Osteoporosis – Osteopenia – Bone Healing

J Bone Joint Surg Am

Prevention of osteoporosis by pulsed electromagnetic fields.

Rubin C. et.al. Dep. of Orthopaedics, State University of New York

Using an animal model, we examined the use of pulsed electromagnetic fields, induced at a physiological frequency and intensity, to prevent the osteoporosis that is concomitant with disuse. By protecting the left ulnae of turkeys from functional loading, we noted a loss of bone of 13.0 per cent compared with the intact contralateral control ulnae over an eight-week experimental period. Using a treatment regimen of one hour per day of pulsed electromagnetic fields, we observed an osteogenic dose-response to induced electrical power, with a maximum osteogenic effect between 0.01 and 0.04 tesla per second. Pulse power levels of more or less than these levels were less effective. The maximum osteogenic response was obtained by a decrease in the level of intracortical remodeling, inhibition of endosteal resorption, and stimulation of both periosteal and endosteal new-bone formation. These data suggest that short daily periods of exposure to appropriate electromagnetic fields can beneficially influence the behavior of the cell populations that are responsible for bone-remodeling and that there is an effective window of induced electrical power in which bone mass can be controlled in the absence of mechanical loading.

Journal of Bone and Mineral Metabolism
Publisher: Springer-Verlag Tokyo Inc.
ISSN: 0914-8779 (Paper) 1435-5604 (Online)
DOI: 10.1007/s007740200050
Issue: Volume 20, Number 6
Date: November 2002
Pages: 345 - 349

The preventive effect on bone loss of 50-Hz, 1-mT electromagnetic field in ovariectomized rats

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Abstract. Osteoporosis is a common health problem, especially in the elderly and in women after menopause. Although there are some treatment methods, they impose serious side effects. Recently, the use of an electromagnetic field (EMF) has been a promising candidate for better treatment of osteoporosis. In the present study, we investigated the preventive effects of low-frequency (50 Hz), low-intensity (1 mT), and long-term (6 weeks) EMF on bone loss in ovariectomized rats. We used 18 female albino Wistar rats (8 unexposed and 10 exposed) to assess the effect of EMF. We examined the mineralization and the morphology of the tibia in control and EMF-exposed rats. The cortical thickness of the tibia was increased in EMF-exposed rats ($P < 0.002$). The levels of Na and K in the tibia were significantly increased in rats exposed to EMF ($P < 0.001$; $P < 0.002$, respectively). We also observed an increased blood alkaline phosphatase (ALP) level after EMF exposure ($P < 0.05$). No significant differences in the levels of Ca, Mg, Li, or creatine were found between the exposed and unexposed groups. Our data support the notion that an EMF may prove to be an effective treatment method for osteoporosis and other abnormalities related to bone loss.

Arch Oral Biol. 1993 Jan;38

Autoradiographic study of the effects of pulsed electromagnetic fields on bone and cartilage growth in juvenile rats.

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Application of pulsed electromagnetic fields (PEMF) has been used in growth and repair of non-union bone fractures. The similarities between the fibrocartilage callus in non-union bone fractures and the secondary cartilage in the mandibular condyle, both histologically and functionally, lead naturally to study the effects of PEMFs on growth in the condyle. The purposes of this study were: (1) to describe the effects of PEMFs on the growth of the condyle using autoradiography, [3H]-proline and [3H]-thymidine, and (2) to differentiate between the effects of the magnetic and electrical components of the field. Male pre-adolescent Sprague-Dawley rats (28 days old) were divided into three experimental groups of five animals each: (1) PEMF-magnetic (M), (2) PEMF-electrical (E) and (3) control, and were examined at three different times-3, 7 and 14 days of exposure. Each animal was exposed to the field for 8 h per day. Histological coronal sections were processed for quantitative autoradiography to determine the mitotic activity of the condylar cartilage and the amount of bone deposition. The PEMF (magnetic or electrical) had statistically significant effects only on the thickness of the articular zone, with the thickness in the PEMF-M group being the most reduced. Length of treatment was associated with predictable significant changes in the thickness of the condylar cartilage zones and the amount of bone deposition.(ABSTRACT TRUNCATED AT 250 WORDS)

Int Orthop. 1991;15(4):341-6.

Effects of pulsing electromagnetic fields on cultured cartilage cells.

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In order to evaluate the effects of pulsing electromagnetic fields (PEMFs) on cell proliferation and glycosaminoglycan (GAG) synthesis and to study the action site of PEMF stimulation in the cells, we performed a series of experiments on rabbit costal growth cartilage cells and human articular cartilage cells in culture. A PEMF stimulator was made using a Helmholz coil. Repetitive pulse burst electric currents with a burst width of 76 ms, a pulse width of 230 microseconds and 6.4 Hz were passed through this coil. The magnetic field strength reached 0.4 mT (tesla) on the average. The syntheses of DNA and GAG were measured by 3H-thymidine and 35S-sulfuric acid incorporations. The effects on the cells treated with lidocaine, adriamycin and irradiation were also measured using a colony forming assay. The PEMF stimulation for the duration of 5 days promoted both cell proliferation and GAG synthesis in growth cartilage cells and intermittent stimulation on and off alternatively every 12 h increased them most significantly, while, in articular cartilage cells, the stimulation promoted cell proliferation, but did not enhance GAG synthesis. PEMF stimulation promoted cells treated with lidocaine more significantly than with other agents. These results present evidence that intermittent PEMF stimulation is more effective on both cell proliferation and GAG synthesis of cartilage cells than continuous stimulation, and that the stimulation could exert effects not by nucleus directly, but by the cellular membrane-dependent mechanism. This study provides further basic data to encourage the clinical application of PEMF stimulation on bone and cartilage disorders.

J Bone Miner Res. 1989 Apr;4(2):227-33.

Stimulation of experimental endochondral ossification by low-energy pulsing electromagnetic fields.

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Pulsed electromagnetic fields (PEMFs) of certain configuration have been shown to be effective clinically in promoting the healing of fracture nonunions and are believed to enhance calcification of extracellular matrix. In vitro studies have suggested that PEMFs may also have the effect of modifying the extracellular matrix by promoting the synthesis of matrix molecules. This study examines the effect of one PEMF upon the extracellular matrix and calcification of

endochondral ossification in vivo. The synthesis of cartilage molecules is enhanced by PEMF, and subsequent endochondral calcification is stimulated. Histomorphometric studies indicate that the maturation of bone trabeculae is also promoted by PEMF stimulation. These results indicate that a specific PEMF can change the composition of cartilage extracellular matrix in vivo and raises the possibility that the effects on other processes of endochondral ossification (e.g., fracture healing and growth plates) may occur through a similar mechanism.

Osteoarthritis Cartilage. 2003 Jun;11(6):455-62.

Modification of osteoarthritis by pulsed electromagnetic field--a morphological study.

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OBJECTIVE: Hartley guinea pigs spontaneously develop arthritis that bears morphological, biochemical, and immunohistochemical similarities to human osteoarthritis. It is characterized by the appearance of superficial fibrillation by 12 months of age and severe cartilage lesions and eburnation by 18 months of age. This study examines the effect of treatment with a pulsed electromagnetic field (PEMF) upon the morphological progression of osteoarthritis in this animal model. DESIGN: Hartley guinea pigs were exposed to a specific PEMF for 1h/day for 6 months, beginning at 12 months of age. Control animals were treated identically, but without PEMF exposure. Tibial articular cartilage was examined with histological/histochemical grading of the severity of arthritis, by immunohistochemistry for cartilage neoepitopes, 3B3(-) and BC-13, reflecting enzymatic cleavage of aggrecan, and by immunoreactivity to collagenase (MMP-13) and stromelysin (MMP-3). Immunoreactivity to TGFbeta, interleukin (IL)-1beta, and IL receptor antagonist protein (IRAP) antibodies was examined to suggest possible mechanisms of PEMF activity. RESULTS: PEMF treatment preserves the morphology of articular cartilage and retards the development of osteoarthritic lesions. This observation is supported by a reduction in the cartilage neoepitopes, 3B3(-) and BC-13, and suppression of the matrix-degrading enzymes, collagenase and stromelysin. Cells immunopositive to IL-1 are decreased in number, while IRAP-positive cells are increased in response to treatment. PEMF treatment markedly increases the number of cells immunopositive to TGFbeta. CONCLUSIONS: Treatment with PEMF appears to be disease-modifying in this model of osteoarthritis. Since TGFbeta is believed to upregulate gene expression for aggrecan, downregulate matrix metalloprotease and IL-1 activity, and upregulate inhibitors of matrix metalloprotease, the stimulation of TGFbeta may be a mechanism through which PEMF favorably affects cartilage homeostasis.

Bioelectromagnetics. 2003 Apr;24(3):189-98.

Pulsed electromagnetic fields prevent osteoporosis in an ovariectomized female rat model: a prostaglandin E2-associated process.

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With the use of Helmholtz coils and pulsed electromagnetic field (PEMF) stimulators to generate uniform time varying electromagnetic fields, the effects of extremely low frequency electromagnetic fields on osteoporosis and serum prostaglandin E(2) (PGE(2)) concentration were investigated in bilaterally ovariectomized rats. Thirty-five 3 month old female Sprague-Dawley rats were randomly divided into five different groups: intact (INT), ovariectomy (OVX), aspirin treated (ASP), PEMF stimulation (PEMF + OVX), and PEMF stimulation with aspirin (PEMF + ASP) groups. All rats were subjected to bilateral ovariectomy except those in INT group. Histomorphometric analyses showed that PEMF stimulation augmented and restored proximal tibial metaphyseal trabecular bone mass (increased hard tissue percentage, bone volume percentage, and trabecular number) and architecture (increased trabecular perimeter, trabecular thickness, and decreased trabecular separation) in both PEMF + OVX and PEMF + ASP. Trabecular bone mass of PEMF + OVX rats after PEMF stimulation for 30 days was restored to levels of age matched INT rats. PEMF exposure also attenuated the higher serum PGE(2) concentrations of OVX rats and restored it to levels of INT rats. These experiments demonstrated that extremely low intensity, low frequency, single pulse electromagnetic fields significantly suppressed the trabecular bone loss and restored the trabecular bone structure in bilateral ovariectomized rats. We, therefore, conclude that PEMF may be useful in the prevention of osteoporosis resulting from ovariectomy and that PGE(2) might relate to these preventive effects.

J Bone Miner Res. 1990 May;5(5):437-42.

Bone density changes in osteoporosis-prone women exposed to pulsed electromagnetic fields (PEMFs).

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To determine the effect of a 72 Hz pulsating electromagnetic field (PEMF) on bone density of the radii of osteoporosis-prone women, the nondominant forearms of 20 subjects were exposed to PEMF 10 h daily for a period of 12 weeks. Bone density before, during, and after the exposure period was determined by use of a Norland-Cameron bone mineral analyzer. Bone mineral densities of the treated radii measured by single-photon

densitometry increased significantly in the immediate area of the field during the exposure period and decreased during the following 36 weeks. A similar but weaker response occurred in the opposite arm, suggesting a "cross-talk" effect on the nontreated radii, from either possible arm proximity during sleep or very weak general field effects. The data suggest that properly applied PEMFs, if scaled for whole-body use, may have clinical application in the prevention and treatment of osteoporosis.

J Bone Joint Surg Am. 1989 Mar;71(3):411-7.

Prevention of osteoporosis by pulsed electromagnetic fields.

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Using an animal model, we examined the use of pulsed electromagnetic fields, induced at a physiological frequency and intensity, to prevent the osteoporosis that is concomitant with disuse. By protecting the left ulnae of turkeys from functional loading, we noted a loss of bone of 13.0 per cent compared with the intact contralateral control ulnae over an eight-week experimental period. Using a treatment regimen of one hour per day of pulsed electromagnetic fields, we observed an osteogenic dose-response to induced electrical power, with a maximum osteogenic effect between 0.01 and 0.04 tesla per second. Pulse power levels of more or less than these levels were less effective. The maximum osteogenic response was obtained by a decrease in the level of intracortical remodeling, inhibition of endosteal resorption, and stimulation of both periosteal and endosteal new-bone formation. These data suggest that short daily periods of exposure to appropriate electromagnetic fields can beneficially influence the behavior of the cell populations that are responsible for bone-remodeling, and that there is an effective window of induced electrical power in which bone mass can be controlled in the absence of mechanical loading.

Wiad Lek. 2003;56(9-10):434-41.

[Application of variable magnetic fields in medicine--15 years experience]

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The results of 15-year own experimental and clinical research on application of variable magnetic fields in medicine were presented. In experimental studies analgesic effect (related to endogenous opioid system and nitrogen oxide activity) and regenerative effect of variable magnetic fields with therapeutical parameters was observed. The influence of this fields on enzymatic and hormonal activity, free oxygen radicals, carbohydrates, protein and lipid metabolism, dielectric and rheological properties of blood as well as behavioural reactions and activity of central dopamine receptor in experimental animals

was proved. In clinical studies high therapeutic efficacy of magnetotherapy and magnetostimulation in the treatment of osteoarthrosis, abnormal ossification, osteoporosis, nasosinusitis, multiple sclerosis, Parkinson's disease, spastic paresis, diabetic polyneuropathy and retinopathy, vegetative neurosis, peptic ulcers, colon irritable and trophic ulcers was confirmed.

J Orthop Res. 2005 Jun 2; [Epub ahead of print]

Pulsed electromagnetic field treatments enhance the healing of fibular osteotomies.

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This study tested the hypothesis that pulsed electromagnetic field (PEMF) treatments augment and accelerate the healing of bone trauma. It utilized micro-computed tomography imaging of live rats that had received bilateral 0.2mm fibular osteotomies (approximately 0.5% acute bone loss) as a means to assess the in vivo rate dynamics of hard callus formation and overall callus volume. Starting 5days post-surgery, osteotomized right hind limbs were exposed 3h daily to PEMF, 7days a week for up to 5weeks of treatment. The contralateral hind limbs served as sham-treated, within-animal internal controls. Although both PEMF- and sham-treatment groups exhibited similar onset of hard callus at approximately 9days after surgery, a 2-fold faster rate of hard callus formation was observed thereafter in PEMF-treated limbs, yielding a 2-fold increase in callus volume by 13-20days after surgery. The quantity of the new woven bone tissue within the osteotomy sites was significantly better in PEMF-treated versus sham-treated fibulae as assessed via hard tissue histology. The apparent modulus of each callus was assessed via a cantilever bend test and indicated a 2-fold increase in callus stiffness in the PEMF-treated over sham-treated fibulae. PEMF-treated fibulae exhibited an apparent modulus at the end of 5-weeks that was approximately 80% that of unoperated fibulae. Overall, these data indicate that PEMF treatment improved osteotomy repair.

J Orthop Res. 2005 May 20; [Epub ahead of print]

Pulsed electromagnetic fields stimulation affects osteoclast formation by modulation of osteoprotegerin, RANK ligand and macrophage colony-stimulating factor.

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Electromagnetic stimulation has been documented to treat recalcitrant problems of musculoskeletal system. Yet, the underlying mechanisms are not completely understood. In this study, we investigated effect of pulsed electromagnetic fields (PEMF) with parameters modified from clinical bone growth stimulator on osteoclast formation, bone resorption, and cytokines associated with osteoclastogenesis. Marrow cells were harvested from both femora and tibiae of 6 week-old mice and cultured in 8-well chamber slides or 16-well calcium phosphate apatite-coated multitest slides. After 1-day incubation, marrow cells were exposed to PEMF at different electric field intensities for 2h/day and continued for 9 days. Osteoprotegerin (OPG), receptor activator of NFkappaB-ligand (RANKL) and macrophage colony-stimulating factor (M-CSF) concentrations of each group were determined after PEMF stimulation. Osteoclast identity was confirmed by both tartrate resistant acid phosphatase (TRAP) stain and bone resorption assay. A statistically significant increase and decrease of osteoclastogenesis and bone resorption areas were found when exposed to PEMF with different intensities. Besides, consistent correlations among OPG, RANKL, M-CSF, osteoclast numbers, and bone resorption after exposure to different intensities of PEMF were observed. These data demonstrated that PEMF with different intensities could regulate osteoclastogenesis, bone resorption, OPG, RANKL, and M-CSF concentrations in marrow culture system.

Int J Artif Organs. 2004 Aug;27(8):681-90.

Current trends in the enhancement of biomaterial osteointegration: biophysical stimulation.

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To enhance bone implant osteointegration, many strategies for improving biomaterial properties have been developed which include optimization of implant material, implant design, surface morphology and osteogenetic coatings. Other methods that have been attempted to enhance endogenous bone healing around biomaterials are different forms of biophysical stimulations such as pulsed electromagnetic fields (PEMFs) and low intensity pulsed ultrasounds (LIPUS), which were initially developed to accelerate fracture healing. To aid in the use of adjuvant biophysical therapies in the management of bone-

implant osteointegration, the present authors reviewed experimental and clinical studies published in the literature over the last 20 years on the combined use of biomaterials and PEMFs or LIPUS, and summarized the methodology, and the possible mechanism of action and effectiveness of the different biophysical stimulations for the enhancement of bone healing processes around bone implanted biomaterials.

Int J Low Extrem Wounds. 2002 Sep;1(3):152-60.

Electromagnetic fields for bone healing.

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Electrical stimulation has been applied in a number of different ways to influence tissue healing. Most of the early work was carried out by orthopedic surgeons looking for new ways of enhancing fracture healing, particularly those fractures that had developed into nonunions. Electrical energy can be supplied to a fracture by direct application of electrodes or inducing current by use of pulsed electromagnetic field or capacitive coupling. Many of these techniques have not been standardized, so interpretation of the literature can be difficult and misleading. Despite this, there have been a few good laboratory and clinical studies to investigate the effect of electrical stimulation on fracture healing, which are reviewed. These do not permit recommendation or rejection of the technique per se; however, there is some room for optimism. The authors present some of the guidelines for using this treatment modality but suggest that all treatment should be carried out as part of a clinical trial in order to generate reliable data.

J Foot Ankle Surg. 2004 Mar-Apr;43(2):93-6.

The effect of pulsed electromagnetic fields on hindfoot arthrodesis: a prospective study.

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The aim of this study was to evaluate the effect of pulsed electromagnetic fields in a consecutive series of 64 patients undergoing hindfoot arthrodesis (144 joints). All patients who underwent elective triple/subtalar arthrodesis were randomized into control and pulsed electromagnetic field study groups. Subjects in the study group had an external pulsed electromagnetic fields device applied over the cast for 12 hours a day. Radiographs were taken pre- and postoperatively until radiographic union occurred. A senior musculoskeletal radiologist, blinded to the treatment scheme, evaluated the radiographic parameters. The average time to radiographic union in the control group was 14.5 weeks in 33 primary subtalar arthrodeses. There were 4 nonunions. The study group consisted of 22 primary subtalar arthrodeses and 5 revisions. The average time to radiographic union was 12.9 weeks (P =.136). The average time to fusion of the talonavicular joint in the control group was 17.6 weeks in 19 primary procedures. In the pulsed electromagnetic fields group of 20 primary and 3 revision talonavicular arthrodeses, the average time to radiographic fusion was 12.2 weeks (P =.003). For the 21 calcaneocuboid arthrodeses in control group, the average time to radiographic fusion was 17.7 weeks; it was 13.1 weeks (P =.010) for the 19 fusions in the study group. This study suggests that, if all parameters are equal, the adjunctive use of a pulsed electromagnetic field in elective hindfoot arthrodesis may increase the rate and speed of radiographic union of these joints.

Am J Orthop. 2004 Jan;33(1):27-30.

Pseudarthrosis after lumbar spine fusion: nonoperative salvage with pulsed electromagnetic fields.

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We studied 100 patients in whom symptomatic pseudarthrosis had been established at more than 9 months after lumbar spine fusion. All patients were treated with a pulsed electromagnetic field device worn consistently 2 hours a day for at least 90 days. Solid fusion was achieved in 67% of patients. Effectiveness was not statistically significantly different for patients with risk factors such as smoking, use of allograft, absence of fixation, or multilevel fusions. Treatment was equally effective for posterolateral fusions (66%) as with interbody fusions (69%). For patients with symptomatic pseudarthrosis after lumbar spine fusion, pulsed electromagnetic field stimulation is an effective nonoperative salvage approach to achieving fusion.

J Am Acad Orthop Surg. 2003 Sep-Oct;11(5):344-54.

Use of physical forces in bone healing.

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During the past two decades, a number of physical modalities have been approved for the management of nonunions and delayed unions. Implantable direct current stimulation is effective in managing established nonunions of the extremities and as an adjuvant in achieving spinal fusion. Pulsed electromagnetic fields and capacitive coupling induce fields through the soft tissue, resulting in low-magnitude voltage and currents at the fracture site. Pulsed electromagnetic fields may be as effective as surgery in managing extremity nonunions. Capacitive coupling appears to be effective both in extremity nonunions and lumbar fusions. Low-intensity ultrasound has been used to speed normal fracture healing and manage delayed unions. It has recently been approved for the management of nonunions. Despite the different mechanisms for stimulating bone healing, all signals result in increased intracellular calcium, thereby leading to bone formation.

J Pediatr Orthop. 2003 Jul-Aug;23(4):478-83.

Effects of pulsed electromagnetic field stimulation on distraction osteogenesis in the rabbit tibial leg lengthening model.

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The purpose of this study was to determine whether exposure to pulsed electromagnetic field (PEMF) would shorten the healing time of regenerate bone in a rabbit tibial distraction model. Beginning 1 day after surgery, mid-shaft tibial osteotomies, stabilized with external fixators, were distracted 0.25 mm twice daily for 21 days and received either no exposure (sham control) or 1 hour per day exposure to low-amplitude, low-frequency PEMF. Tibiae were tested for torsional strength after 9, 16, and 23 days post-distraction. PEMF-treated tibiae were significantly stronger than shams at all three time points. By 16 days post-distraction, the PEMF group had achieved biomechanical strength essentially equivalent to intact bone. Shams did not achieve normal biomechanical strength even after 23 days post-distraction. In this tibial distraction model, short daily PEMF exposures accelerated consolidation of regenerate bone. Clinical usefulness awaits testing.

Int J Adult Orthodon Orthognath Surg. 1997;12(1):43-53.

Effects of static magnetic and pulsed electromagnetic fields on bone healing.

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The purpose of the present study was to evaluate the healing pattern of an experimentally induced osteotomy in Hartley guinea pigs in the presence of static magnetic and pulsed electromagnetic fields. The sample consisted of 30 Hartley guinea pigs 2 weeks of age divided into 3 groups: pulsed electromagnetic, static magnetic, and control. An osteotomy was performed in the mandibular postgonial area in all groups under general anesthesia. During the experimental period of 9 days, the animals were kept in experiment cages 8 hours per day, the first two groups being in the presence of pulsed electromagnetic and static magnetic field, respectively. Based on histologic results, both static and pulsed electromagnetic fields seemed to accelerate the rate of bone repair when compared to the control group. The osteotomy sites in the control animals consisted of connective tissue, while new bone had filled the osteotomy areas in both magnetic field groups.

How can pulsed electromagnetic field therapy assist in the healing of bones and ligaments?

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Bone is essentially calcium structure which contains trace elements. One particular element recently identified is Alpha Quartz. This is the same type of material used in computers and digital or electronic watches. When this material is compressed, it develops a voltage across its two compressive faces, a phenomenon known as the piezoelectric effect. The old crystal pickups on record players used this effect to generate electrical sound signals. Gas appliances and some cigar lighters also utilize the same effect to generate a spark for ignition.

In bone, areas of stress generate small electric charges which are greater than those of less stressed areas, so that polarized bone-laying cells (osteoblasts) are believed to be attracted to these areas and begin to build up extra bone material to counter the stress.

With bone injuries, bleeding occurs to form a haematoma in which capillaries quickly form, transporting enriched blood to the injury site. Pulsed Magnetic Field therapy of a base frequency of 50Hz, pulsed at above 12Hz, causes vasodilatation and capillary dilatation, so helping to speed up the process of callus formation. Within the bone itself, pulsed electromagnetism causes the induction of small eddy currents in the trace elements, which in turn purify and strengthen the crystal structures. These have the same effect as the stress-induced voltages caused by the alpha quartz and as such, attract bone cells to the area under treatment. This can, therefore, accelerate the bone healing process to allow earlier mobilization and eventual full union. Ligaments and tendons are affected in similar ways to solid bone by pulsed electromagnetic therapy, since they are uncalcified bone structures in themselves.

J Bone Joint Surg Am

The effect of low-frequency electrical fields on osteogenesis.

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An in vivo animal model of disuse osteopenia was used to determine the osteogenic potential of specific components of electrical fields. The ability of a complex pulsed electrical field to inhibit loss of bone was compared with the remodeling response generated by extremely low-power, low-frequency (fifteen, seventy-five, and 150-hertz) sinusoidal electrical fields. The left ulnae of thirty adult male turkeys were functionally isolated by creation of distal and proximal epiphyseal osteotomies and then were exposed, for one hour each day, to an electrical field that had been induced exogenously by means of magnetic induction. After a fifty-six-day protocol, the remodeling response was quantified by a comparison of the cross-sectional area of the mid-part of the diaphysis of the functionally isolated ulna with that of the intact contralateral ulna. Disuse resulted in a 13 per cent mean loss of osseous tissue, which was not significantly different than the 10 per cent loss that was caused by disuse treated with inactive coils. Exposure to the pulsed electrical fields prevented this osteopenia and stimulated a 10 per cent mean increase in the bone area. The osteogenic influence of the sinusoidal electrical fields was strongly dependent on the frequency; the 150, seventy-five, and fifteen-hertz sinusoidal fields, respectively, generated a -3 per cent, + 5 per cent, and + 20 per cent mean change in the bone area. These results suggest a tissue sensitivity that is specific to very low-frequency sinusoidal electrical fields and they imply that the induced electrical fields need not have complex waveforms to be osteogenic. Since the frequency and intensity range of the sinusoidal fields producing the greatest osteogenic response are similar to the levels produced intrinsically by normal functional activity, these results support the hypothesis that electricity plays a role in the retention of the normal remodeling balance within mature bone.

Med Biol Eng Comput. 1991 Mar;29(2):113-20.

Comparative study of bone growth by pulsed electromagnetic fields.

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Pulsed electromagnetic fields have been widely used for treatment of non-united fractures and congenital pseudarthrosis. Several electrical stimulation systems such as air-cored and iron-cored coils and solenoids have been used the world over and claimed to be effective. Electrical parameters such as pulse shape, magnitude and frequency differ widely, and the exact bone-healing mechanism is still not clearly understood. The study attempts to analytically investigate the effectiveness of various parameters and suggests an optimal stimulation waveform. Mathematical analysis of electric fields inside the bone together with Fourier analysis of induced voltage waveforms produced by commonly used electrical stimulation wave-forms has been performed. A hypothesis based on assigning different weightings to different frequencies for osteogenic response has been proposed. Using this hypothesis astonishingly similar effective values of electric fields have been found in different systems. It is shown that effective electric field rather than peak electric field is the main parameter responsible for osteogenesis. The results are in agreement with experimental findings made on human beings by different investigators.

Vestn Khir Im I I Grek. 1989 Feb;142(2):63-6.

Rehabilitation treatment of patients with uncomplicated fractures of the spine at a hospital rehabilitation center

Bagaturiia GO et. Al..

The authors make an analysis of treatment of 188 patients with noncomplicated compressive fractures of the vertebral column in the thoracolumbar part performed at the stationary rehabilitation center. The course of restorative treatment was as long as 31-40 days and included individual and group trainings of exercise therapy, massage, hydrokinesotherapy, thermo-, electro-, photo- and magnetotherapy. Results of the treatment were followed in 81 patients. Excellent and good results were obtained in 43 patients (53%), unsatisfactory--in 7 patients (8.6%). The period of follow-up observation was from 1 month to 1 year.

Crit Rev Biomed Eng. 1989;17(5):451-529.

Fundamental and practical aspects of therapeutic uses of pulsed electromagnetic fields (PEMFs).

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The beneficial therapeutic effects of selected low-energy, time-varying magnetic fields, called PEMFs, have been documented with increasing frequency since 1973. Initially, this form of athermal energy was used mainly as a salvage for patients with long-standing juvenile and adult nonunions. Many of these individuals were candidates for amputation. Their clearly documented resistance to the usual forms of surgical treatment, including bone grafting, served as a reasonable control in judging the efficacy of this new therapeutic method, particularly when PEMFs were the sole change in patient management. More recently, the biological effectiveness of this approach in augmenting bone healing has been confirmed by several highly significant double-blind and controlled prospective studies in less challenging clinical circumstances. Furthermore, double-blind evidence of therapeutic effects in other clinical disorders has emerged. These data, coupled with well-controlled laboratory findings on pertinent mechanisms of action, have begun to place PEMFs on a therapeutic par with surgically invasive methods but at considerably less risk and cost. As a result of these clinical observations and concerns about electromagnetic "pollution", interactions of nonionizing electromagnetic fields with biological processes have been the subject of increasing investigational activity. Over the past decade, the number of publications on these topics has risen exponentially. They now include textbooks, speciality journals, regular reviews by government agencies, in addition to individual articles, appearing in the wide spectrum of peer-reviewed, scientific sources. In a recent editorial in Current Contents, the editor reviews the frontiers of biomedical engineering focusing on Science Citation Index methods for identifying core research endeavors. Dr. Garfield chose PEMFs from among other biomedical engineering efforts as an example of a rapidly emerging discipline. Three new societies in the bioelectromagnetics, bioelectrochemistry, and bioelectrical growth and repair have been organized during this time, along with a number of national and international committees and conferences. These activities augment a continuing interest by the IEEE in the U.S. and the IEE in the U.K. This review focuses on the principles and practice behind the therapeutic use of "PEMFs". This term is restricted to time-varying magnetic field characteristics that induce voltage waveform patterns in bone similar to those resulting from mechanical deformation. These asymmetric, broad-band pulses affect a number of biologic processes athermally. Many of these processes appear to have the ability to modify selected pathologic states in the musculoskeletal and other systems. (ABSTRACT TRUNCATED AT 400 WORDS)

Spine. 1990 Jul;15(7):708-12.

A randomized double-blind prospective study of the efficacy of pulsed electromagnetic fields for interbody lumbar fusions.

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A randomized double-blind prospective study of pulsed electromagnetic fields for lumbar interbody fusions was performed on 195 subjects. There were 98 subjects in the active group and 97 subjects in the placebo group. A brace containing equipment to induce an electromagnetic field was applied to patients undergoing interbody fusion in the active group, and a sham brace was used in the control group. In the active group there was a 92% success rate, while the control group had a 65% success rate (P greater than 0.005). The effectiveness of bone graft stimulation with the device is thus established.

J Cell Biochem. 1993 Apr;51(4):387-93.

Beneficial effects of electromagnetic fields.

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Selective control of cell function by applying specifically configured, weak, time-varying magnetic fields has added a new, exciting dimension to biology and medicine. Field parameters for therapeutic, pulsed electromagnetic field (PEMFs) were designed to induce voltages similar to those produced, normally, during dynamic mechanical deformation of connective tissues. As a result, a wide variety of challenging musculoskeletal disorders have been treated successfully over the past two decades. More than a quarter million patients with chronically ununited fractures have benefitted, worldwide, from this surgically non-invasive method, without risk, discomfort, or the high costs of operative repair. Many of the

athermal bioresponses, at the cellular and subcellular levels, have been identified and found appropriate to correct or modify the pathologic processes for which PEMFs have been used. Not only is efficacy supported by these basic studies but by a number of double-blind trials. As understanding of mechanisms expands, specific requirements for field energetics are being defined and the range of treatable ills broadened. These include nerve regeneration, wound healing, graft behavior, diabetes, and myocardial and cerebral ischemia (heart attack and stroke), among other conditions. Preliminary data even suggest possible benefits in controlling malignancy.