Pain Management with Pulsed Electromagnetic Fields (PEMF) Treatment

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The issue of pain treatment is an extremely urgent health and socio-economic problem. Pain, in acute, recurrent and chronic forms, is prevalent across age, cultural background, and sex, and costs North American adults an estimated $10,000 to $15,000 per person annually. Estimates of the cost of pain do not include the nearly 30,000 people that die in North America each year due to aspirin-induced gastric lesions[70] 17% of people over 15 yr of age suffer from chronic pain that interferes with their normal daily activities. Studies suggest that at least 1 in 4 adults in North America is suffering from some form of pain at any given moment. This large population of people in pain relies heavily upon the medical community for the provision of pharmacological treatment. Many physicians are now referring chronic pain sufferers to non-drug based therapies, that is, "Complementary and Alternative Medicine," in order to reduce drug dependencies, invasive procedures and/or side effects. The challenge is to find the least invasive, toxic, difficult and expensive approach possible.

The ability to relieve pain is very variable and unpredictable, depending on the source or location of pain and whether it is acute or chronic. Pain mechanisms are complex and have peripheral and central nervous system aspects. Therapies should be tailored to the specifics of the pain process in the individual patient. Psychological issues have a very strong influence on whether and how pain is experienced and whether it will become chronic. Most effective pain management strategies require multiple concurrent approaches, especially for chronic pain. It is rare that a single modality solves the problem.

Static or electromagnetic fields have been used for centuries to control pain and other biologic problems, but scientific evidence of their effect had not been gathered until recently. This review explores the value of magnetic therapy in rehabilitation medicine in terms of static magnetic fields and time varying magnetic fields (electromagnetic). A historical review is given and the discussion covers the areas of scientific criteria, modalities of magnetic therapy, mechanisms of the biologic effects of magnetic fields, and perspectives on the future of magnetic therapy.

In the past few years a new and fundamentally different approach has been increasingly investigated. This includes the use of magnetic fields (MF), produced by both static (permanent) and time-varied (most commonly, pulsed) magnetic fields (PEMFs). Fields of various strengths and frequencies have been evaulated. There is as yet no “gold standard”. The fields selected will vary based on experience, confidence, convenience and cost. Since there does not appear to be any major advantage to any one MF application, largely because of the unpredictability of ascertaining the true underlying source of the pain, regardless of the putative pathology, any approach may be used empirically and treatment adjusted based on the response. After thousands of patient-years of use globally, there very little risk has been found to be associated with MF therapies. The primary precautions relate to implanted electrical devices and pregnancy and seizures with certain kinds of frequency patterns in seizure prone individuals.

Magnetic fields affect pain perception in many different ways. These actions are both direct and indirect. Direct effects of magnetic fields are: neuron firing, calcium ion movement, membrane potentials, endorphin levels, nitric oxide, dopamine levels, acupuncture actions and nerve regeneration. Indirect benefits of magnetic fields on physiologic function are on: circulation, muscle, edema, tissue oxygen, inflammation, healing, prostaglandins, cellular metabolism and cell energy levels.

Most studies on pain use subjective measures to quantitate baseline and outcome values. Subjective perception of pain using a visual analogue scale (VAS) and pain drawings is 95% sensitive and 88% specific for current pain in the neck and shoulders and thoracic spine[2].

Measured pain intensity (PI) changes with pain relief and satisfaction with pain management[63]. Based on a numerical descriptor scale (NDS) and a visual analog scale (VAS), the average reduction in PI with medical treatment in an emergency room setting was 33%. A 5%, 30%, and 57% reduction in PI correlated with "no," "some/partial," and "significant/complete" relief. If initial PI scores were moderate/severe pain (NDS > 5), PI had to be reduced by 35% and 84%, to achieve "some/partial" and "significant/complete" relief, respectively. Patients in less pain (NDS < or = 5) needed 25% and 29% reductions in PI. However, relief of pain appears to only partially contribute to overall satisfaction with pain management.

Several authors have reviewed the experience with pulsed magnetotherapy (PEMF) in Eastern Europe[28] and the west[72]. PEMFs have been used extensively in many conditins and medical disciplines. They have been most effective in treating rheumatic disorders. PEMFs produced significant reduction of pain, improvement of spinal functions and reduction of paravertebral spasms. Although PEMFs have been proven to be a very powerful tool, they should always be considered in combination with other therapeutic procedures.

Certain pulsed electromagnetic fields (PEMF) affect the growth of bone and cartilage in vitro, with potential application as an arthritis treatment[72]. PEMF stimulation is already a proven remedy for delayed fractures, with potential clinical application for osteoarthritis, osteonecrosis of bone, osteoporosis, and wound healing. Static magnets may provide temporary pain relief under certain circumstances.

The ability of PEMFs to affect pain is dependant on the ability of PEMFs to positively affect human physiologic or anatomic systems. Research is showing that the human nervous system is strongly affected by therapeutic

PEMFs. Behavioral and physiologic responses of animals to static and extremely low frequency (ELF) magnetic fields are affected by the presence of light[49].

PEMF exposure or sham exposure does not affect balance with the eyes open. With eyes closed under low light, exposure to PEMF significantly increases sway movements. With eyes closed under high intensity light, PEMF tends to decrease sway. Under low light conditions, light levels through the closed eyelids are too low to affect magnetic field effects, but under high light conditions sufficient light reaches the magnetic field receptor(s) even with the eyes closed. These experiments suggest that humans have light-dependent magnetic field detection mechanisms similar to animals as diverse as insects, birds, and rodents.

One of the most reproducible results of weak, extremely low-frequency (ELF) magnetic field (MF) exposure is an effect upon neurologic pain signal processing[70]. Pulsed electromagnetic field (PEMFs) have been designed for use as a therapeutic agent for the treatment of chronic pain in humans. Recent evidence suggests that PEMFs would also be an effective complement for treating patients suffering from acute pain. Recent studies also suggest that magnetic field treatments involving the manipulation of standing balance would be effective in the determination of the etiology of chronic pain and hence be effective in the diagnosis of the underlying disease state. Static magnetic field devices with strong gradients have also been shown to have therapeutic potential. Specifically placed static magnetic field devices, such as the Magnabloc device, have been shown to reduce neural action potentials in vitro and alleviate spinal mediated pain in human subjects. Human studies involving the induction of analgesia, whether utilizing pharmacology or magnetic field treatments, also need to account for the placebo response, which may explain as much as 40% of the analgesia response. However, the placebo response, or at least the central nervous system mechanisms responsible for the placebo response, may be an appropriate target for magnetic field induced therapies. Magnetic field manipulation of cognitive and behavioral processes has been well-documented in animal behavior studies and subjective-measure studies involving human subjects, which may also be one of the mechanisms of the use of MFs in managing pain.

Since the turn of this century, a number of electrotherapeutic, magnetotherapeutic and electromagnetic medical devices have emerged for treating a broad spectrum of trauma, tumors and infections with a static, time-varying and/or pulsed fields. Over the years, some of these non-invasive devices have proven highly efficacious in certain applications, notably bone repair, pain relief, autoimmune and viral diseases (including HIV), and immunopotentiation[75]. Their acceptance in clinical practice has been very slow in the medical community. Practitioner resistance seems largely based on confusion of the different modalities, the wide variety of frequencies employed (from ELF to microwave) and the general lack of understanding of the biomechanics involved. The current scientific literature indicates that short, periodic exposure to pulsed electromagnetic fields (PEMF) has emerged as the most effective form of electromagnetic therapy.

Magnetotherapy is accompanied by an increase in the threshold of pain sensitivity and activation of the anticoagulation system[30]. PEMF treatment stimulates production of opioid peptides; activates mast cells, Langerhans', and Merkel cells, promotes vacuolization of sarcoplasmic reticulum and increases electric capacity of muscular fibers. Long bone fractures that did not unite over 4 mo to 4 years are repaired in 87% of cases with 14-16 hr of daily PEMF treatment. Several of these devices are FDA approved. PEMF of 1.5- or 5-mT field strength, proved helpful edema and pain before or after a surgical operation. Results of studies and experience with PEMF argue for a wider introduction of PEMF treatment techniques in clinical practice.

Treatment of bone pathologies, nerve and ligament regeneration, pain, and inflammation has prompted research on the fundamental mechanism of action. Such studies have centered on modifications of membrane transport activity and the effect of small changes in ionic fluxes on metabolism, cAMP levels, and on stimulation of mRNA and protein synthesis. A limited number of specific combinations of EMF parameters stimulate cellular activities. Departures from these specific field characteristics may produce opposite effects. PEMF for 15-360 minutes increased amino acid uptake about 45%[8]. Uptake of AIB then declined progressively but was still significantly higher after 6 hr in exposed skin than in controls. Comparison of the effect of PEMF for 2 hr induced conformational changes in transmembrane energy transport enzymes, allowing energy coupling and transduction of absorbed resonant PEMF energy into transport work.

Research has been conducted since 1990 in Italy the effects of EMFs on animal responses to adverse environmental stimuli[20]. Researchers demonstrated that ELFs lowered the density of pigeons' brain *mu* opiate receptors by about 30% and decreased their pain perception. Similar were obtained by Canadian reserachers in mice and snails with various kinds of MFs. A 2 hr exposure of healthy humans was found to reduce pain perception and decreased pain-related brain signals. Treatment with a sinusoidal 100 Hz MF was found to induce analgesic and therapeutic effects, supported by evidence of biophysical effects in cell cultures and guinea pigs. Biochemical changes were found in the blood of treated patients that supported the pain reduction benefit.

Normal standing balance produces an individual pattern of postural sway that is sensitive to a variety of factors such as age, physical condition, light level, gender, changing visual patterns or audible tones, and eyes open or closed condition. Balance is subject to control by the vestibular area of the brain. PEMF may be coupling with muscular processing or upper body nervous tissue functions[31]. 200-uT PEMFs cause a significant improvement in normal standing balance in adult (18-34 yr old) humans. Further evidence of the sensitivity of the nervous system on MFs.

Several magnetic fields with different characteristics have been shown to reduce pain inhibition (i.e. analgesia) in various species of animals including land snails, mice, pigeons, as well as humans[78]. 0.5 Hz rotating MF, 60 Hz ELF magnetic fields and MRI reduced analgesia induced by both exogenous opiates (i.e. morphine) and endogenous opioids (i.e. stress-induced). Reduction in stress-induced analgesia can be obtained not only by exposing animals to a variety of different magnetic fields, but also after a short-term stay in a near-zero magnetic field. This suggests that even for magnetic field, as for other environmental factors (i.e. temperature or gravity), alterations in the normal conditions in which the species has evolved can induce alterations in physiology as well as in behavior.

Various electromagnetic fields (EMFs: microwaves, pulsed, low-frequency, and constant magnetic fields and magnetically-shielded spaces) have been applied to fish, birds, mice, rats, cats, rabbits, and humans[49] to the head or to an extremity, from 1 to 60 minutes, with intervals from several minutes to several hours, randomly sequenced with sham exposures. Brain reactions were studied by psychophysiological, behavioral, electrophysiological, and histological methods, and compared to reactions evoked by "standard" stimuli (light and sound). Multiyear studies showed a non-specific initial response (NSIR) of the brain to various EMFs. EMF-induced changes in brain function were regarded as "modulatory" and manifested themselves as a greater probability of sensory responses to EMF exposures than to sham exposures. The sensory reactions were a weak pain, tickling, pressure, etc., mediated by the body's sensory systems. Reactions could be prevented by local anesthesia of the exposed area. EEG-responses were enhancement of the low-frequency rhythms and were particularly pronounced with mechanical or radiation brain damage. Cell analysis showed that all types of cells (neurons, glia, vascular wall cells) react to EMFs, while astroglial cells were most sensitive; the function of astrocytes is known to be related to memory processes and slow activity in the EEG.

In diabetic neuropathy, sinusoidal MFs, treated every day for 12 minutes, improved pain, paresthesias and vibration sensation and increased muscular strength in 85% of patients[6] compared to controls.

Chronic pain is often accompanied with or results from decreased circulation or perfusion to the affected tissues, for example, cardiac angina or intermittent claudication. PEMFs have been shown to improve circulation[22]. Skin infrared radiation increases due to immediate vasodilation with low frequency fields and increased cerebral blood perfusion in animals. Pain syndromes due to muscle tension and neuralgias also improved.

Another group having more than 20 yr experience of using magnetic or electromagnetic fields (EMF) in the treatment of about 1500 patients with trauma, musculoskeletal diseases, circulation and nervous system problems[9]. They used various magnetic devices produced in Eastern Europe, including static magnetic fields (SMF), sinusoidal or PEMF extremely low-frequency fields (ELF EMF) and extremely high-frequency (EHF) EMFs ranging in field strength from 1-40 mT. Treatments lasted from 20-30 minutes per day, to 5-8 hr per day for up to 3-4 wk. The treatments had anti-pain, anti-edema, anti-inflammatory, macro- and microcirculation benefits. The results of the treatment depended not only on the parameters of the fields but also on the individual sensitivity of the organism.

PEMFs can vary widely in frequencies, waveforms, harmonics and duty cycles. The most effective results in clinical use were found with extremely ultra low frequency PEMFs[21].

Back pain is endemic in North America. Lumbar arthritis is a very common cause of back pain. 35-40 mT PEMFs, for 20 min daily for 20-25 days successfully treat back pain[44]. This was shown in 220 patients and 60 controls. Relief or elimination of pain, improved rehabilitation and improvement of secondary neurologic symptoms. Continuous use over the treatment episode works best, in about 90-95% of the time. The control patients only showed a 30% improvement.

Chronic back pain treated for 2 to 12 years with PEMFs, which failed other treatment modalities, also improves[55]. PEMF is used at the site of pain and related trigger points for 20 to 45 minutes as found in single and double blind studies, in patients from 41 to 82 yr of age. The field strengths were from 5 to 15 G in the frequency range from 7 Hz to 4 kHz. Pain elimination was measured by visual analogue scale (VAS) scale. The VAS value 0, no pain to 10, maximum pain is recorded before and after each treatment session. Some patients remain pain free 6 months after treatment. Some return to jobs they had been unable to perform. Short term effects are thought due to decrease in cortisol and noradrenaline and an increase serotonin, endorphins and enkephalins. Longer term effects may be due to a CNS, peripheral nervous system biochemical and neuronal effects in which correction of pain messages occurs and the pain is not just masked as in the case of medication.

The benefits of PEMF use may last considerably longer than the time of use[5]. In rats, a single exposure produces pain reduction both immediately after treatment and at 24 hrs after treatment. The analgesic effect is observed also at 7th and 14th day of repeated treatment and also at 7th day and 14th day after the last treatment.

High frequency PEMF over 10-15 single treatments every other day either eliminates or improves, even at 2 weeks following therapy, in 80% of patients with pelvic inflammatory disease, 89% with back pain, 40% with endometriosis, 80% with postoperative pain, and 83% with lower abdominal pain of unknown cause[53].

PEMFs have also been found only slightly useful in treating pain, muscle spasms and swelling during wisdom tooth extraction[26] in a double-blind, controlled study with a high frequency system. As is often seen in pain studies, a placebo response is high, 30-40% of the time.

Pelvic pain of gynecological origin was also found to be benefited by a different high voltage, high frequency system[29]. This includes ruptured ovarian cysts, postoperative pelvic hematomas, chronic urinary tract infection, uterine fibrosis, dyspareunia, endometriosis and dysmenorrhea. Treatment times varied from 15 to 30 minutes on subsequent or alternate days. 90% experience marked, rapid relief from pain with pain subsiding within 1-3 days. Most patients don't require supplementary analgesics.

Post-herpetic neuralgia (PHN), a very common and painful condition, which is often medically-resistant, responds to pulsed magnetic field (PEMF) and whole body AC magnetic field (ACMF) stimulation[34]. PEMF therapy was for 20-30 minutes daily for 19 treatments over 34 days and ACMF therapy 30 minutes daily for 38 treatments over 85 days. The PEMF was a 4-16 Hz and 0.6-T samarium/cobalt magnet system surrounded by spiral coil pads with a maximum 0.1-T pulse at 8 Hz. The pads were pasted on the pain/paresthesia areas. The ACMF treatment bed consisted of 19 electrodes containing paired coils producing 0.08 T sine wave pulses. Three electrodes were applied to the head region, 3 to the thoracoabdominal region, 4 to the dorsolumbar region, 6 to the upper limbs, and 3 to the lower limbs. Both treatments continued until symptoms improved or an adverse side effect occurred. Pain was rated on a 10 point VAS scale and paresthesia on a 5 point scale. Outcomes were also evaluated clinically with infrared thermography and Doppler ultrasonography to assess blood flow. PEMF therapy was effective in 80%. No pain was made worse. ACMF therapy was effective in 73%. The average pain score following the first treatment was better for PEMF vs ACMF. This treatment approach shows again that treatment for pain problems may either be localized to the pain or done over the spinal column or limbs, away from the pain.

The use of PEMFs is rapidly increasing and extending to soft tissue from its first applications to hard tissue[47]. EMF in current orthopedic clinical practice is used to treat delayed and non-union fractures, rotator cuff tendinitis, spinal fusions and avascular necrosis, all of which can be very painful. Clinically relevant response to the PEMF is generally not always immediate, requiring daily treatment for several months in the case of non-union fractures. PEMF signals induce maximum electric fields in the mV/cm range at frequencies below 5 kHz. Pulse radiofrequency fields (PRF) consist of bursts of sinusoidal waves in the short wave band, usually in the 14-30 MHz range. PRF induces fields in the V/cm range. PRF signals have higher field strengths than PEMFs. PRF signals have low frequency bursts nearly equivalent in size to PEMFs. This means that PRF signals have a broader band. PRF applications are best for reduction of pain and edema. The tissue inflammation that accompanies the majority of traumatic and chronic injuries is essential to the healing process, however the body often over-responds and the resulting edema causes delayed healing and pain. For soft tissue and musculoskeletal injuries and post-surgical, post-traumatic and chronic wounds, reduction of edema is thus a major therapeutic goal to accelerate healing and associated pain. Double-blind clinical studies have now been reported for chronic wound repair, acute ankle sprains, and acute whiplash injuries. PRFs accelerated reduction of edema in acute ankle sprains by 5-fold. Response to MFs is during or immediately after treatment of acute injuries. Responses are significantly slower for bone repair. The voltage changes induced by PRF at binding sites in macromolecules affect ion binding kinetics with resultant modulation of biochemical cascades relevant to the inflammatory stages of tissue repair.

Treatment of persistent neck pain, studied in a double-blind, placebo-controlled trial, reduced pain and improved mobility with a low-power pulsed short wave 27 Hz diathermy system[18]. The neck pain lasted longer than 8 wk and was unresponsive to at least 1 course of nonsteroidal anti-inflammatory drugs. A soft cervical collar was fitted with a miniaturized, pulsed, short-wave diathermy generator. Each unit was powered by two 9-V batteries and had a frequency of 27 MHz. Treatments were for 3-6 weeks, 8 hr daily, analgesics could be used as needed and nonsteroidal anti-inflammatory drugs. 75% of the patients improved in range of motion and pain within 3 wk of treatment

PEMFs applied to the inner thighs for at least 2 wk is an effective short-term therapy for migraine. Greater reduction of headache activity is possible with longer exposure[62]. PEMF using a 27.12-MHz signal to the inner thigh femoral artery area for 1 hr/day, 5 day/wk, for 2 weeks decreases headache. One month after a treatment course, 73% of patients report decreased headache activity vs. only half of those receiving placebo treatment. Another 2-wk of treatment after the 1-month follow-up gave an additional 88% decrease in headache activity. If there is no additional treatment after an initial course 72% still show a benefit. Placebo patients getting active treatment afterwards report much better additional improvement in headache.

PEMFs have been found to have benefit in the treatment of neck pain in some studies, compared to physical therapy, for both pain and mobility[32].

Repetitive magnetic stimulation (rMS) has been found to relieve musculoskeletal pain[52]. Specific diagnoses were painful shoulder with abnormal supraspinatus tendon, tennis elbow, ulnar compression syndrome, carpal tunnel syndrome, semilunar bone injury, traumatic amputation neuroma of the median nerve, persistent muscle spasm of the upper and lower back, inner hamstring tendinitis, patellofemoral arthrosis, osteochondral lesion of the heel and posterior tibial tendinitis. Patients received rMS for 40 minutes. rMS was applied. 8,000 pulsed magnetic stimuli were applied in 40 min sessions. A VAS rated pain severity. Mean pain intensity 59% lower vs 14% for sham treated. Patients with amputation neuroma and patellofemotal arthritis obtained no benefit. Those with upper back muscle spasms, rotator cuff injury and osteochondral heel lesions showed more than 85% decrease in pain even after a single rMS session. Pain relief persists for several days. None had worsening of their pain.

Results obtained to date with PEMF therapy in animal models and clinical human studies suggest that this type of treatment can reduce edema, but only during treatment sessions[40]. PRF applied for 20-30 min causes a significant decrease in edema lasting several hours. PRF seems to affect sympathetic outflow, inducing vasoconstriction, which in turn restricts movement of blood constituents that promote edema from vascular to extravascular components at the injury site. The passage of electrical current through the tissue displaces negatively charged plasma proteins normally found in the interstitium of traumatized tissue. This increased mobility could accelerate protein uptake by lymphatic capillaries, thereby increasing lymphatic flow, an established mechanism for extracellular fluid uptake. Each pathological stage in an injury may require different PRF parameters for optimal effects. PRFs promote healing of soft tissue injuries by reducing edema and increasing the rate of reabsorption of hematomas.

Osteoarthritis (OA) affects about 40 million people in the USA. OA of the knee is a leading cause of disability in the elderly. Medical management is often ineffective and creates additional side-effect risks. The QRS has been in use for about 20 yr in Europe. The QRS applied 8 min twice a day for 6 weeks improved knee function and walking ability significantly[46]. Pain, general condition and well-being also improved. Medication use decreased and plasma fibrinogen decreased 14%, C-reactive protein 35% and blood sedimentation rate 19%. The QRS has also been found effective in degenerative arthritis, pain syndrome and inflammatory joint disorders. Sleep disturbances often contribute to increased pain perception. The QRS has also been found to improve sleep. 68% reported good/very good results. Even after one year follow-up, 85% claimed a benefit in pain reduction. Medication consumption decreased from 39% at 8 weeks to 88% after 8 weeks.

A 50 Hz pulsed magnetic field sinusoidal, 0.035 Tesla field PEMF for 15 min for 15 treatment sessions improved hip arthritis pain in 86% of patients. Average mobility without pain improved markedly[56].

Post-traumatic Sudeck-Leriche syndrome (late stage reflex sympathetic dystrophy - RSD) is very painful pain and largely untreatable. Ten 30-minute PEMF sessions of 50 Hz followed by a further 10 sessions at 100 Hz plus physiotherapy and medication reduced edema and pain at 10 days with no further improvement at 20 days[60].

Patients suffering from headache were treated with a PEMF over a 5-year period after failing acupuncture and medications[41]. PEMF applied to the whole body, 20 min/day for 15 days were very effective for migraine, tension and cervical headaches at one month after treatment. They had at least a 50% reduction in frequency or intensity of the headaches and reduction in analgesic drug use. Poor results were observed in cluster and posttraumatic headache.

Neuropathic pain syndrome (NPS) patients benefit from pulsed radiofrequency (PRF) treatment[45]. Patients had severe left-sided sciatica and back pain, neuropathic pain in the anterior chest wall associated with removal of a tumor from the left pleural cavity, left-sided sciatica in a classical sacral root distribution and low back pain and left sided sciatica. All patients had been taking oral medications and had received repeated injections of local anesthetic agents and steroids with poor results. The patients were treated with a 300-kHz PRF. Treatments were applied to left L5 dorsal root ganglion (DRG) for 2 minutes, the spinal roots of the T2-T4 dermatomes and the left L5 DRG and S1 root and to the left L5 DRG, respectively. All patients experienced significant pain relief.

Three hundred-fifty-three patients with chronic pain, treated with PEMFs[10], were followed for 2-60 months. They noted better results in patients with post-herpetic pain and in patients simultaneously suffering from neck and low back pain.

Research has shown that repeated presentation painful stimuli in rats significantly elevated the threshold of response to painful stimuli. One group[17] investigated the ability of magnetic pulse stimuli to produce increases in pain thresholds, simulating thalamic pain syndrome. Study rats were exposed for 20 min daily on 3 successive days to PEMFs. Controls were sham exposed. PEMF consisted of 1-sec pulses every 4 sec at a 5 x 10(-6) T (50 mG), for 20 min daily. Other rats were injected intraperioneally with saline, 4 mg/kg morphine sulfate, or 10 mg/kg naloxone. Exposure to the PEMFs increased the pain threshold progressively over the 3 days. There was a maintained elevation in pain supression for the PEMF treatment on the second and third days relative to other treatments. The pain thresholds following exposure to morphine, naloxone, or saline decreased between the second and third trials so that the threshold following the third magnetic field exposure was significantly greater than those associated with morphine and the other treatments. Brain injured and normal rats both showed a 63% increase in mean pain. PEMFs elicit prolonged pain suppression effects and this effect is larger than that produced by treatment with morphine, naloxone, or saline. This may be of clinical relevance for patients with closed head injuries. The duration and magnitude of PEMF analgesia suggests that the mechanism may involve endorphins rather than enkephalins.

Chronic pain is often mediated by aberrantly functioning small neural networks involved in self-perpetuated neurogenic inflammation. High intensity pulsed magnetic stimulation (HIPMS) noninvasively depolarizes neurons and can facilitate recovery following injury[12]. Patients suffering from posttraumatic or postoperative low-back pain, reflex sympathetic dystrophy, peripheral neuropathy, thoracic outlet syndrome and endometriosis had pain relief. Up to ten,10-min exposures to 1.17 T at a rate of 45 pulses/min using a custom-built magnetic stimulator were applied to the areas of maximal pain for 6 treatments and 4 sham treatments in random order. Pain was rated on a VAS. One patient became pain free after 4 HIPMS treatments. All patients reported some pain relief. Pain relief ranged from 0.4 to 5.2 vs 0 to 0.5 for sham treatments. The average amount of pain relief per 10-minute treatment was 1.86 for HIPMS and 0.19 for sham treatment. Maximum pain relief occurred 3 hr after treatment. Two patients had complete pain relief and 3 had partial pain relief that lasted for 4 months. The other subjects experienced pain relief that lasted for 8-72 hr. The action of HIPMS on pain is probably mediated by eddy currents induced in the exposed tissues.

Chronic musculoskeletal pain treated with MFs for three days, at one per day. EMF is an alternative to standard therapeutic practices, in the elimination and/or maintenance of chronic musculoskeletal pain[64].

The chronic pain frequently presented by postpolio patients can be relieved by application of magnetic fields applied directly over an identified pain trigger point [73]. This was shown in a double-blind randomized clinical trial. 300 to 500 Gauss magnetic devices for 45 minutes, assessed by an objective measurement result in significant and prompt relief of pain.

A double-blind clinical study evaluated the effectiveness of low strength extremely low frequency PEMFs for treating knee pain in osteoarthritis[27]. Treatment was for eight 6-min sessions over a 2-wk period. Each patient recorded perceived pain on a 10-point scale before and after each treatment session. Patients did not use pain medication or other pain treatment. The active treatment group perceived a 46% decrease in pain vs. an average 8% in the placebo group. 2 wk after the study concluded, pain decreased 49% vs the the placebo group's 9% decrease.

Weak AC magnetic fields affect pain perception and pain-related EEG changesin humans[59] . 2 hr exposure to 0.2-0.7G ELF magnetic fields in a placebo-controlled double-blind crossover design caused a significant decrease in pain-related EEG levels.

In periodontal disease bone resorption may be severe enough to require bone grafting. Grafting is followed by moderate pain peaking several hours afterwards. Repeated PEMF exposure for two weeks eliminated pain within a week[66]. Even single PEMF exposure to the face for 30 minutes of a 5mT field and conservative treatment produced much lower pain scores vs controls.

PEMFs are a real aid in the therapy of orthopedic and trauma problems[3] after even only 6 months of experience.

A static magnetic foil placed in a molded insole for the relief of heel pain was used for 4 weeks to treat heel pain[4]. 60% of patients in the treatment and sham groups reported improvement. There was no significant difference in the improvement on a foot function index. A molded insole alone was effective after 4 weeks. The magnetic foil offered no advantage over the plain insole, in this study. This study like others with low numbers of patients, may not have had a large enough sample. Placebo reactions in pain studies can be large and differences in benefit may be harder to detect. In addition, since magnetic foils produce fairly weak fields, placement against tissue becomes important, as does consideration of the depth into the body of the target lesion or tissue[40]. Magnetic fields drop off in strength very rapidly from the surface[47].

Pain relief mechanisms vary by the type of stimulus used[65]. For example, needling to the pain-producing muscle, application of a static magnetic field or external qigong or needling to an acupuncture point all reduce pain but by different mechanisms. This was studied experimentally in guinea pigs. Pain could be induced by reduction of circulation in the muscle and reduced by recovery of circulation. Pain mediating substances may be accumulated in a muscle under reduced circulation, and such an accumulated substance might be eliminated by recovery of circulation. Atropine increases muscle pain. Cutting a nerve does not affect direct muscle stimulation but does eliminate the acupuncture effect. Capsaicin abolishes a direct muscle effect. Substance P and a calcitonin gene-related peptide (CGRP) reduces pain. Atropine blocks the effect of CGRP, but not substance P. The effect of static magnetic field or external qigong was equivalent to that of anticholinesterase. Muscle pain relief is induced by recovery of circulation due to the enhanced release of acetylcholine as a result of activation of the cholinergic vasodilator nerve endings innervated to the muscle artery. Pain reduction by needling the pain-producing muscle might be induced by axon reflex of the CGRP nerve, by using a static magnetic field or external qigong might be induced by inhibition of cholinesterase and needling to an acupuncture point might be induced by a somato-autonomic reflex through the brain, in the anterior hypothalamus.

Pain patients with lumbar radiculopathy or whiplash syndrome had a PEMF applied twice a day for two weeks and their pain medications decreased[70]. Radiculopathy pain relief happened in 8 days in the PEMF group vs 12 days in the controls. Headache pain was halved in the PEMF group and one third less of neck and shoulder/arm pain vs control.

In normal subjects, a magnetic stimulus over the cerebellum reduced the size of responses evoked by magnetic cortical stimulation[72]. Suppression of motor cortical excitability was reduced or absent in patients with a lesion in the cerebellum or cerebellothalamocortical pathway. Magnetic stimulation over the cerebellum produces the same effect as electrical stimulation, even in ataxic patients and may be useful for the pain associated with muscle spasticity.

Even small, battery-operated PEMF devices with very weak field strengths have been found to have a benefit in musculoskeletal disorders[16]. This matchbox-sized device was tested in a non-controlled fashion in a general medical practice in a wide age range of individuals. They were treated for between 11 to 132, or 73 days on average, at the site of pain and ranged between 2 times for 4 hours each week to continuous use. Use at night was mainly near the head, e.g., beneath the pillow, to facilitate sleep. Their pain scale scores were statistically significantly positive in the majority of the cases. The conditions treated were arthritis, lupus erythematosus, chronic neck pain, epicondylitis, femoropatellar degeneration, fracture of the lower leg and Sudeck's atrophy.

Chronic low back pain affects approximately 15% of the United States (US) population during their lifetime, with 93 million lost work days and a cost of more than $5 billion per year. Permanent magnetic therapy can be a useful tool in reducing chronic muscular low back pain[50]. The patients were treated with a real or sham flexible permanent magnetic pad for 21 days. Diagnoses included herniated lumbar discs, spondylosis, radiculopathy, sciatica, arthritis. Pain response was measured using a 5 point VAS scale. The experimental group had a significant mean reduction in pain of 1.83 points, while the control group had a mean reduction in pain of 0.333 points ($P>0.006$). Pain relief varied was experienced as early as 10 minutes to 14 days.

Patients with musculoskeletal ailments were treated solely using a broad band very low strength PEMF mattress-like device (QRS) [33]. The patients had no prior surgery for their ailments. Diagnoses included intervertebral disc prolapse, spinal stenosis and osteoporosis. They received 20 sessions of 8 minutes, twice daily over two weeks. Pain was assessed by a 10 point VAS scale and forward bending ability. Pain was significantly reduced and flexibility in bending was also highly improved.

A report of a series of 240 patients[33] treated with PEMFs in a conservative orthopedic practice found decreased pain, increased functionality and ability to take pressure, disappearance of swelling and pathological skin coloration, removal of need for orthopedic devices and decreased reaction to changes in the weather. Treatments were daily for an hour long. Conditions treated were: rheumatic illnesses, delayed healing process in bones and pseudo-arthritis, some with infections, fractures, aseptic necrosis, loosened protheses, venous and arterial circulation, reflex symapatheic dystrophy all stages, osteo-chondritis dissecans, osteomyelitis and sprains and strains and bruises. Their success rate approached 80%. Many cases had X-ray improvement. They observed reformation of cartilage/bone tissue in one case of destructive cyst of the the hip joint, including reformation of the joint margin. About 60% of loosened hip protheses subjective relief occurred and ability to walk without a cane. X-rays frequently showed a seam of absorption which continued after magnetic field therapy was over. One case of Perthes' disease had complete reformation of the articular head of the hip.

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