

## Scientific Articles and Abstracts

A wealth of articles on Pulsing Electromagnetic Field therapy (PEMF) technology is available. Following is a selection of abstracts, articles and references on PEMF. This information has been collected to indicate the benefits on the use of pulsing electromagnetic field therapy and many are double blind, placebo controlled studies.

The Effect of Pulsed Electromagnetic Fields in the Treatment of Osteoarthritis of the Knee and Cervical Spine. Report of Randomized, Double-Blind, Placebo Controlled Trials.

Low-amplitude, extremely low frequency magnetic fields for the treatment of osteoarthritic knees. A double-blind clinical study.

Pulsed Electromagnetic Field Therapy, PEMT. How does it work?

Magnetic pulse treatment for knee osteoarthritis: a randomised, double-blind, placebo-controlled study.

Electrochemical therapy of pelvic pain: effects of pulsed electromagnetic fields (PEMF) on tissue trauma.

Evaluation of electromagnetic fields in the treatment of pain in patients with lumbar radiculopathy or whiplash syndrome.

We assessed the efficacy and tolerability of low-frequency pulsed electromagnetic fields (PEMF) therapy in patients with clinically symptomatic knee osteoarthritis (OA) in a randomised, placebo-controlled, double-blind study of six weeks' duration.

Pulsed magnetic field therapy and the physiotherapist

Treatment of migraine with pulsing electromagnetic fields: a double-blind, placebo-controlled study.

## **The Effect of Pulsed Electromagnetic Fields in the Treatment of Osteoarthritis of the Knee and Cervical Spine. Report of Randomized, Double-Blind, Placebo Controlled Trials**

**OBJECTIVE.** We conducted a randomized, double blind clinical trial to determine the effectiveness of pulsed electromagnetic fields (PEMF) in the treatment of osteoarthritis (OA) of the knee and cervical spine. **METHODS.** A controlled trial of 18 half-hour active or placebo treatments was conducted in 86 patients with OA of the knee and 81 patients with OA of the cervical spine, in which pain was evaluated using a 10 cm visual analog scale, activities of daily living using a series of questions (answered by the patient as never, sometimes, most of the time, or always), pain on passive motion (recorded as none, slight, moderate, or severe), and joint tenderness (recorded using a modified Ritchie scale). Global evaluations of improvement were made by the patient and examining physician. Evaluations were made at baseline, midway, end of treatment, and one month after completion of treatment.

**RESULTS.** Matched pair t tests showed extremely significant changes from baseline for the treated patients in both knee and cervical spine studies at the end of treatment and the one month follow-up observations, whereas the changes in the placebo patients showed lesser degrees of significance at the end of treatment, and had lost significance for most variables at the one month follow-up. Means of the treated group of patients with OA of the knee showed greater improvement from baseline values than the placebo group by the end of treatment and at the one month follow-up observation. Using the 2-tailed t test, at the end of treatment the differences in the means of the 2 groups reached statistical significance for pain, pain on motion, and both the patient overall assessment and the physician global assessment. The means of the treated patients with OA of the cervical spine

showed greater improvement from baseline than the placebo group for most variables at the end of treatment and one month follow-up observations; these differences reached statistical significance at one or more observation points for pain, pain on motion, and tenderness.

CONCLUSION. PEMF has therapeutic benefit in painful OA of the knee or cervical spine.

Trock D. et.al. Department of Medicine, Danbury Hospital, CT. J. of Rheumatology

### **Low-amplitude, extremely low frequency magnetic fields for the treatment of osteoarthritic knees: a double-blind clinical study.**

CONTEXT: Non-invasive magneto-therapeutic approaches to bone healing have been successful in past clinical studies. OBJECTIVE: To determine the effectiveness of low-amplitude, extremely low frequency magnetic fields on patients with knee pain due to osteoarthritis. DESIGN: Placebo-controlled, randomized, double-blind clinical study. SETTING: 4 outpatient clinics. PARTICIPANTS: 176 patients were randomly assigned to 1 of 2 groups, the placebo group (magnet off) or the active group (magnet on). INTERVENTION: 6-minute exposure to each magnetic field signal using 8 exposure sessions for each treatment session, the number of treatment sessions totalling 8 during a 2-week period, yielded patients being exposed to uniform magnetic fields for 48 minutes per treatment session 8 times in 2 weeks. The magnetic fields used in this study were generated by a resonator, which consists of two 18-inch diameter (46-cm diameter) coils connected in series, in turn connected to a function generator via an attenuator to obtain the specific amplitude and frequency. The range of magnetic field amplitudes used was from  $2.74 \times 10^{-7}$  to  $3.4 \times 10^{-8}$  G, with corresponding frequencies of 7.7 to 0.976 Hz. OUTCOME MEASURES: Each subject rated his or her pain level from 1 (minimal) to 10 (maximal) before and after each treatment and 2 weeks after treatment. Subjects also recorded their pain intensity in a diary while outside the treatment environment for 2 weeks after the last treatment session (session 8) twice daily: upon awakening (within 15 minutes) and upon retiring (just before going to bed at night). RESULTS: Reduction in pain after a treatment session was significantly ( $P < .001$ ) greater in the magnet-on group (46%) compared to the magnet-off group (8%). CONCLUSION: Low-amplitude, extremely low frequency magnetic fields are safe and effective for treating patients with chronic knee pain due to osteoarthritis.

Jacobson J. et.al. Inst. for Biophysical Research, Jupiter, FL, USA

### **Pulsed Electromagnetic Field Therapy, PEMT. How does it work?**

All living cells within the body possess potentials between the inner and outer membrane of the cell, which, under normal healthy circumstances, are fixed. Different cells, e.g. Muscle cells and Nerve cells, have different potentials of about -70 mV respectively. When cells are damaged, these potentials change such that the balance across the membrane changes, causing the attraction of positive sodium ions into the cell and negative trace elements and proteins out of the cell. The net result is that liquid is attracted into the interstitial area and swelling or oedema ensues. The application of pulsed magnetic fields has, through research findings, been shown to help the body to restore normal potentials at an accelerated rate, thus aiding the healing of most wounds and reducing swelling faster. The most effective frequencies found by researchers so far, are very low frequency pulses of a 50Hz base. These, if gradually increased to 25 pulses per second for time periods of 600 seconds (10 minutes), condition the damaged tissue to aid the natural healing process.

Pain reduction is another area in which pulsed electromagnetic therapy has been shown to be very effective. Pain signals are transmitted along nerve cells to pre-synaptic terminals. At these terminals, channels in the cell alter due to a movement of ions. The membrane potential changes, causing the release of a chemical transmitter from a synaptic vesicle contained within the membrane. The pain signal is chemically transferred across the synaptic gap to chemical receptors on the post-synaptic nerve cell. This all happens in about 1/2000th of a second, as the synaptic gap is only 20 to 50 nm wide. As the pain signal, in chemical form, approaches the post-synaptic cell, the membrane changes and the signal is transferred. If we look at the voltages across the synaptic membrane then, under no pain conditions, the level is about -70 mV. When the pain signal approaches, the membrane potential

increases to approximately +30 mV, allowing a sodium flow. This in turn triggers the synaptic vesicle to release the chemical transmitter and so transfer the pain signal across the synaptic gap or cleft. After the transmission, the voltage reduces back to its normal quiescent level until the next pain signal arrives.

The application of pulsed magnetism to painful sites causes the membrane to be lowered to a hyper-polarization level of about -90 mV. When a pain signal is detected, the voltage must now be raised to a relatively higher level in order to fire the synaptic vesicles. Since the average change of potential required to reach the trigger voltage of nearly +30 mV is +100 mV, the required change is too great and only +10 mV is attained. This voltage is generally too low to cause the synaptic vesicle to release the chemical transmitter and hence the pain signal is blocked. The most effective frequencies that have been observed from research in order to cause the above changes to membrane potentials, are a base frequency of around 100Hz and pulse rate settings of between 5 and 25Hz.  
Lecture abstract Dr. D. Laycock, Ph.D. Med. Eng. MBES, MIPEM, B.Ed.

### **Magnetic pulse treatment for knee osteoarthritis: a randomised, double-blind, placebo-controlled study.**

We assessed the efficacy and tolerability of low-frequency pulsed electromagnetic fields (PEMF) therapy in patients with clinically symptomatic knee osteoarthritis (OA) in a randomised, placebo-controlled, double-blind study of six weeks' duration. While the treated group demonstrated improvement over different indices to the contrary, the control group demonstrated none. There were no clinically relevant adverse effects attributable to active treatment. These results suggest that the unipolar magnetic devices are beneficial in reducing pain and disability in patients with knee OA resistant to conventional treatment in the absence of significant side effects.  
Pipitone N. et.al. Rheumatology Department, King's College Hospital (Dulwich), London, UK.

### **Electrochemical therapy of pelvic pain: effects of pulsed electromagnetic fields (PEMF) on tissue trauma.**

Unusually effective and long-lasting relief of pelvic pain of gynaecological origin has been obtained consistently by short exposures of affected areas to the application of a magnetic induction device. Treatments are short, fast-acting, economical and in many instances have obviated surgery. This report describes typical cases such as dysmenorrhoea, endometriosis, ruptured ovarian cyst, acute lower urinary tract infection, post-operative haematoma, and persistent dyspareunia in which pulsed magnetic field treatment has not, in most cases, been supplemented by analgesic medication. Of 17 female patients presenting with a total of 20 episodes of pelvic pain, 16 patients representing 18 episodes (90%) experienced marked, even dramatic relief, while two patients representing two episodes reported less than complete pain.  
Jorgensen W. et.al. International Pain Research Institute, Los Angeles, California.

### **Evaluation of electromagnetic fields in the treatment of pain in patients with lumbar radiculopathy or whiplash syndrome.**

Back pain and whiplash syndrome are very common diseases involving tremendous costs and extensive medical effort. A quick and effective reduction of symptoms, especially pain, is required. In two prospective randomized studies, patients with either lumbar radiculopathy in the segments L5/S1 or whiplash syndrome were investigated. Electromagnetic devices are pulsed field (PEMF) and constant wave (CW) types. These studies indicate both are effective, PEMF usually more quickly than CW. Pulsed magnetic fields appear to have a considerable and statistically significant potential for reducing pain in cases of lumbar radiculopathy and whiplash syndrome.  
Thuile Ch. et.al. International Society of Energy Medicine, Vienna, Austria.

### **We assessed the efficacy and tolerability of low-frequency pulsed electromagnetic fields (PEMF) therapy in**

## **patients with clinically symptomatic knee osteoarthritis (OA) in a randomised, placebo-controlled, double-blind study of six weeks' duration.**

Patients with radiographic evidence and symptoms of OA (incompletely relieved by conventional treatments), according to the criteria of the American College of Rheumatology, were recruited from a single tertiary referral centre. 75 Patients fulfilling the above criteria were randomised to receive active PEMF treatment by unipolar magnetic devices or placebo. Six patients failed to attend after the screening and were excluded from analysis. The primary outcome measure was reduction in overall pain assessed on a four-point Likert scale ranging from nil to severe. Secondary outcome measures included the WOMAC Osteoarthritis Index (Likert scale) and the EuroQol (Euro-Quality of Life, EQ-5D). Baseline assessments showed that the treatment groups were equally matched. Although there were no significant differences between active and sham treatment groups in respect of any outcome measure after treatment, paired analysis of the follow-up observations on each patient showed significant improvements in the actively treated group in the WOMAC global score ( $p = 0.018$ ), WOMAC pain score ( $p = 0.065$ ), WOMAC disability score ( $p = 0.019$ ) and EuroQol score ( $p = 0.001$ ) at study end compared to baseline. In contrast, there were no improvements in any variable in the placebo-treated group. There were no clinically relevant adverse effects attributable to active treatment. These results suggest that PEMF magnetic devices are beneficial in reducing pain and disability in patients with knee OA resistant to conventional treatment in the absence of significant side-effects. Further studies using different types of magnetic devices, treatment protocols and patient populations are warranted to confirm the general efficacy of PEMF therapy in OA and other conditions.

Nicolò Pipitone, David L. Scott

## **Pulsed magnetic field therapy and the physiotherapist**

The therapeutic effect of the application of pulsed magnetic field therapy (PMFT) has at last received world-wide recognition, although for a long time many practitioners saw it only as an aid to fracture union. Research has now shown that it has the potential to improve a wide range of conditions, although few understood just how it achieved its effectiveness. Extensive research has since been carried out to determine the mechanism by which this occurs. For the physiotherapist, presented with a wide range of clinical problems, PMFT is an invaluable aid to the clinic.

Resolution of soft tissue injuries:

Over the past few years, research has shown that its effectiveness is not through heat production - as is the case with some modern treatments - but is at the cellular level. One significant outcome of this is the effect it has on soft tissue injuries. As early as 1940 it was suggested that magnetic fields might influence membrane permeability. It has since been established that magnetic fields can influence ATP (Adenosine Tri-phosphate) production; increase the supply of oxygen and nutrients via the vascular system; improve the removal of waste via the lymphatic system; and help to re-balance the distribution of ions across the cell membrane. Healthy cells in tissue have a membrane potential difference between the inner and outer membrane. This causes a steady flow of ions through its pores. In a damaged cell the potential is raised and an increased and an increased sodium inflow occurs. As a result, interstitial fluid is attracted to the area, resulting in swelling and oedema. The application of PMFT to damaged cells accelerates the re-establishment of normal potentials (Sansaverino) increasing the rate of healing and reducing swelling. This can help to disperse bruising also. A magnetic field pulsed at 5Hz with a base frequency of 50Hz can have the same effect as an ice pack in that in that it causes vasoconstriction.

Effects on fracture repair:

Acceptance of magnetic fields in medicine came about foremost in the field of orthopedics. Low frequency and low intensity fields have been used extensively for the treatment of non-union fractures. By 1979 this method was approved in the USA as a safe and effective treatment for non-union fractures; for failed arthroses; and for congenital pseudo-arthroses. According to Bassett this method has been used by more than 6,000 surgeons. The success rate was over 80% for tibial lesions. No patient suffered complications and biological side-effects included

improved healing and increased neural function. In-depth research carried out to investigate this, shows that magnetic fields influence the process of bone formation in the intercellular medium. Madronero showed that bone healing was promoted by means of the influence of the magnetic field on the crystal formation of calcium salts.

Pain reduction:

Pulsed magnetic field therapy has been shown to bring about a reduction of pain, which again is due to action at the cellular level. Pain is transmitted as an electric signal, which encounters gaps at intervals along its path. The signal is transferred in the form of a chemical signal across the synaptic gap and this is detected by receptors on the post-synaptic membrane. A charge of about -70mV exists across the inner and outer membranes, but when a pain signal arrives it raises this to +30mV. This action causes channels to open in the membrane, triggering the release of a chemical transmitter and allowing ions to flow into the synaptic gap. The cell then re-polarizes to its previous resting level. Research by Warnke suggests that PMFT affects the quiescent potential of the membrane, lowering it to a hyper-polarized level of -90mV. Transmission is effectively blocked since the pain signal is unable to raise the potential to the level required to trigger the release of the chemical transmitter. Again, the frequency of the applied magnetic field is important, as the most effective frequency to produce this effect was found to be a base frequency of 100Hz pulsed at between 5 and 25 pulses per second.

Clinical applications:

The value of pulsed magnetic field therapy has been shown to cover a wide range of conditions, with well documented trials carried out by hospitals, rheumatologists and physiotherapists. For example, the department of rheumatology at Addenbrookes Hospital carried out investigations into the use of PMFT for the treatment of persistent rotator cuff tendinitis. The treatment was applied to patients who had symptoms refractory to steroid injection and other conventional treatments. At the end of the trial, 65% of these were symptom free, with 18% of the remainder being greatly improved.

Lau (School of Medicine, Loma University, USA) reported on the application of PMFT to the problems of diabetic retinopathy. Patients were treated over a 6-week period, 76% of the patients had a reduction in the level of numbness and tingling. All patients had a reduction of pain, with 66% reporting that they were totally pain-free. Many research studies, including Lau, reported on the application of PMFT for conditions such as sports injuries and for patients with joint and spinal problems. Although these are too numerous to mention individually, in almost every instance there was a reduction, if not complete resolution of symptoms. Soft tissue injuries and joint pains tended to be resolved within 5 days of treatment. Patients with cervical problems and low back pain were also successfully treated, whereas previous treatment with ice, traction and other therapies had been unsuccessful. In yet another trial, the effect of applying PMFT to sufferers of Multiple Sclerosis was investigated (Geseo) 70% of sufferers had a reduction of weakness, pain and spasticity, with 50% reporting improvement of their bladder incontinence. Through the evaluation of hundreds of research papers, a number of points have been established regarding PMFT: The field must be pulsed, with low frequency to achieve the best effect.

Different conditions require different frequencies. For example, 5Hz causes vasoconstriction whilst 10Hz and above causes vasodilatation. Biological effectiveness is achieved in just 10 minutes for most injuries, so that long treatment sessions are not required. When used at the correct level there are no recorded side effects. Although PMFT is not yet recommended for use during pregnancy or in the presence of tumors, there are papers to suggest that magnetic fields can inhibit the growth of tumors.

Dr. D. C. Laycock, Ph.D. Med. Eng. Westville Consultants

### **Treatment of migraine with pulsing electromagnetic fields: a double-blind, placebo-controlled study.**

The effect of exposure to pulsing electromagnetic fields on migraine activity was evaluated by having 42 subjects (34 women and 8 men), who met the International Headache Society's criteria for migraine, participate in a double-blind, placebo-controlled study. During the first month of follow-up, 73% of those receiving actual exposure, reported decreased headaches (45% substantial decrease, 14% excellent decrease) compared to half of those receiving the placebo (15% worse, 20% good, 0% excellent). Ten of the 22 subjects who had actual exposure received 2 additional weeks of actual exposure, after their initial 1-month follow-up. All showed decreased

headache activity (50% substantial, 38% excellent). Eight of the subjects in the placebo group elected to receive 2 weeks of actual exposure after the initial 1-month follow-up with 75% showing decreased headache activity (38% substantial, 38% excellent). In conclusion, exposure to pulsing electromagnetic fields for at least 3 weeks is an effective, short-term intervention for migraine.

Sherman R. et.al. Orthopedic Surgery Service, Madigan Army Medical Center, Tacoma, WA, USA

### **Spine fusion for discogenic low back pain: outcome in patients treated with or without pulsed electromagnetic field stimulation.**

Sixty-one randomly selected patients who underwent lumbar fusion surgeries for discogenic low back pain between 1987 and 1994 were retrospectively studied. All patients had failed to respond to preoperative conservative treatments. Forty-two patients received adjunctive therapy with pulsed electromagnetic field (PEMF) stimulation, and 19 patients received no electrical stimulation of any kind. Average follow-up time was 15.6 months postoperatively. Fusion succeeded in 97.6% of the PEMF group and in 52.6% of the unstimulated group ( $P < .001$ ).

Marks RA. Richardson Orthopaedic Surgery, Texas, USA.

### **Beneficial effects of electromagnetic fields.**

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.

Bassett C. Bioelectric Research Center, Columbia University New York

### **Therapeutic effects of pulsed magnetic fields on joint diseases.**

The present paper describes the effects of pulsed magnetic fields (PMF) on diseases of different joints, in chronic as well as acute conditions where the presence of a phlogistic process is the rule. Optimal parameters for PMF applications were sought at the beginning of the study and then applied for 11 years; a technical modification in the PMF generator was introduced 5 years ago to satisfy the requirement of a hypothesis advanced to understand the mechanism of PMF treatment.

3,014 patients were treated by means of MF at extremely low frequencies and intensities. Patient follow-up was pursued as constantly as possible. Pain removal, recovery of joint mobility and maintenance of the improved conditions represented the parameters for judging the results as good or poor. The chi-square test was applied in order to evaluate the probability that the results are not casual. A general average value of 78.8% of good results and 21.2% of poor results was obtained. Higher (82%) percentages of good results were observed when single joint diseases were considered with respect to multiple joint diseases (polyarthrosis); in the latter, the percentage of good results was definitely lower (66%). The high percentage of good results obtained and the absolute absence of both negative results and undesired side-effects, together with the therapeutic advantage due to a

technical modification in the PMF generator, led to the conclusion that magnetic field treatment is an excellent physical therapy in cases of joint diseases. A hypothesis is advanced that external magnetic fields influence trans-membrane ionic activity.

Riva Sanseverino, E. et.al. Universita di Bologna, Italy.

### **Modification of biological behavior of cells by Pulsing Electromagnetic fields, (PMFT)**

On the major part of the calcified mass of adult bone there are no changes in bone mass, however there is a part on which bone is being formed and a part on which bone is being resorbed. Decalcification occurs when bone *resorption* is greater than bone *formation*. Bone formation comprises two steps, the laying down of the extra-cellular matrix and the deposition therein of bone salts. The dynamic processes of formation and destruction of bone are under cellular control. Bone formation is controlled by single nuclear cells called *Osteoblasts*, and bone resorption by multinuclear giant cells are called *Osteoclasts*. Bone is a specialized connective tissue, in which a matrix consisting of collagen fibers and a large variety of other proteins and ground substance are impregnated with a solid mineral. The bone matrix is responsible for the resistance of bone to tractional and torsional forces. The collagen forms more than 25 % of the bones and is synthesized by osteoblasts. On the bone surface collagen fibers are normally arranged in concentric rings of hard calcified matrix.

The bone minerals provide to the bone compressive strength and rigidity. It contains the mineral salts hydroxyapatite and calcium. In addition there are small amounts of magnesium hydroxide, fluoride and sulphate. As these salts are deposited in the framework formed by the collagen fibers of the matrix, crystallization occurs and the tissue hardens. This process is called calcification or mineralisation. Both the concentrations of ions of calcium and phosphate in the extracellular fluid maintain crystallization. If the concentration is not adequate the tissue will not be hard enough resulting in increased bone fracture risk.

There are two types of bone structure. Cortical (compact) bone and trabecular (spongy) bone. Cortical bone is more dense and constitutes of 80 % of the skeletal mass and forms the external layer of all bones in the human body. Trabecular bone consists of lamellae arranged in an irregular latticework of thin plates of bone and helps long bones to resist the stress of weight placed on them.

The process by which bone forms is called ossification. Bone forms either by the mineralisation of cartilage or directly by osteoblasts in a collagenous matrix. During the first two decades of life bone grows, followed by consolidation and reaching its peak value around thirty five years. After this peak, bone loss starts. Nutritional factors, especially calcium intake, the level of physical activity and generic factors are important in determining the peak bone mass.

When a bone is fractured, it heals with bone. Bone is the only solid tissue in the body that can replace itself. Bone healing is simple when it occurs smoothly, complicated when it does not. The process is being initiated by stimuli from the bone itself. Fractures through bone with a good blood supply, surrounded by muscle and without soft tissue trauma, have an excellent chance of healing, but fractures at the middle of long bones, particularly with extensive soft tissue damage, have a high incidence of non-union.

Selected low-energy time-varying electromagnetic fields have been used during the past 15 years to treat un-united fractures (non-unions). More than 100,000 patients, mainly in the USA, have been treated. Retrospective studies have substantiated their biological effectiveness in large numbers. Bone is responsive to the mechanical demands placed on it. When loading diminishes, as it does during bed rest, immobilization and weightlessness, bone mass is lost. On the other hand when loading is increased correctly, bone mass increases.

Results of bio-mechanical and histologic investigations prove that electromagnetic fields not only prevent bone loss, but also restores bone mass, once lost. A program was set up at McGill University of Montreal, where was found that electromagnetic fields *damp* bone *resorption* activity. Furthermore prove was found that selected electromagnetic fields increase bone formation.

The resorption of bone is lowest and formation of new bone greatest, when energy of the imposed fields is concentrated in the lower frequency components. These results are consistent with other studies showing, that cells respond to a broad spectrum of frequencies. They appear to be most sensitive to frequencies in the range of those produced endogenously, that is in the range of 100 Hz or less.

Tissue dosimetry studies show that the frequency response of cortical bone over a range of 100 Hz to 20 kHz show a steep roll off between 100 and 200 Hz.

Electromagnetic fields at specific frequencies have shown to produce osteogenic effects in a turkey ulna model. Furthermore low-amplitude signals decrease bone resorption in a canine fibular model. Lifestyle factors like malnutrition, smoking, excessive use of alcohol and a sedentary lifestyle contribute to, and worsen, osteoporosis. It is not known whether this response derives from decreased osteoblastic activity, increased osteoclastic resorption, or both. Elderly persons can heal fractures in normal intervals, showing that osteoblasts can be activated by appropriate stimuli.

A study at the University of Hawaii School of Medicine was designed to provide concrete data on the restoration of bone mass in post-menopausal females. A total of 20 subjects between 57 and 75 years, all with decreased bone mineral density as defined by a bone densitometer, were treated during a period of 12 weeks. After a period of 6 weeks the bone density rose in those patients with an average of 5.6%.

Electromagnetic fields do modify biological behavior by inducing electrical changes around and within the cell. The key to rational use of electromagnetic fields lies in the ability *to define the specific treatment parameters* (amplitude, frequency, orientation and timing). Properly applied pulsed electromagnetic fields, *if scaled for whole body use*, has clear clinical benefits in the treatment of bone diseases and related pain, often caused by micro-fractures in vertebrae. In addition, joint pain caused by worn out cartilage layers can be treated successfully, through electromagnetic stimulation, increasing the partial oxygen pressure and resulting in increased calcium transport. Repair and growth of cartilage is thus stimulated, preventing grinding of the bones.

Ben Philipson.

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

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.

Dr. D. C. Laycock, Ph.D. Med. Eng. Westville Consultants.

### **Prevention of osteoporosis by pulsed electromagnetic fields.**

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.

Rubin C. et.al. Dep. of Orthopaedics, State University of New York J Bone Joint Surg Am

### **A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures.**

A total of 45 tibial shaft fractures, all conservatively treated and with union delayed for more than 16 but less than 32 weeks were entered in a double-blind multi-centre trial. The fractures were selected for their liability to delayed union by the presence of moderate or severe displacement, angulation or comminution or a compound lesion with moderate or severe injury to skin and soft tissues. Treatment was by plaster immobilisation in all, with active electromagnetic stimulation units in 20 patients and dummy control units in 25 patients for 12 weeks. Radiographs were assessed blindly and independently by a radiologist and an orthopaedic surgeon. Statistical analysis showed the treatment groups to be comparable except in their age distribution, but age was not found to affect the outcome and the effect of treatment was consistent for each age group. The radiologist's assessment of the active group showed radiological union in five fractures, progress to union in five but no progress to union in 10. In the control group there was union in one fracture and progress towards union in one but no progress in 23. Using Fisher's exact test, the results were very significantly in favour of the active group ( $p = 0.002$ ). The orthopaedic surgeon's assessment showed union in nine fractures and absence of union in 11 fractures in the active group. There was union in three fractures and absence of union in 22 fractures in the control group. These results were also significantly in favour of the active group ( $p = 0.02$ ). It was concluded that pulsed electromagnetic fields significantly influence healing in tibial fractures with delayed union.

Sharrard WJ Royal Hallamshire Hospital, Sheffield, England. J Bone Joint Surg

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

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.

Mooney V. Orthopaedic Surgery, University of California Spine

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

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.

Bassett C. Dep. Orthopedic Surgery, Columbia University, New York. *Crit Rev Biomed Eng*

### **Pulsed electromagnetic fields promote collagen production in bone marrow fibroblasts via athermal mechanisms.**

Primary and passaged cultures of fibroblasts (RBMFs) raised from the bone marrow stroma of young rabbits were treated with pulsed electromagnetic fields (PEMFs) from the start of each culture until 1 week after they became confluent. The PEMF treatment had no effect on cell proliferation, estimated by phase contrast microscopy, by <sup>3</sup>H-thymidine incorporation into DNA, or by total DNA assay. Collagen production, estimated by conversion of <sup>3</sup>H-proline to <sup>3</sup>H-hydroxyproline in nondialyzable material was markedly elevated in postconfluent cultures, but not in cultures that had only just reached confluence. About 65% of <sup>3</sup>H-hydroxyproline was in low molecular weight form, and a correlation between collagen breakdown and cyclic AMP (cAMP) levels in RBMFs was demonstrated by adding dibutyryl cAMP or prostaglandin E<sub>3</sub> (PGE<sub>2</sub>) to the culture medium concurrently with <sup>3</sup>H-proline. The PEMF apparatus caused an insufficient temperature rise (less than 0.1 degree C) to account for these results. We propose that the rise in collagen production is consistent with the hypothesis that PEMFs act by reducing cAMP levels in RBMFs, and that thermal effects are insignificant.

Farndale R. et.al *Calcif Tissue Int*

### **Modulation of collagen production in cultured fibroblasts by a low-frequency pulsed magnetic field.**

Primary cultures of chicken tendon fibroblasts have been exposed for various periods to a low-frequency, pulsed magnetic field, and the effects on protein and collagen synthesis have been examined by radioisotopic incorporation. Total protein synthesis was increased in confluent cells treated with a pulsed magnetic field for the last 24 h of culture as well as in cells treated for a total of 6 days. However, in 6 day-treated cultures, collagen accumulation was specifically enhanced as compared to total protein, whereas after short-term exposure, collagen production was increased only to the same extent as total protein. Levels of cyclic AMP were significantly decreased after 6-day pulsed magnetic field treatment, probably as a consequence of diminished adenylate cyclase activity. Exposure to pulsed magnetic field had no effect on cell proliferation or collagen phenotype. These results indicate that a pulsed magnetic field can specifically increase production of collagen, the major differentiated function of fibroblasts, possibly by altering cyclic-AMP metabolism.

Murray J. et.al. *Biochim Biophys Acta*

### **Results of pulsed electromagnetic fields (PEMFs) in ununited fractures after external skeletal fixation.**

Of 147 patients with fractures of the tibia, femur and humerus, in whom an average of 3.3 operations had failed to produce union, all were treated with external skeletal fixation in situ and pulsed electromagnetic fields (PEMFs). Of the 147, 107 patients united for an overall success rate of 73%. Union of the femur occurred in 81% and the tibia in 75%. Only five of 13 humeri united. Failure to achieve union with PEMFs was most closely associated with very wide fracture gaps and insecure skeletal fixation devices.

Marcer M. et.al. Clin Orthop

### **Osteonecrosis of the femoral head treated by pulsed electromagnetic fields (PEMFs): a preliminary report.**

This has been a preliminary report with a short-term follow-up of a small number of observations (28 hips of 24 patients). The follow-ups ranged from 6 to 36 months, with an average of 17.8 months. Only eleven hips (in eleven patients) were followed an average of 8 months after cessation of the treatment. It should be emphasized that this was a "pilot" study, in which no control series was used to determine the natural course of the disease in a comparable clinical setting. Of note was the pain relief, in 19 of 23 patients with moderate to severe pretreatment pain. Also there was an improved function, which suggests that at least in approximately two thirds of the patients there was some clinical benefit from this mode of treatment. In eight hips, clinical conditions did not change; and in two they worsened, requiring further treatment. Eighteen remaining hips were thought to have benefited by the treatment. Six femoral heads that had already developed varying degrees of collapse (Ficat Type III) collapsed further (1 to 2 mm), and two round heads (Ficat II) progressed to off-round (Ficat III). This preliminary study suggests that further exploration of pulsed electromagnetic fields (PEMFs) is warranted in the treatment of osteonecrosis of the femoral head.

Eftekhari N. et.al. Hip

### **Treatment of therapeutically resistant non-unions with bone grafts and pulsing electromagnetic fields.**

This study reviews the cases of eighty-three adults with ununited fractures who were treated concomitantly with bone-grafting and pulsed electromagnetic fields. An average of 1.5 years had elapsed since fracture and the use of this combined approach. Nearly one-third of the patients had a history of infection, and an average of 2.4 prior operations had failed to produce bone union. Thirty-eight patients who were initially treated with grafts and pulsed electromagnetic fields for ununited fractures with wide gaps, synovial pseudarthrosis, and malalignment achieved a rate of successful healing of 87 per cent. Forty-five patients who had initially been treated unsuccessfully with pulsing electromagnetic fields alone had bone-grafting and were re-treated with pulsing electromagnetic fields. Ninety-three per cent of these fractures healed. The residual failure rate after two therapeutic attempts, one of which was operative, was 1.5 per cent. The median time to union for both groups of patients was four months.

Bassett C. Et.al. J Bone Joint Surg Am

### **Effects of a pulsed electromagnetic field on a mixed chondroblastic tissue culture.**

A mixed tissue culture predominantly composed of chondroblastic tissue was perturbed by a pulsed electromagnetic field (PEMF). Some cultures were nonconfluent, and purposely retarded in growth to resemble an atrophic nonunion, while others were grown to confluence in about one-half the time as a model for a hypertrophic nonunion. These two groups tested the effect of growth rate upon the products of cell proliferation and differentiation. The slowly growing cultures were stimulated to synthesize hydroxyproline. The rapidly growing cultures showed a large increase in lysozyme activity, and increase in hyaluronate and DNA, and a decrease in glycosaminoglycan. Exogenous lysozyme further decreased the glycosaminoglycan synthesis in the

presence of PEMF. Chitotriose, a specific lysozyme inhibitor abolished this effect. Cycloheximide, a protein synthesis inhibitor, did not abolish the activation of lysozyme found in the matrix. Thus lysozyme appears to be activated by PEMF. These observations of the rapidly growing confluent cultures are consistent with events described in the normal healing of a bone fracture or endochondral growth. Thus, PEMF appears to promote normal healing, probably by altering cartilaginous lysozyme activity in the matrix, and possibly the sequence of events leading to calcification.

Norton LA Clin Orthop

### **Biological effects of magnetic fields: studies with microorganisms.**

Five bacteria and one yeast were grown in magnetic fields of 50-900 gauss with frequencies of 0-0.3 HZ and square, triangular, or sine waveform. Growth of these microorganisms could be stimulated or inhibited depending upon the field strength and frequency of the pulsed magnetic field. Spore germination and mutation frequency were unaffected by the magnetic fields used in this study.

Moore R. Can J Microbiol

### **Influence of magnetic fields on calcium salts crystal formation: an explanation of the 'pulsed electromagnetic field' technique for bone healing.**

In the search for a mechanism by means of which a magnetic field deparalyses non-unions and enhances bone tissue formation, the influence of continuous magnetic fields on the formation of calcium phosphate crystal seeds has been investigated. From this perspective, an explanation is given of a working mode in conventional equipment for pulsed electromagnetic field treatment; this is compared with multifunction equipment.

Madronero A J Biomed Eng

### **Treatment of nonunion using pulsed electromagnetic fields: a retrospective follow-up study.**

Pulsed electromagnetic fields (PEMF) are a useful means of treating cases of fracture nonunion. In 67.7% of nonunions with a disability time of at least 24 months, complete consolidation was obtained. This success rate is increased to 76.6% if we exclude nonunion, that presented contraindications for treatment with PEMF. The disability time had no effect on the success rate. Lesions of the humerus and atrophic nonunion had an unfavorable prognosis.

Meskens M. et.al. Dep. Orthopedic Surgery, University Hospital, Pellenberg, Belgium. Acta Orthop Belg

### **Effects of pulsed electromagnetic fields on Steinberg ratings of femoral head osteonecrosis.**

95 Patients with femoral head osteonecrosis met the protocol for treatment of 118 hips with selected pulsed electromagnetic fields (PEMFs). Etiologies included trauma (17), alcohol (9), steroid use (46), sickle cell disease (2), and idiopathy (44). The average age was 38 years, and the average follow-up period since the onset of symptoms was 5.3 years. PEMF treatment had been instituted an average of 4.1 years earlier. By the Steinberg quantitative staging method of roentgenographic analysis, none of the 15 hips in Stages 0-III showed progression, and grading improved in nine of 15. Eighteen of 79 hips (23%) with Stage IV lesions progressed and none improved. In the Stage V category, one of 21 hips (5%) worsened and none improved. Three Stage VI lesions were unchanged. The overall rate of quantified progression for the 118 hips, 87% of which had collapse present when entering the program, was 16%. This value represents a reversal of the percentage of progression reported recently by other investigators using conservative and selected surgical methods. PEMF patients also have experienced long-term improvements in symptoms and signs, together with a reduction in the need for early joint arthroplasty.

Bassett C. et.al. Orthopaedic Hospital, Riverdale, NY Clin Orthop

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

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.

Aaron R. et.al. Dep. Biochemistry and Biophysics, University of Rhode Island J Bone Miner Res

### **Role of pulsed electromagnetic fields in recalcitrant non-unions.**

Twenty-nine patients of recalcitrant nonunion of long bones were treated by pulsed electromagnetic fields in an attempt to bring about osteogenesis. The pulse used was rectangular, equal mark space wave in the astable, continuous mode operating at a frequency of 40 Hertz. The success rate was 82.5%. The result was not dependent on the age, sex, time of nonunion or the presence of infection. However, the results were uniformly poor when infection and fracture instability were coexistent in the same patient.

Delima DF, Tanna DD J Postgrad Med

### **In vitro low frequency electromagnetic field effect on fast axonal transport.**

The objective of this study was to evaluate the effects of a low frequency electromagnetic field on fast axonal transport for future neuroprosthetic applications. Changes in speeds and densities of retrograde fast organelle transport in rat sciatic nerve preparations were measured in vitro upon exposure to 15 and 50 Hz pulsed magnetic fields with peak intensities of 4.4 and 8.8 mT. Maximum current density of the induced eddy current was calculated to be about 40 microA/cm<sup>2</sup>. Video enhanced differential interference contrast microscopy was used to record axons supporting active organelle transport. Strong effects were observed in myelinated axons (cessation of transport in up to 10 min). Such effects may eventually be used as part of a neuroprosthesis to noninvasively modify or couple to various parts of the nervous system.

Zborowski M. et.al. Dep. Artificial Organs, Cleveland Clinic Found. ASAIO Trans

### **Effects of pulsed extremely-low-frequency magnetic fields on skin wounds in the rat.**

Rats with skin-wounds surgically created on their backs were exposed immediately after surgery and every 12 h thereafter to pulsed, extremely-low-frequency magnetic fields. The shape of the pulse was a positive triangle (50 Hz, 8 mT peak). The rate of healing of skin wounds was evaluated macroscopically and by light and electron microscopy at 6, 12, 21, and 42 days after the operation. A significant increase in the rate of wound contraction was found in rats treated with magnetic fields. Forty-two days after surgery all treated animals show fully closed wounds, while control rats at the same time intervals still lacked a final 6% of the wound surface to be covered. Treated rats showed earlier cellular organization, collagen formation and maturation, and a very early appearance of newly formed vascular network.

Ottani V. et.al. Istituto di Anatomia, Bologna, Italy. Bioelectromagnetics

### **Treatment of delayed union and nonunion of the tibia by pulsed electromagnetic fields. A retrospective follow-up.**

The results of a clinical follow-up of 57 tibial lesions treated with pulsed electromagnetic fields at least six months after the primary lesion occurred proved that this noninvasive method can be a valuable alternative to other commonly accepted modes of therapy. The overall success rate was 75% but could be improved to 81% when the proper indications were met.

Meskens M. et.al. Dep. Orthopaedics, University Hospital, Pellenberg Bull Hosp Jt Dis Orthop Inst

### **Enhanced responsiveness to parathyroid hormone and induction of functional differentiation of cultured rabbit costal chondrocytes by a pulsed electromagnetic field.**

Pulsed electromagnetic fields promote healing of delayed united and ununited fractures by triggering a series of events in fibrocartilage. We examined the effects of a pulsed electromagnetic field (recurrent bursts, 15.4 Hz, of shorter pulses of an average of 2 gauss) on rabbit costal chondrocytes in culture. A pulsed electromagnetic field slightly reduced the intracellular cyclic adenosine 3',5'-monophosphate (cAMP) level in the culture. However, it significantly enhanced cAMP accumulation in response to parathyroid hormone (PTH) to 140% of that induced by PTH in its absence, while it did not affect cAMP accumulation in response to prostaglandin E1 or prostaglandin I2. The effect on cAMP accumulation in response to PTH became evident after exposure of the cultures to the pulsed electromagnetic field for 48 h, and was dependent upon the field strength. cAMP accumulation in response to PTH is followed by induction of ornithine decarboxylase, a good marker of differentiated chondrocytes, after PTH treatment for 4 h. Consistent with the enhanced cAMP accumulation, ornithine decarboxylase activity induced by PTH was also increased by the pulsed electromagnetic field to 170% of that in cells not exposed to a pulsed electromagnetic field. Furthermore, stimulation of glycosaminoglycan synthesis, a differentiated phenotype, in response to PTH was significantly enhanced by a pulsed electromagnetic field. Thus, a pulsed electromagnetic field enhanced a series of events in rabbit costal chondrocytes in response to PTH. These findings show that exposure of chondrocytes to a pulsed electromagnetic field resulted in functional differentiation of the cells.

Hiraki Y. et.al. Dep. Biochemistry and Calcified-Tissue Metabolism, Faculty of Dentistry, Osaka University, Japan. *Biochim Biophys Acta*

### **Impulse magnetic-field therapy for erectile dysfunction: a double-blind, placebo-controlled study.**

This double-blind, placebo-controlled study assessed the efficacy of 3 weeks of pulsing magnetic-field therapy for erectile dysfunction (ED). In the active-treatment group, all efficacy endpoints were significantly improved at study end ( $P < \text{or} = .01$ ), with 80% reporting increases in intensity and duration of erection, frequency of genital warmth, and general well-being. Only 30% of the placebo group noted some improvement in their sexual activity; 70% had no change. No side effects were reported.

Pelka R. Et.al. Universitat der Bundeswehr Munchen, Neubiberg/Munich, Germany.

### **Comparison of electromagnetic field stimulation on the healing of small and large intestinal anastomoses.**

Magnetic fields have been shown to affect biologic processes. Accordingly, an experimental study was designed to investigate the effect of electromagnetic field therapy on intestinal healing and to compare small and large intestinal anastomoses. Conclusions: Electromagnetic field stimulation provided a significant gain in anastomotic healing in both small and large intestine. The study demonstrated a significant increase in both biochemical and mechanical parameters.

Nayci A. et.al. Cakmak M, Aksoyek S, Renda N, Yucesan S. Department of Pediatric Surgery, Mersin University Medical Faculty, Turkey.

### **The efficacy of un-united tibial fracture treatment using pulsing electromagnetic fields: relation to biological activity on non-union bone ends.**

Thirty un-united tibial fractures with a median time since injury of 18+/-9 months were treated by electrical stimulation using pulsing electromagnetic field therapy. Union was achieved in 25 cases (83.3%) in a median interval of 8.6+/-3.2 months. Patient age, gender, the presence of surgical hardware, length of disability, and the number of surgical procedures did not affect the outcome. Un-united fractures that appeared to be hypertrophic or sclerotic, indicating a good blood supply to the bone ends, all healed.. Pulsing electromagnetic field therapy is an effective treatment for un-united tibial fractures with good blood supply to the bone ends.

Ito H. et.al. Department of Orthopaedic Surgery, Nippon Medical School, Tokyo, Japan.

### **Ultrastructural study of hyaluronic acid before and after the use of a pulsed electromagnetic field, electrorlysis, in the treatment of wrinkles.**

BACKGROUND. Treatment of wrinkles has become an increasing problem for dermatologists. Hyaluronic acid is a component of the family of glycosaminoglycans (GAGS, substances known for their property of retaining water), that significantly decreases with aging and in wrinkles. A new technique that uses a specific pulsed electromagnetic field, electrorlysis, has been introduced in the treatment of wrinkles associated with aging. The treatment is based on the reported in vitro effects of specific electromagnetic fields on fibroblast cultures (e.g., an increase in DNA synthesis and in the production of collagen and presumably also of GAGS). METHODS. The in vivo effects of the electromagnetic field on aged skin (3 subjects aged 50, 56 and 60 years), with particular focus on the ultrastructural modifications and GAGS amount before and after the treatment, were evaluated by electron microscope. RESULTS. The ultrastructural study (tissue stained with alcian blue) showed after treatment a significant increase ( $p < 0.005$ ) of the electron-dense granules (corresponding to hyaluronic acid), located in collagen elastic fibers, and in the soluble matrix. This presumably leads to subsequent edema that was clinically evident after the treatment. CONCLUSIONS. These data suggest that the increased levels of GAGS and the subsequent edema of the dermis could explain at least in part the clinical changes observed after electrorlysis treatment (e.g., swelling and "disappearance" of the wrinkle).

Ghersetich I. Et.al. De. of Dermatology, University of Florence, Italy. Int J Dermatol

### **Optimization of electric field parameters for the control of bone remodeling: exploitation of an indigenous mechanism for the prevention of osteopenia.**

The discovery of piezoelectric potentials in loaded bone was instrumental in developing a plausible mechanism by which functional activity could intrinsically influence the tissue's cellular environment and thus affect skeletal mass and morphology. Using an in vivo model of osteopenia, we have demonstrated that the bone resorption that normally parallels disuse can be prevented or even reversed by the exogenous induction of electric fields. Importantly, the manner of the response (i.e., formation, turnover, resorption) is exceedingly sensitive to subtle changes in electric field parameters. Fields below 10 microV/cm, when induced at frequencies between 50 and 150 Hz for 1 h/day, were sufficient to maintain bone mass even in the absence of function. Reducing the frequency to 15 Hz made the field extremely osteogenic. Indeed, this frequency-specific sinusoidal field initiated more new bone formation than a more complex pulsed electromagnetic field (PEMF), though inducing only 0.1% of the electrical energy of the PEMF. The frequencies and field intensities most effective in the exogenous stimulation of bone formation are similar to those produced by normal functional activity. This lends strong support to the hypothesis that endogenous electric fields serve as a critical regulatory

factor in both bone modeling and remodeling processes. Delineation of the field parameters most effective in retaining or promoting bone mass will accelerate the development of electricity as a unique and site-specific prophylaxis for osteopenia. Because fields of these frequencies and intensities are indigenous to bone tissue, it further suggests that such exogenous treatment can promote bone quantity and quality with minimal risk or consequence.

Rubin C. Et.al. Dep. Orthopaedics, State University of New York J Bone Miner Res

### **Pulsed magnetic fields improve osteoblast activity during the repair of an experimental osseous defect.**

The influence of pulsed low-frequency electromagnetic fields (PEMFs) on bone formation was investigated in studies of the healing process of transcortical holes, bored at the diaphyseal region of metacarpal bones of six adult horses, exposed for 30 days to PEMFs (28 G peak amplitude, 1.3 ms rise time, and 75 Hz repetition rate). A pair of Helmholtz coils, continuously powered by a pulse generator, was applied for 30 days to the left metacarpal bone, through which two holes, of equal diameter and depth, had been bored at the diaphyseal region. Two equal holes, bored at the same level in the right metacarpal and surrounded by an inactive pair of Helmholtz coils, were used as controls. All horses were given an intravenous injection of 25-30 mg/kg of tetracycline chloride on the 15th and again on the 25th day after the operation and were killed 5 days later. The histomorphometric analysis indicated that both the amount of bone formed during 30 days and the mineral apposition rate during 10 days (deduced from the interval between the two tetracycline labels) were significantly greater ( $p < 0.01$  and  $p < 0.0001$ , respectively) in the PEMF-treated holes than in the controls. As did a previous investigation, these preliminary findings indicate that PEMFs at low frequency not only stimulate bone repair but also seem to improve the osteogenic phase of the healing process, at least in our experimental conditions.

Cane V. et.al. Institute of Human Anatomy, University of Modena, Italy. : J Orthop Res

### **Use of pulsed electromagnetic fields in treatment of loosened cemented hip prostheses. A double-blind trial.**

A double-blind trial of pulsed electromagnetic fields (PEMFs) for loosened cemented hip prostheses was conducted at two centers. Of the 40 patients who enrolled, 37 met entry criteria and were available for analysis. All patients completed six months of treatment (either active or control units). Success was determined clinically by a Harris hip score greater than or equal to 80 points (or an increase of ten points if initially greater than or equal to 70 points). Ten of the 19 active units were successes (53%), whereas two of the 18 controls (11%) exhibited a placebo effect, a statistically significant and clinically relevant result. A 60% relapse rate among the active successes was seen at 14 months poststimulation, and despite maintenance therapy of one hour per day, the relapse rate increased to 90% at three years. These data suggest that for loosened cemented hip prostheses, use of PEMFs is a treatment option to delay revision hip surgery.

Kennedy W. et.al. Theda Clark Regional Medical Center, Wisconsin. Clin Orthop

### **The effect of low-frequency electrical fields on osteogenesis.**

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.

McLeod K. et.al. Dep. Orthopaedics, School of Medicine, State University of New York, : J Bone Joint Surg Am

### **Treatment of ununited tibial fractures: a comparison of surgery and pulsed electromagnetic fields (PEMF).**

The use of pulsed electromagnetic fields (PEMF) is gaining acceptance for the treatment of ununited fractures. The results of 44 articles published in the English language literature have been compiled to assess the effectiveness of PEMF vs surgical therapy. For ununited tibial fractures, 81% of reported cases healed with PEMF vs 82% with surgery. After multiple failed surgeries, the success rate of PEMF is reported to be greater than with surgery; this discrepancy increases with additional numbers of prior surgeries. In infected nonunions, the results of surgical treatment decreased by 21% and were less than the results utilizing PEMF (69% vs 81%). In open fractures, surgical healing exceeded PEMF (89% vs 78%), whereas in closed injuries PEMF cases healed more frequently (85% vs 79%). In general, PEMF treatment of ununited fractures has proved to be more successful than noninvasive traditional management and at least as effective as surgical therapies. Given the costs and potential dangers of surgery, PEMF should be considered an effective alternative. Experience supports its role as a successful method of treatment for ununited fractures of the tibia.

Gossling H. Et.al. Dep. Orthopedic Surgery, University of Connecticut Orthopedics

### **Long-term pulsed electromagnetic field (PEMF) results in congenital pseudarthrosis.**

Ninety-one patients with congenital pseudarthrosis of the tibia have been treated with pulsed electromagnetic fields (PEMFs) since 1973 and all except 4 followed to puberty. Lesions were stratified by roentgenographic appearance. Type I and type II had gaps less than 5 mm in width. Type III were atrophic, spindled, and had gaps in excess of 5 mm. Overall success in type I and II lesions was 43 of 60 (72%). Of those 28 patients seen before operative repair had been attempted, 7 of 8 type I lesions healed (88%), whereas 16 of 20 type II lesions healed (80%) on PEMFs and immobilization alone. Only 19% (6 of 31) type III lesions united, only one of which did not require surgery. Sixteen of 91 limbs (18%) were ultimately amputated, most before treatment principles were fully defined in 1980. Fourteen of these 16 patients (88%) had type III lesions. Refracture occurred in 22 patients, most as the result of significant trauma, in the absence of external brace support. Twelve of the 19 refractures, retreated with PEMFs and casts, healed on this regime. Episodic use of PEMFs proved effective in controlling stress fractures in several patients until they reached puberty. PEMFs, which are associated with no known risk, appear to be an effective, conservative adjunct in the management of this therapeutically challenging, congenital lesions.

Bassett C. et.al. Bioelectric Research Center, Riverdale, New York Calcif Tissue Int

### **Protection against focal cerebral ischemia following exposure to a pulsed electromagnetic field.**

There is evidence that electromagnetic stimulation may accelerate the healing of tissue damage following ischemia.. Exposure to pulsed electromagnetic field attenuated cortical ischemia edema on MRI at the most anterior coronal level by 65% ( $P < 0.001$ ). On histologic examination, PEMF exposure reduced ischemic neuronal

damage in this same cortical area by 69% ( $P < 0.01$ ) and by 43% ( $P < 0.05$ ) in the striatum. Preliminary data suggest that exposure to a PEMF of short duration may have implications for the treatment of acute stroke. Grant G. et.al. Department of Neurosurgery, Stanford University, California

#### **Modulation of bone loss during disuse by pulsed electromagnetic fields.**

The effect of pulsed electromagnetic fields (PEMFs) on bone loss associated with disuse was investigated by applying 1.5 Hz repetitions of 30 ms bursts of asymmetric pulses, varying from +2.5 to -135 mV, to bones deprived of their normal functional loading. The proximal portion of one fibula in each of a group of ovariectomised adult female beagle dogs was isolated from functional loading in vivo by proximal and distal osteotomies. Comparison of these prepared bones with their intact contralateral controls after 12 weeks, showed a 23% reduction in cross-sectional area. In similarly prepared bones exposed to PEMFs for 1 h per day, 5 days per week, this bone loss was substantially and significantly reduced to 9% ( $p = 0.029$ ). There was no evidence of any new bone formation on the periosteal surface of prepared fibulae in treated or untreated situations. PEMF treatment was not associated with any significant change in number of osteons per mm<sup>2</sup> formed within the cortex of the bones, their radial closure rate, or their degree of closure. The modulation in loss of bone area associated with exposure to PEMFs can, therefore, be inferred to be due to a reduction in resorption on the bone surface.

Skerry T. et.al. Dep. of Anatomy, University of Bristol, U.K. J Orthop Res

#### **Treatment of chronic varicose ulcers with pulsed electromagnetic fields: a controlled pilot study.**

To evaluate the efficacy of pulsed electromagnetic fields (PEMF) in healing of chronic varicose ulcers, 19 patients with this condition were included in a double-blind controlled clinical trial. All patients received standard ulcer therapy throughout the duration of the study and were randomly divided into two groups to receive either active or inactive PEMF therapy. Active therapy was provided by the use of a pair of Helmholtz coils on a twice weekly basis over a five week period and inactive therapy was provided on an identical regimen with identical coils wound so that no magnetic field was produced when an electric current was passed through them. The clinician and patients were unable to distinguish the active or inactive coils. No statistically relevant difference was noted between the two groups in the healing rates of the ulcer, change in the lower leg girth, pain or infection rates. However there was a trend in favour of a decrease in ulcer size and lower leg girth in the group treated with active PEMF. As PEMF is a novel treatment for chronic varicose ulcers, more work needs to be done to establish treatment parameters and its usefulness in the treatment of this condition.

Todd D. et.al. Dep. Dermatology, Belfast City Hospital. Ir Med J

#### **Low energy high frequency pulsed electromagnetic therapy for acute whiplash injuries. A double blind randomized controlled study.**

The standard treatment of acute whiplash injuries (soft collar and analgesia) is frequently unsuccessful. Pulsed electromagnetic therapy PEMT has been shown to have pro-healing and anti-inflammatory effects. This study examines the effect of PEMT on the acute whiplash syndrome. PEMT as described is safe for domiciliary use and this study suggests that PEMT has a beneficial effect in the management of the acute whiplash injury.

Foley-Nolan D. et.al. Mater Hospital, Dublin, Ireland.

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

To determine the effect of a 72 Hz pulsating electromagnetic field (PEMF). 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. The data suggest that properly applied PEMF, if

scaled for whole-body use, may have clinical application in the prevention and treatment of osteoporosis. Tabrah F. et.al. University of Hawaii School of Medicine, Honolulu.

### **Effect of pulsed magnetic fields on human umbilical endothelial vein cells**

The long-term goal of this program was to examine the efficacy of electromagnetic fields as an adjunct therapy to facilitate wound repair. The experiments reported here were directed to the question of whether pulsed electromagnetic fields (PEMF) could facilitate endothelial cell migration following induction of a wound. These studies were based on a report that weak PEMF facilitated cell migration in a wounded confluent monolayer culture of human umbilical vein cells. Experiments reported in this paper were an attempt to reproduce and extend these observations. Our data support the original observations. Further, we examined several hypotheses in an attempt to clarify the mechanism of interaction between the applied electromagnetic fields and cells. The data do not support the hypothesis that PEMF is acting in a manner similar to endothelial cell-growth factor, a normal component of the growth medium, or that PEMF applied at the time of cell transfer enhance DNA replication. We have found that PEMF is more effective in accelerating migration if they induce an electric field that is perpendicular rather than parallel to the sides of the wound.

Goodman, E. et.al J. Biomedical Res. Inst., Univ. Wisconsin, WI, USA

### **Effects of pulsed magnetic fields in the therapy of osteoporosis induced by ovariectomy in the rat.**

This paper presents preliminary results on the effects of pulsed electromagnetic fields (EMF) in the therapy of post menopausal osteoporosis induced by ovariectomy in female rats aged ten months. In particular, the effects of the intensity of pulsed EMF applied at constant frequency has been studied. Magnetic fields pulsed at 50 Hz were used having a positive sinusoidal wave form with a maximum intensity of 30 and 70 Gauss. Treatment lasting one hour per day for 4 months showed that the pulsed EMF with 30 Gauss of maximum intensity are able to slow down the bone mass loss, keeping it within some 10%; with pulsed EMF with 70Gauss of maximum intensity, instead, no significant bone mass loss was observed.

Zati, A.et.al. Institute Orthopaedic Rizzoli, University of Bologna.

### **Possible therapeutic applications of pulsed magnetic fields**

Magnetotherapy is a relatively new, nowadays however, relatively widespread method in several medical disciplines. The mechanism proper of the favorable action of the pulsed magnetic field on the living organism is not quite clear so far, clinical investigations revealed, however, a favorable anti-inflammatory, angioedematous and analgesic therapeutic effect. The authors sought an optimal frequency of the pulsed magnetic field with regard to the character of the disease. They focused attention above all on treatment of acute and chronic inflammatory conditions of the locomotor apparatus, ischaemia of the blood vessels of the lower extremities, dyspeptic syndrome, lactation mastitis and other diseases. One therapeutic cycle lasted 20 minutes, the mean number of cycles varied between 5.8 and 7.7. A regression of complaints was recorded as a rule after 2-3 sessions. The optimal frequency of the pulsed magnetic field seems to be a value between 10.0 and 25.0 Hz. It is useful in particular in severe conditions to repeat the therapeutic cycle after 2-3 months. The advantage of this therapeutic method is the minimal number of contraindications.

Navratil, L. et.al. Czech Republic

### **The Canadian experience with pulsed magnetic fields in the treatment of un-united tibial fractures**

A clinical survey of 56 patients was conducted at four different centers in Canada to evaluate the effect of extremely low frequency pulsed magnetic fields (PMF) on un-united fractures of the tibia. All ten patients with

delayed union and 84% of the 44 patients with non-union healed. One case with a traumatic pseudarthrosis and one with a congenital pseudarthrosis failed to respond to treatment. These results compare favorably to those reported by others using a system with different pulse characteristics. Prolonged immobilization is necessary and poses problems of rehabilitation. Non-unions with a gap between the tibial fragments and pseudarthroses are better treated with bone grafting and internal fixation prior to electrical stimulation.

Haas, W. et.al. J. of Clin. Orthop.

#### **Pulsed magnetic field therapy for tibial non-union. Interim results of a double-blind trial.**

English patients with tibial fractures which had remained un-united for at least 52 weeks were randomly allocated to either active or dummy pulsed magnetic field stimulators and treated in full leg plasters for 24 weeks with a non-weight bearing conservative regimen, as is usual with such techniques. Fractures in 5 of the 9 patients with working machines united and fractures in 5 of the 7 patients with dummy machines also united. These early results of this double-blind trial are compatible with a difference in success rate at 24 weeks on active treatment of + 33% to -61% (95% confidence limits) compared with the success rate on the dummy stimulators. The high proportion of fractures uniting in the control group suggests that conservative management of non-union is effective and this may explain much of the success attributed to pulsed magnetic field therapy.

Barker, A. et.al Lancet

#### **Pulsed Magnetic Field Therapy For Insomnia: A Double-Blind, Placebo-Controlled Study**

This 4-week double-blind, placebo-controlled study assessed the efficacy of impulse magnetic-field therapy for insomnia. One hundred one patients were randomly assigned to either active treatment (n = 50) or placebo (n = 51) and allocated to one of three diagnostic groups: (1) sleep latency; (2) interrupted sleep; or (3) nightmares. Efficacy endpoints were intensity of sleep latency, frequency of interruptions, sleepiness after rising, daytime sleepiness, difficulty with concentration, and daytime headaches. In the active-treatment group, the values of all criteria were significantly lower at study end ( $P < .00001$ ). The placebo group also showed significant symptomatic improvement ( $P < .05$ ), but the differences between groups were highly significant ( $P < .00001$ ). Seventy percent (n = 34) of the patients given active treatment experienced substantial or even complete relief of their complaints; 24% (n = 12) reported clear improvement; 6% (n = 3) noted a slight improvement. Only one placebo patient (2%) had very clear relief; 49% (n = 23) reported slight or clear improvement; and 49% (n = 23) saw no change in their symptoms. No adverse effects of treatment were reported.

Uni der Bundeswehr Munich, Germany.

#### **Pulsed electromagnetic fields increase growth factor release by nonunion cells.**

The mechanisms involved in pulsed electromagnetic field stimulation of nonunions are not known. Animal and cell culture models suggest endochondral ossification is stimulated by increasing cartilage mass and production of transforming growth factor-beta 1. For the current study, the effect of pulsed electromagnetic field stimulation on cells from human hypertrophic (n = 3) and atrophic (n = 4) nonunion tissues was examined. Cultures were placed between Helmholtz coils, and an electromagnetic field (4.5-ms bursts of 20 pulses repeating at 15 Hz) was applied to 1/2 of them 8 hours per day for 1, 2, or 4 days. There was a time-dependent increase in transforming growth factor-beta 1 in the conditioned media of treated hypertrophic nonunion cells by Day 2 and of atrophic nonunion cells by Day 4. There was no effect on cell number, [3H]-thymidine incorporation, alkaline phosphatase activity, collagen synthesis, or prostaglandin E2 and osteocalcin production. This indicates that human nonunion cells respond to pulsed electromagnetic fields in culture and that transforming growth factor-beta 1 production is an early event. The delayed response of hypertrophic and atrophic nonunion cells (> 24 hours) suggests that a cascade of regulatory events is stimulated, culminating in growth factor synthesis and release.

Guerkov H. et.al. Dep. of Orthopaedics, Univ. of Texas Health Science Center. Clin Orthop

### **Comparative study of bone growth by pulsed electromagnetic fields.**

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.

Gupta T. et.al. Dep. Electrical Engineering, Harcourt Butler Technological Institute, Kanpur, India. Med Biol Eng Comput

### **Long-term follow-up of fracture non-unions treated with PEMF.**

One hundred thirty-nine established fracture non-unions were treated using a pulsed electromagnetic field (PEMF) device that also recorded patient usage. Patients who used the device less than an average of three hours a day had a success rate of 35.7% (5/14), while those who used the device in excess of three hours daily had an 80% success rate (108/135). The difference in the success rate was statistically significant at  $p$  less than .05. Treatment success was unaffected by long versus short bone, open versus closed fractures, nonunion of nine to 12 months duration compared to one to ten years, age of patient (whether less than or greater than age 60), gender, recalcitrant versus first time treatment, infected versus non-infected non-unions, fracture gaps up to 1cm, or weight bearing versus non-weight bearing. Ninety-seven fractures in 90 patients (90% follow-up) who averaged more than three hours of PEMF treatment daily and were originally classified as healed were reevaluated clinically and radiographically at four years following treatment (range: 3.6-5.4 years; mean: 4.1 years). Eighty-nine (92%) maintained a solid union. The success rate of PEMF treatment for nonunion repair demonstrated no statistically significant change over long-term follow-up.

Garland D. Et.al. University of Southern California School of Medicine, Los Angeles, California. Contemp Orthop

### **Augmentation of bone repair by pulsed elf magnetic fields.**

Tibial osteotomies in rats were exposed for 2, 3, 5 and 8 weeks to a pulsed extremely low frequency magnetic field. The shape of the pulse was a double halfwave (50 Hz, 70 G). The rate of bone healing was evaluated by light and electron microscopy. An increase of bone healing was found in rats treated with magnetic fields persisting throughout the tested time. The accelerated healing process produced a sequence of morphological appearances identical to those of a normal fracture callus being the enhancement of osteogenesis produced by an acceleration of preliminary ossification.

Ottani V. et.al. Istituto di Anatomia Umana Normale, Bologna, Italy. Anat Anz

### **The development and application of pulsed electromagnetic fields (PEMFs) for ununited fractures and arthrodeses.**

This article deals with the rational and practical use of surgically noninvasive pulsed electromagnetic fields

(PEMFs) in treating ununited fractures, failed arthrodeses, and congenital pseudarthroses (infantile nonunions). The method is highly effective (more than 90 per cent success) in adult patients when used in conjunction with good management techniques that are founded on biomechanical principles. When union fails to occur with PEMFs alone after approximately four months, their proper use in conjunction with fresh bone grafts insures a maximum failure rate of 1 to 1.5 per cent. Union occurs because the weak electric currents induced in tissues by the time-varying fields effect calcification of the fibrocartilage in the fracture gap, thereby setting the stage for the final phases of fracture healing by endochondral ossification. The efficacy, safety, and simplicity of the method has prompted its use by the majority of orthopedic surgeons in this country. In patients with delayed union three to four months postfracture, PEMFs appear to be more successful and healing, generally, is more rapid than in patients managed by other conservative methods. For more challenging problems such as actively infected nonunions, multiple surgical failures, long-standing (for example, more than two years postfracture) atrophic lesions, failed knee arthrodeses after removal of infected prostheses, and congenital pseudarthroses, success can be expected in a large majority of patients in whom PEMFs are used. Finally, as laboratory studies have expanded knowledge of the mechanisms of PEMF action, it is clear that different pulses affect different biologic processes in different ways. Selection of the proper pulse for a given pathologic entity has begun to be governed by rational processes similar, in certain respects, to those applied to pharmacologic agents.

Bassett CA Clin Plast Surg & Orthop Clin North Am

### **Pulsed electromagnetic field stimulation of MG63 osteoblast-like cells affects differentiation and local factor production.**

Pulsed electromagnetic field stimulation has been used to promote the healing of chronic non-unions and fractures with delayed healing, but relatively little is known about its effects on osteogenic cells or the mechanisms involved. The purpose of this study was to examine the response of osteoblast-like cells to a pulsed electromagnetic field signal used clinically and to determine if the signal modulates the production of autocrine factors associated with differentiation. Confluent cultures of MG63 human osteoblast-like cells were placed between Helmholtz coils and exposed to a pulsed electromagnetic signal consisting of a burst of 20 pulses repeating at 15 Hz for 8 hours per day for 1, 2, or 4 days. Controls were cultured under identical conditions, but no signal was applied. Treated and control cultures were alternated between two comparable incubators and, therefore, between active coils; measurement of the temperature of the incubators and the culture medium indicated that application of the signal did not generate heat above the level found in the control incubator or culture medium. The pulsed electromagnetic signal caused a reduction in cell proliferation on the basis of cell number and [3H]thymidine incorporation. Cellular alkaline phosphatase-specific activity increased in the cultures exposed to the signal, with maximum effects at day 1. In contrast, enzyme activity in the cell-layer lysates, which included alkaline phosphatase-enriched extracellular matrix vesicles, continued to increase with the time of exposure to the signal. After 1 and 2 days of exposure, collagen synthesis and osteocalcin production were greater than in the control cultures. Prostaglandin E2 in the treated cultures was significantly reduced at 1 and 2 days, whereas transforming growth factor-beta1 was increased; at 4 days of treatment, however, the levels of both local factors were similar to those in the controls. The results indicate enhanced differentiation as the net effect of pulsed electromagnetic fields on osteoblasts, as evidenced by decreased proliferation and increased alkaline phosphatase-specific activity, osteocalcin synthesis, and collagen production. Pulsed electromagnetic field stimulation appears to promote the production of matrix vesicles on the basis of higher levels of alkaline phosphatase at 4 days in the cell layers than in the isolated cells, commensurate with osteogenic differentiation in response to transforming growth factor-beta1. The results indicate that osteoblasts are sensitive to pulsed electromagnetic field stimulation, which alters cell activity through changes in local factor production.

Lohmann C. et.al. Dep. Orthopaedics, University Texas Health Science Center, San Antonio J Orthop Res

### **Pulsed electromagnetic fields affect the intracellular calcium concentrations in human astrocytoma cells.**

Experiments assessed whether long term exposure to 50 Hz pulsed electromagnetic fields with a peak magnetic

field of 3 mT can alter the dynamics of intracellular calcium in human astrocytoma U-373 MG cells. Pretreatment of cells with 1.2  $\mu$ M substance P significantly increased the  $[Ca^{2+}]_i$ . The same effect was also observed when  $[Ca^{2+}]_i$  was evaluated in the presence of 20 mM caffeine. After exposure to electromagnetic fields the basal  $[Ca^{2+}]_i$  levels increased significantly from 143  $\pm$  46 nM to 278  $\pm$  125 nM. The increase was also evident after caffeine addition, but in cells treated with substance P and substance P + caffeine we observed a  $[Ca^{2+}]_i$  decrease after exposure. When we substituted calcium-free medium for normal medium immediately before the  $[Ca^{2+}]_i$  measurements, the  $[Ca^{2+}]_i$  was similar to that measured in the presence of  $Ca^{2+}$ . In this case, after EMFs exposure of cells treated with substance P, the  $[Ca^{2+}]_i$ , measured without and with addition of caffeine, declined from 824  $\pm$  425 to 38  $\pm$  13 nM and from 1369  $\pm$  700 to 11  $\pm$  4 nM, respectively, indicating that electromagnetic fields act either on intracellular  $Ca^{2+}$  stores or on the plasma membrane. Moreover the electromagnetic fields that affected  $[Ca^{2+}]_i$  did not cause cell proliferation or cell death and the proliferation indexes remained unchanged after exposure.

Pessina G. et.al. Inst. of General Physiology and Nutritional Science, University of Siena, Italy.

Bioelectromagnetics

### **Pulsed electromagnetic fields promote bone formation around dental implants inserted into the femur of rabbits.**

The present study examined the effect of applying a pulsed electromagnetic field (PEMF) on bone formation around a rough-surfaced dental implant. A dental implant was inserted into the femur of Japanese white rabbits bilaterally. A PEMF with a pulse width of 25 microseconds and a pulse frequency of 100 Hz was applied. PEMF stimulation was applied for 4 h or 8 h per day, at a magnetic intensity of 0.2 mT, 0.3 mT or 0.8 mT. The animals were sacrificed 1, 2 or 4 weeks after implantation. After staining the resin sections with 2% basic fuchsin and 0.1% methylene blue, newly formed bone around the implant on tissue sections was evaluated by computer image analysis. The bone contact ratios of the PEMF-treated femurs were significantly larger than those of the control groups. Both the bone contact ratio and bone area ratio of the 0.2 mT- and 0.3 mT-treated femurs were significantly larger than the respective value of the 0.8 mT-treated femurs ( $P < 0.001$ ). No significant difference in bone contact ratio or bone area ratio was observed whether PEMF was applied for 4 h/day or 8 h/day. Although a significantly greater amount of bone had formed around the implant of the 2-week treated femurs than the 1-week treated femurs, no significant difference was observed between the 2-week and 4-week treated femurs. These results suggest that PEMF stimulation may be useful for promoting bone formation around rough-surfaced dental implants. It is important to select the proper magnetic intensity, duration per day, and length of treatment. Matsumoto H. et.al. Dep. of Fixed Prosthodontics, School of Dentistry, University of Hokkaido, Ishikari-Tobetsu, Japan. J. of Clin Oral Implants

### **PEMF data collection and analysis.**

Eighty-five patient records were reviewed retrospectively to determine the status of lumbar spinal fusion in patients who had undergone surgery of posterior lumbar interbody fusion (PLIF) and/or by a posterolateral (PL) approach, and received postoperative therapy with a noninvasive device that generated pulsed electromagnetic fields (PEMF). Sixty-six patients (77.6%) had risk factors associated with a poor prognosis for healing, including smoking, prior back surgery, multiple spinal levels fused, diabetes mellitus, and obesity. Roentgenographic and clinical evidence indicated that all but two patients achieved successful fusion. The characteristics of these two patients were age 40-55 years, 1 male and 1 female, both were smokers, 1 primary fusion and 1 revision fusion, and both patients underwent single-level PLIF using autogenous graft. After the treatment, seven (8%) patients reported no change in level of pain, but the remainder (92%) reported that pain decreased by one to three levels. Of the 83 patients with successful spinal fusion, 29 (34.9%) were assessed as "excellent," 45 (54.2%) as "good," 3 (3.6%) as "fair," and 6 (7.2%) as "poor." Adjunctive treatment with PEMF appeared effective in promoting spinal fusion following PLIF or PL procedures across all patient subgroups.

Richard A. Silver, M.D. Tucson Orthopaedic & Fracture Surgery Associates, Ltd., Tucson, AZ.

### **Therapeutic effects of alternating current pulsed electromagnetic fields in multiple sclerosis.**

Multiple sclerosis is the third most common cause of severe disability in patients between the ages of 15 and 50 years. The cause of the disease and its pathogenesis remain unknown. The last 20 years have seen only meager advances in the development of effective treatments for the disease. No specific treatment modality can cure the disease or alter its long-term course and eventual outcome. Moreover, there are no agents or treatments that will restore pre-morbid neuronal function. A host of biological phenomena associated with the disease involving interactions among genetic, environmental, immunologic, and hormonal factors, cannot be explained on the basis of demyelination alone and therefore require refocusing attention on alternative explanations, one of which implicates the pineal gland as pivotal. The pineal gland functions as a magnetoreceptor organ. This biological property of the gland provided the impetus for the development of a novel and highly effective therapeutic modality, which involves transcranial applications of alternating current (AC) pulsed electromagnetic fields flux density. This review summarizes recent clinical work on the effects of transcranially applied pulsed electromagnetic fields for the symptomatic treatment of the disease.

Sandyk R. Dep. of Neuroscience, Institute for Biomedical Engineering and Rehab Services of Touro College, Dix Hills, New York.

### **Double-blind study of pulsing magnetic field effects on multiple sclerosis.**

We performed a double-blind study to measure the clinical and sub-clinical effects of an alternative medicine electromagnetic device on disease activity in multiple sclerosis (MS). The MS patients were exposed to a magnetic pulsing device where the frequency of the magnetic pulse was in the 4-13 Hz range. A total of 30 MS patients wore the device on pre-selected sites between 10 and 24 hours a day for 2 months. Half of the patients (15) randomly received a device that was magnetically inactive and the other half received an active device. Each MS patient received a set of tests to evaluate MS disease status before and after wearing the device. The tests included (1) a clinical rating (Kurtzke, EDSS), (2) patient-reported performance scales, and (3) quantitative electroencephalography (QEEG) during a language task. Although there was no significant change between pretreatment and post-treatment in the EDSS scale, there was a significant improvement in the performance scale (PS) combined rating for bladder control, cognitive function, fatigue level, mobility, spasticity, and vision (active group  $-3.83 \pm 1.08$ ,  $p < 0.005$ ; placebo group  $-0.17 \pm 1.07$ , change in PS scale). There was also a significant change between pre-treatment and post-treatment in alpha EEG magnitude during the language task recorded at various electrode sites on the left side. In this double-blind, placebo-controlled study, we have demonstrated a statistically significant effect of the magnetic pulsing device on patient performance scales and on alpha EEG magnitude during a language task.

Richards T. et.al. Dep. Radiology, University of Washington

### **Pulsing magnetic field effects on brain electrical activity in multiple sclerosis**

Multiple sclerosis (MS) is a disease of the central nervous system. Clinical symptoms include central fatigue, impaired bladder control, muscle weakness, sensory deficits, impaired cognition, and others. The cause of MS is unknown, but from histologic, immunologic, and radiologic studies, we know that there are demyelinated brain lesions (visible on magnetic resonance images) that contain immune cells such as macrophages and T-cells (visible on microscopic analysis of brain sections). Recently, a histologic study has also shown that widespread axonal damage occurs in MS along with demyelination. What is the possible connection between MS and bio-electromagnetic fields? We recently published a review entitled "Bio-electromagnetic applications for multiple sclerosis," which examined several scientific studies that demonstrated the effects of electromagnetic fields on nerve regeneration, brain electrical activity (electro-encephalography), neurochemistry, and immune system

components. All of these effects are important for disease pathology and clinical symptoms in multiple sclerosis (MS). EEG was measured in this study in order to test our hypothesis that the pulsing magnetic device affects the brain electrical activity, and that this may be a mechanism for the effect we have observed on patient-reported symptoms. The EEG data reported previously were measured only during resting and language conditions. The purpose of the current study was to measure the effect of the electromagnetic device on EEG activity during and after photic stimulation with flashing lights. After photic stimulation, there was a statistically significant increase in alpha EEG magnitude that was greater in the active group compared to the placebo group in electrode positions P3, T5, and O1 (analysis of variance  $p < .001$ ,  $F = 14$ ,  $DF = 1, 16$ ). In the comparison between active versus placebo, changes measured from three electrode positions were statistically significantly even after multiple comparison correction.

Richards TL, Acosta-Urquidi, J In Biologic Effects of Light 1998 Symposium

### **Treatment with weak electromagnetic fields improves fatigue associated with multiple sclerosis.**

It is estimated that 75-90% of patients with multiple sclerosis (MS) experience fatigue at some point during the course of the disease and that in about half of these patients, subjective fatigue is a primary complaint. In the majority of patients fatigue is present throughout the course of the day being most prominent in the mid to late afternoon. Sleepiness is not prominent, but patients report that rest may attenuate fatigability. The pathophysiology of the fatigue of MS remains unknown. Delayed impulse conduction in demyelinated zones may render transmission in the brainstem reticular formation less effective. In addition, the observation that rest may restore energy and that administration of pemoline and amantadine, which increase the synthesis and release of monoamines, often improve the fatigue of MS suggest that depletion of neurotransmitter stores in damaged neurons may contribute significantly to the development of fatigue in these patients. The present report concerns three MS patients who experienced over several years continuous and debilitating fatigue throughout the course of the day. Fatigue was exacerbated by increased physical activity and was not improved by rest. After receiving a course of treatments with picotesla flux electromagnetic fields (EMFs), which were applied extracranially, all patients experienced improvement in fatigue. Remarkably, patients noted that several months after initiation of treatment with EMFs they were able to recover, after a short period of rest, from fatigue which followed increased physical activity. These observations suggest that replenishment of monoamine stores in neurons damaged by demyelination in the brainstem reticular formation by periodic applications of picotesla flux intensity EMFs may lead to more effective impulse conduction and thus to improvement in fatigue including rapid recovery of fatigue after rest.

Sandyk R. NeuroCommunication Research Laboratories, Danbury, CT, USA.

### **Effects of pulsed electromagnetic fields on rat skin metabolism.**

In an attempt to approach the mechanism of action of pulsed electromagnetic fields (PEMF) on biological systems, the effects on protein synthesizing activity and on membrane transport have been examined in rat skin. PEMF characterized by specific physical parameters stimulate the incorporation of L-[U-<sup>14</sup>C] isoleucine into the proteins of rat skin as well as the alpha-amino [1-<sup>14</sup>C] isobutyric acid uptake during incubation in buffer medium with extracellular electrolyte composition. Analogous incubation experiments carried out in an intracellular medium results in an inhibitory effect of PEMF on both biological functions. Addition of 10<sup>-3</sup> M ouabain to the incubation medium, partially blocking the Na<sup>+</sup>/K<sup>+</sup>-ATPase pump mechanism, apart from reducing amino acid transport, results in an overall disappearance of any stimulatory effects by PEMF. PEMF applied to the skin in the presence of 10<sup>-3</sup> M 2,4-dinitrophenol uncoupling the oxidative phosphorylation in the mitochondria and seriously restricting protein synthesis, still provides a limited stimulatory effect on protein synthesizing activity and on membrane transport. The effects of PEMF may well be understood by an increased availability of precursor elements controlled at the cell membrane level. Indeed the observed effects may even be simulated outside electromagnetic fields by modifications in the electrolyte composition of the incubation medium.

De Loecker W. Et.al. Biochemal dep. Universiteit Leuven, Belgium. Biochim Biophys Acta

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