthritis-related disability.

Lei et. al., (2018) This in vitro study explores the effects of ELF-EMF on the migration of mesenchymal stem cells, which play a crucial role in bone healing. It investigates the intracellular signaling pathways involved and sheds light on the potential mechanisms underlying the effects of ELF-EMF on cellular behavior.

Ahmet et. al., (2020). aimed to investigate whether 0 Hz-Static and 50 Hz-Electric fields have an effect on bone healing. 45 male Wistar-Albino rats were equally and randomly separated into three groups as follows: a 0 Hz-Static electric field (SEF), a 50-Hz low-frequency electric field (LFEF) and a control group. A manual fracture was performed in the left tibia diaphysis of all rats, and fractures were fixed using circular plaster over the knee. The LFEF group was exposed to 50 Hz electric field for 30 minutes a day, five days a week, for a total of eight weeks. The SEF group was exposed to 0 Hz electric field within the same time interval. The control group was held in identical environmental conditions, without exposure to electric field. Periodic radiographs were taken from all the animals. At the end of this study, rats were sacrificed and mechanical/histopathology examinations were performed. However, no significant difference was found in group comparisons in terms of average histologic and radiologic scores (p>0.05).

• Low-frequency 50 Hz EF has no effect on fracture healing in rat models.

• The results about 0 Hz (Static) field are similar to 50 Hz EF.

PRINCIPLES

The principles underlying the effects of extremely low-frequency electromagnetic fields (ELF-EMF) on bone healing are not fully understood and are still a subject of ongoing research. However, several key principles have emerged from studies conducted in this field. Here are some principles that researchers have proposed to explain the potential effects of ELF-EMF on bone healing.

PIEZOELECTRIC EFFECT

Bone is known to exhibit piezoelectric properties, meaning it can generate electrical charges when subjected to mechanical stress. ELF-EMF may enhance bone healing by stimulating the piezoelectric properties of bone, leading to the generation of electric fields that promote cellular activities involved in bone repair.

CELL SIGNALING AND GENE EXPRESSION

ELF-EMF exposure has been shown to influence various cellular signaling pathways and gene expression related to bone healing. These pathways, such as the mitogen-activated protein kinase (MAPK) pathway and the phosphoinositide 3-kinase (PI3K)/Akt pathway, are responsible for transmitting external signals to the nucleus, regulating gene expression, and controlling cell behavior. Modulation of these pathways by ELF-EMF may mediate the effects on bone healing. It may affect the activation of growth factors, cytokines, and other molecular factors involved in bone formation, remodeling, and repair.

OSTEOBLAST AND OSTEOCLAST ACTIVITY

ELF-EMF exposure has been observed to influence the activity of bone cells, such as osteoblasts (bone-forming cells) and osteoclasts (bone-resorbing cells). It may stimulate osteoblast proliferation, differentiation, and mineralization, and extracellular matrix production. Stimulation of these cells may promote bone formation and remodeling, thereby enhancing the healing process leading to increased bone formation. Additionally, ELF-EMF may modulate osteoclast activity, potentially promoting bone remodeling and regeneration.

CALCIUM ION INFLUX

ELF-EMF exposure has been linked to the modulation of intracellular calcium ion concentrations ELF-EMF exposure has been shown to affect calcium ion influx and efflux from cells.. Calcium ions play a crucial role in various cellular processes, including those involved in bone healing. Changes in calcium ion influx may influence cell migration, proliferation, differentiation, and other cellular activities relevant to bone repair.

BLOOD FLOW AND ANGIOGENESIS

ELF-EMF exposure has been suggested to affect blood flow and angiogenesis (formation of new blood vessels). Adequate blood supply is crucial for delivering oxygen, nutrients, and growth factors necessary for bone healing. By promoting blood flow and angiogenesis, ELF-EMF may support the healing process.

ANTI-INFLAMMATORY EFFECTS

Inflammation is an integral part of the early stages of bone healing, but excessive or prolonged inflammation can impede the healing process. Some studies suggest that ELF-EMF exposure may have anti-inflammatory effects, potentially reducing inflammation and creating a favorable environment for bone repair.

ELECTROCHEMICAL EFFECTS

ELF-EMF can induce electric currents within tissues, including bone. These electric currents may trigger electrochemical reactions, altering ion concentrations and creating localized electrical fields. These changes in electrical properties can affect cellular behavior and signaling, potentially influencing bone healing processes.

GROWTH FACTORS AND CYTOKINES

ELF-EMF exposure has been reported to influence the release and activity of growth factors and cytokines involved in bone healing. These signaling molecules play important roles in regulating cellular activities, angiogenesis (formation of new blood vessels), and tissue regeneration. Modulation of their expression and function by ELF-EMF may contribute to the enhancement of bone healing processes.

It is important to note that the specific effects of ELF-EMF on bone healing may depend on various factors, including the intensity, frequency, waveform, and duration of exposure, as well as the specific stage of bone healing and the cell types involved. The complexity of biological systems and the interplay between different cellular and molecular processes make it challenging to pinpoint definitive principles underlying the effects of ELF-EMF on bone healing. Further research is needed to unravel these mechanisms and optimize the therapeutic application of ELF-EMF in bone healing contexts.

APPLICATIONS

The potential application of the effects of extremely low-frequency electromagnetic fields (ELF-EMF) on bone healing has been explored in various settings. While the research is still ongoing, some potential applications include:

1. **FRACTURE HEALING**

Delayed union or nonunion. Nonunion refers to a situation where the bone fails to heal within the expected timeframe. ELF-EMF stimulation can be applied externally using specialized devices or internally through surgically implanted electrodes on fracture for a specified duration and frequency. The goal is to promote bone healing by stimulating cellular activity, enhancing calcium ion signaling, and modulating the release of growth factors and cytokines.

2. **OSTEOPOROSIS TREATMENT**

Osteoporosis is a condition characterized by decreased bone density and increased fracture risk. ELF-EMF has been investigated as a potential non-pharmacological treatment to mitigate bone loss and promote bone remodeling in individuals with osteoporosis. The aim is to stimulate bone-forming cells, increase bone density, and reduce the risk of fractures.

3. **DENTAL IMPLANT OSSEOINTEGRATION**

ELF-EMF therapy has been explored as a means to enhance the osseointegration process in dental implants. Osseointegration refers to the integration of the implant with the surrounding bone tissue is or the bonding between the implant and the jawbone. ELF-EMF stimulation can be applied to the implant site to promote faster and more secure bone-implant integration, improving the success rate and long-term stability of dental implants

4. **BONE GRAFT HEALING**

Bone grafts are commonly used in orthopedic and dental procedures to assist in the repair and regeneration of bone defects. ELF-EMF therapy has been investigated as a way to enhance the healing and integration of bone grafts. The application of ELF-EMF may accelerate the formation of new bone tissue, improve graft-host integration, and enhance the overall success of the grafting procedure.

5. **ORTHODONTIC TOOTH MOVEMENT**

In orthodontics, ELF-EMF has been explored as a potential method to accelerate tooth movement during orthodontic treatment. By applying ELF-EMF to the teeth or surrounding bone, researchers aim to enhance bone remodeling and cellular activity, potentially reducing treatment time and improving treatment outcomes.

6. **DELAYED UNION FRACTURES**

Delayed union fractures refer to fractures that take longer than usual to heal. ELF-EMF therapy has also been studied in cases of delayed union fractures. Similar to nonunion fractures, external application of ELF-EMF through portable devices is employed to potentially accelerate the healing process.

7. ORTHOPEDIC SURGERIES

ELF-EMF therapy has been explored as an adjunct to orthopedic surgeries, such as spinal fusion or joint replacement. In some cases, ELF-EMF devices may be implanted near the surgical site or incorporated into implantable fixation devices. The goal is to stimulate bone healing at the surgical site, promote integration of implants, and potentially reduce the risk of complications like nonunion or implant loosening.

It is important to note that while there is promising research suggesting potential benefits, the clinical application of ELF-EMF in bone healing is still evolving. Further studies are needed to establish optimal treatment protocols, including determining the appropriate parameters such as field intensity, frequency, waveform, and duration of exposure.

CONCLUSION

In conclusion, the effects of extremely low-frequency electromagnetic fields (ELF-EMF) on bone healing are still an active area of research. While numerous studies have investigated the potential benefits of ELF-EMF on bone healing, the results have been varied and inconclusive. Some studies have reported positive effects, including enhanced cellular activity, accelerated bone formation, and improved healing outcomes. However, other studies have shown no significant effects or even negative outcomes.

The mechanisms through which ELF-EMF may influence bone healing are not fully understood. Proposed mechanisms include cellular stimulation, electrochemical effects, calcium ion signaling, modulation of growth factors and cytokines, and the activation of signal transduction pathways. However, the specific ways in which these mechanisms translate into improved bone healing outcomes are still being elucidated.

The application of ELF-EMF in bone healing has been explored in various clinical scenarios, including nonunion and delayed union fractures, orthopedic surgeries, and dental implant procedures. However, the clinical efficacy and optimal parameters for ELF-EMF therapy remain subjects of ongoing research and debate. Factors such as intensity, frequency, waveform, duration of exposure, and patient characteristics need to be carefully considered to maximize potential benefits and minimize potential risks.

It is important to note that the evidence regarding the effects of ELF-EMF on bone healing is not yet conclusive, and more well-designed studies, including large-scale clinical trials, are needed to establish clear guidelines and recommendations for its application. Healthcare professionals should approach the use of ELF-EMF in bone healing with caution and consider individual patient factors and the current state of evidence when making treatment decisions.

Overall, while ELF-EMF holds promise as a potential therapeutic modality for bone healing, further research is necessary to fully understand its mechanisms, optimize treatment parameters, and determine its clinical efficacy and safety.

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