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Headache Treatment with Pulsing Electromagnetic Fields: A Literature Review

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Abstract Pulsing electromagnetic field (PEMF) therapy may be a viable form of complementary and alternative medicine. Clinical applications include the treatment of fractures, wounds, and heart disease. More recent applications involve treatment of recurrent headache disorders. This paper reviews available studies investigating PEMF for headache management. Possible mechanisms for effects (neurochemical, electrophysical, and cardiovascular) are discussed. The available data suggest that PEMF treatment for headache merits further study. Suggestions for future research are provided.

Keywords Complementary and alternative medicine (CAM) · Headache · Pulsing electromagnetic fields (PEMFs)

Introduction

The Institute of Medicine's Committee on the Use of Complementary and Alternative Medicine (CAM) in the U.S. (2005) notes that the prevalence of use ranges from 30% to 60% among adults depending on the CAM definition used. CAM may include, but is not limited to, acupuncture, Transcendental Meditation, massage, etc. Out-of-pocket costs for CAM are estimated to be greater than $27 billion in the U.S. (Institute of Medicine 2005). Given the percentage of the adult population in the U.S. that may be using CAM and the amount of money they may be spending on it, such therapies merit closer examination. CAM therapies have been used to treat headache in a number of studies (Long et al. 2001) and some CAM therapies have been found to be successful in alleviating headache (Vernon et al. 1999).

The National Center for Complementary and Alternative Medicine (2000) listed energy-based therapies (e.g., biofield therapies such as qi gong and Therapeutic Touch and bioelectromagnetic field therapies such as pulsing electromagnetic fields) as one of the five categories of CAM, which are inexpensive relative to most conventional medical alternatives. The purpose of this review is to examine the available research on the clinical use of one of these energy-based therapies, pulsing electromagnetic field (PEMF) therapy, for headache. We begin with a brief history of PEMF, which is then followed by a discussion of theorized mechanisms of action. Extant studies employing PEMF are then reviewed. We conclude with suggestions for future research endeavors.

A Brief History of PEMF Therapy

PEMF therapy has long been in development. For centuries, electromagnetic therapeutic methods have been used in a number of clinical applications. These applications range from the use of electric fish to treat headache and arthritis in second century A.D. (Stillings 2004), to the more recent use of PEMFs to treat union and nonunion bone fractures (e.g., Technology Evaluation 1989).

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In the 19th century, Lente (1859) documented cases of slow-healing bone fractures treated by passing direct currents though needles placed in the fracture gap. Although the clinical use of electrical stimulation for bone fractures was suggested to be effective, electrotherapies were abolished, in part, because they were misguidedly used to treat other ailments, such as cancer and the common cold (Oschman 2004). Oschman noted that electrotherapies reemerged in the 1950s and 1960s as a result of key studies in the United States and Japan (Bassett et al. 1964; Yasuda 1953) showing that direct currents stimulate bone healing in animals. It was soon discovered that currents could be induced to flow through the bone fracture site by using PEMFs (Oschman) and that direct, electrical stimulation using needles could be replaced with non-invasive PEMFs.

In 1982, the utility of PEMFs for bone healing had been confirmed for 1007 nonunion bone fractures (Bassett et al. 1982). By 1995, PEMFs had been used to treat 300,000 nonunion fractures with no observed adverse events. About 20% of the 100,000 slow-healing fractures in the United States are treated with PEMFs, while the other 80% are treated with surgical techniques that cost two to three times more and are associated with more complications. Since the Food and Drug Administration approved a PEMF generator for clinical use in the United States for the first time in November 1979, over 17,500 members, approximately 87.5% of the American Academy of Orthopedic Surgeons, have prescribed PEMFs at least once (Oschman 2004).

PEMF therapy has emerged as an alternative treatment that may hold promise for applications other than bone healing. The research literature shows that PEMF therapy has now been investigated for use with a variety of ailments. These include, as examples, bed sores (Duma-Drzewinski and Buczynski 1978), hypertension (Kniazeva et al. 1994), and migraine headache (Sherman et al. 1999). Appendix A illustrates the range of applications for which PEMFs have been used. While many of these studies examined the effects of PEMF therapy, few have attempted to elucidate the mechanism of action of PEMFs for these diverse clinical problems (Lappin 2004).

Theorized Mechanisms of Action for Headache Treatment

There are currently no studies that actually demonstrate how pulsing electromagnetic fields produce clinical effects (Lappin 2004; O'Connor et al. 1990; Pennington et al. 1993), however, a number of studies have shown that PEMFs produce physiological effects. How these effects are produced is simply guesswork. Several types of rationales for the therapeutic effects of PEMFs on headache have been proposed. These rationales include neurochemical, electrophysiological, and vascular phenomena.

Neurochemical Rationale

Lappin (2004) reviewed the literature and described possible neurochemical and electrophysiological mechanisms that may underlie the effects of PEMFs on headache. She noted that animal and human studies suggest that weak electromagnetic fields (EMFs; 0.5–2 mT) at 60-Hz may act on neurotransmitters implicated in the pathophysiology of migraine, such as endorphins, melatonin, cortisol (i.e., abnormal regulation of the hypothalamic–pituitary–adrenocortical axis), and serotonergic and dopaminergic systems. PEMFs may act on neurotransmitters in a manner similar to proposed explanations for why transcranial magnetic stimulation (TMS) reduces symptoms of depression (decreasing cortical excitability and metabolism in some patients, while having the opposite in others, depending upon the frequency used; Gershon et al. 2003). Migraineurs may be four times more likely than non-migraineurs to suffer from depression, indicating high comorbidity (Merikangas and Rasmussen 2000). Lappin cited that migraine and depression might share a minimum of one underlying neurotransmitter or regulatory dysfunction of the central nervous system, making the two disorders amenable to the same treatments.

Electrophysiological Rationale

With regards to electrophysiological mechanisms that may underlie the effects of PEMFs on headache, Lappin's (2004) review suggested that low-frequency stimulation (e.g., 1 Hz) by TMS may decrease excitability of the motor cortex and high-frequency stimulation (e.g., 20 Hz) may increase cortical arousal in normal populations. She cited that the opposite pattern might be true in those with abnormal levels of cortical arousal, such as migraineurs and depressive patients. This is consistent with a growing body of literature showing that migraineurs exhibit abnormal cortical excitability and deficient inhibition (Andrasik and Rime 2007; Schoenen 2006; Siniatchkin et al. 2006). In migraineurs, cortical hypersensitivity and deficient habituation in response to visual and auditory stimuli peak just before migraine onset. These abnormalities tend to normalize during migraine attacks. It may be that migraines help the brain to return to regular, homeostatic functioning after overstimulation.

Another possibly related electrophysiological phenomenon that may be affected by PEMFs is Leão's (1944a, b) cortical spreading depression (CSD), a silencing of cortical activity that spreads over most of the brain within minutes. When CSD occurs in a cortical area, neither sensory stimulation nor direct cortical stimulation can evoke a response (i.e., an event-related potential; ERP) in that area. CSD can be triggered by electrical stimulation. For decades, CSD has been linked with migraine due to the similarity between CSD and the propagation of sensory disturbances in the cortex at the beginning phase of migraine attacks. Lauritzen (2001) stated that migraine attacks might be initiated by CSD marching from posterior to anterior regions of the brain, triggering a prodromal migraine phase and sustained decreases in cortical blood flow. Furthermore, a number of studies have supported the assertion that CSD may be related to migraine and factors associated with migraine, such as migraine pain, migraine aura, the endrocrine system, serotonin, and cerebral blood flow (Gorji 2001). Gorji noted the likelihood that a central theory of migraine etiology will be developed and that CSD will be part of this theory.

Okada et al. (1988) detected magnetic fields from CSD triggered by electrical pulses (e.g., 5-ms 20-Hz train of 50 μs monophase pulses; 500-ms 100-Hz train of 50 μs monophase pulses) applied to the brain of a red-eared turtle. The spatial patterns of the magnetic fields from the resulting CSD varied with the frequency of the electrical pulse used to trigger the CSD. Unfortunately, there appear to be no studies that have measured the effects of PEMFs on CSD in animals or humans. However, Hanke et al. (2001) used standard video imaging techniques to show that EMFs can be used to control the excitability of neuronal tissue in retinal spreading depression in animals. The retina, which consists of neuronal tissue, was used as a model because it was considered part of the central nervous system. Possible means of detecting CSD in humans are currently under investigation. Lauritzen (2001) noted the difficulty of non-invasively measuring CSD in living humans as opposed to using the removed brains of animals planted with electrodes in basic science studies.

Cardiovascular Rationale

Vascular models of migraine have been much discussed in the headache literature, and this focus continues to date (Colson et al. 2006; Peroutka 2005). There is some indication that PEMF may influence blood flow. For example, Erdman (1960) recorded peripheral blood flow in 20 normal participants using both a temporal probe and volumetric measurements while they were exposed to pulsing electromagnetic fields. He found a high correlation between the amount of energy produced by the generator and peripheral blood flow, with increases beginning within about 8 min and plateauing by 35 min. Pulse rate and rectal temperatures did not change. Ross (1990) recently reviewed the basic science and animal studies as well as some of the clinical studies showing the effectiveness of pulsing electromagnetic field generators in increasing blood flow and wound healing.

Possible Synthesis Between Ostensibly Disparate Proposed Mechanisms

On the other hand, changes in blood flow associated with migraine may be secondary to disturbances in neuronal function, such as CSD (Lauritzen 2001). In other words, migraine-associated blood flow abnormalities may be a by-product of neuronal (e.g., electrophysiological, neurochemical) events. For example, experimentally triggered CSD may be accompanied by vasodilation and increases in cerebral blood flow that may exceed increases in the demand for oxygen (Leão 1944a). Irrespective of which phenomenon is primary, vasodilation, blood flow, and CSD may be related. Multiple factors (e.g., blood flow, CSD, neurotransmitters) may be part of the mechanism underlying migraine headache (Gorji 2001). Further study is needed to determine the pathogenesis of migraine and, thus, the underlying mechanism by which PEMFs have their effects on migraine.

Studies Examining the Use of PEMFs for Treating Headache

There are a handful of studies that report on the clinical utility of PEMFs for headaches. These include a case study, as well as uncontrolled and controlled trials. In the mid-1980s, Grunner (1985) published the results of an uncontrolled study with 27 female and 13 male neuropsychiatric patients, all experiencing long-term headaches. An ovular apparatus (a Magnetodiapulse-2, manufacturer information unavailable) emitting the fields was fit snuggly around the participants' head, framing the face. Participants ranged in age from 18 to 57. The pulsed fields had the following waveform characteristics: 260 Hz and 1.9 μT. In contrast to other available articles, the author further reported on the gradient (0.5 μT/cm) and duration (t = 2 μs) of the waveform used. Participants received random sequences of active versus placebo treatment in this within-subjects study. Participants provided subjective reports on their symptoms, which were compared with EEG readings taken from them. Grunner stated that participants endorsed relief of subjectively reported headache symptoms, which corresponded with EEG readings. In particular, EEG readings corresponded with symptoms of patients who had cerebral arteriosclerosis, states associated with cerebral concussion, depression, and tension headache. The author cautioned that waveforms greater than 50 Hz and 20 μT should not be applied directly to the head.

Later, Prusinski et al. (1988) published the results of a PEMF treatment on 90 patients who had been unsuccessfully treated with acupuncture and drugs in the past. The patients received PEMFs (waveforms unreported) for 20 min per day for 15 days. The investigators evaluated patients one month after treatment. The investigators noted that the results were excellent (complete reduction in headache) to good (headaches reduced by 50% or more) for most patients with migraine, tension, and cervical headache. They further stated that patients with cluster and post-traumatic migraine generally demonstrated fair (less than 50% improvement) or no treatment effects.

Four years later, Sandyk (1992) reported on a case study in which a 42-year-old Greek woman was exposed to fields of 2–7 Hz and 7.5 pT. The researcher used the Ergo® device (Athens, Greece). The participant suffered from attacks of migraine, as she described them. When first given a placebo treatment, no changes were observed. An hour and one half later, the participant received the active treatment. About 45 min after treatment, the participant reported that her headache symptoms began to ameliorate. One hour and 10 min after treatment, the participant complained of sleepiness and heaviness of the head. The following morning, the participant was re-examined. She described her sleep as deep and reported that she had no symptoms of headache. The participant stated that she had never experienced such a rapid improvement of these symptoms. However, the researcher did not report any follow-up data beyond the morning after treatment.

Later, in the early 1990s, Young and Davey (1993) examined the clinical effects of an early version of the Enermed (Energy Medicine Developments, Vancouver, B.C.) PEMF device on 54 participants with migraine in an uncontrolled outcome study. The waveform of fields emitted by the devices ranged from 3 to 12 Hz. Participants wore the device for 3 months. The small devices used in this investigation can be worn near the head for up to 24 h a day. However, it is unclear whether the participants were prescribed to wear the devices continuously or at specific time intervals, thus the dosage of treatment is unknown. Participants' headache logs suggested that the frequency of headaches dropped by one-half, from 1.2 to 0.6 per week. Participants also reported significant reductions in duration and severity of symptoms. This investigation lacked a control/comparison group and no follow-up measures were reported. Thus, the available information on this study is limited.

In 1995, Lappin (2004) followed with an uncontrolled study of 1,000 consumers who had purchased early versions of the Enermed PEMF device. The results of this 1995 study are part of an internal report. In the study, copies of a brief questionnaire that included ratings of both pre- and post-treatment symptoms were mailed to the participants. The response rate was 42%. Of those who responded, 262 purchased the Enermed for migraine symptoms. On a scale of 1–10, 94% reported severe pre-treatment symptoms (scores seven to 10). Reports of post-treatment symptom severity indicated a reduction, with only 21% of participants reporting severe problems remained after treatment. Two-thirds of the sample (63%) reported improvements in symptoms of 5 points or more based on the 10-point rating scale.

Several years later, in 1999, Lappin (2004) studied the clinical effects of the Enermed device in an NIH-funded, double-blind, placebo-controlled trial. Participants were randomized to a treatment group (n = 21), a subgroup of the control group that received inactive placebo devices (n = 9), or another subgroup of the control group that received a device programmed to emit a single 2-Hz frequency field (n = 9). The waveform of the fields emitted during the active treatment ranged from 4 Hz to 15 Hz. There was no significant difference between the two control subgroups. The average number of headaches per month for the control subgroups combined, which was 6.7, remained unchanged. The average number of headaches for participants in the active treatment group decreased from 7.2 to 4.8 headaches per month. Approximately one-fourth of the control group saw a reduction of 25% or more in the number of days in which they experienced migraine, while roughly half of the active treatment group saw a reduction of 25% or more. Age and gender seemed to interact, in that postmenopausal women greater than or equal to the age of 55 experienced no substantial decrease, which was in contrast to the rest of the active treatment group. The researcher attributed this disparity to the relationship between fluctuations in hormonal activity and headache activity among women who suffer from migraines.

Using a waveform of greater frequency and strength (27.12 MHz, t = 65 μs, unknown strength value) and a different device (Diapulse®; Diapulse Corporation of America, Great Neck, NY), Sherman et al. (1998) performed a two-part pilot study testing the therapeutic effects of PEMFs on headache in 23 participants between the ages of 20 and 73 (19 females and 4 males). Unlike other studies investigating the clinical use of PEMFs for headache, the researchers used the medial thigh area as the anatomical site of treatment. They chose the inner thigh area, in part, because of comments made by a patient that they were treating for a nonunion fracture involving the knee. This patient reported that her migraine headaches had ceased shortly after PEMF treatment and noted that her headaches did not return for months after treatment.

The first part of their study (Sherman et al. 1998) was an uncontrolled examination of the use of PEMFs with 11 of the participants. The average number of headaches during the pre-treatment period was 4.03 (±2.02) headaches per week. During treatment, the average number fell to 0.43 (±0.36) headaches per week (p = .001; paired t = 5.998, df = 10). The average number of headaches continued to decrease to 0.14 (±0.08) headaches per week during follow-up (p = .001; paired t = 5.77, df = 9).

In the second part of their study, Sherman and colleagues (1998) conducted a double-blind, placebo-controlled examination with the 12 remaining participants who were randomly assigned to either a placebo condition or a treatment condition. The criteria for inclusion were the same. Half of the participants in each condition had migraine with auras. Sherman and associates incorporated a crossover design in which participants were asked to switch from the treatment condition to the placebo condition and vice versa. However, only one participant in the active treatment condition agreed to complete the crossover.

Attrition of this type can make a crossover design problematic. Partly in response to the problem of attrition, Ernst and Resch (1995) described an optional crossover design that could be incorporated into randomized, placebo-controlled clinical trials. In this optional crossover, patients are asked whether they would like to continue receiving the treatment they are receiving, which could be the placebo or active treatment, or if they would like to crossover to the alternate condition. The research staff and the participants remain blind to condition and crossover sequences. The researchers can then analyze the data on the participants' choices. If participants perceive an improvement in their condition in response to the placebo treatment, then they will likely choose to remain in the placebo condition. In the same manner, the investigators may use the participants' choices regarding the active treatment.

This optional crossover design may compromise the results of a PEMF treatment outcome study, however. Unlike many short-acting pharmaceutical agents, PEMF therapy may have long-lasting effects. In essence, PEMF therapy may be more similar to behavioral and surgical procedures with respect to the duration of post-treatment effects. For example, a crossover design may not be feasible in a study on relaxation training in an individual with tension-type headache. Participants will have learned skills that may not be unlearned after crossover to a control condition. In a study on a surgical technique, the surgeon may not be able to undo the surgical procedure or the effects of the procedure. If PEMF therapy produces effects that last months, if not years, then a crossover design may present a significant confound when examining the results.

Sherman and colleagues (1998) were still able to use data from nine of the 12 participants. They found that, for the treatment condition, headaches where reduced from 3.32 (±1.40) headaches per week to 0.67 (±0.26) during the exposure period (p = .003; paired t = 5.56, df = 5). During follow-up, headaches averaged 0.58 (±0.80) per week (p = 0.001, paired t = 7.81, df = 5). The overall difference between periods was significant, as revealed by a significant one-way repeated measures ANOVA (p = 0.0001, F = 35.67).

In another double-blind, placebo-controlled study using the same waveform and device, Sherman et al. (1999) examined PEMFs in 42 participants (34 female and 8 male) between the ages of 20 and 72. Participants met the criteria of the International Headache Society for migraine headache. Participants were randomized to either the placebo (20 participants) or the treatment (22 participants) condition. Some participants had concurrent mixed, sinus, or cluster headaches. However, roughly half of the participants in each condition had migraine only. Participants completed standard headache logs, rating their headaches on a scale of 1 (no pain) to 10 (pain strong enough to make participants faint if it persisted for another second). Of the 22 participants in the treatment condition, 73% reported decreased headache severity (14% assessed as having a minor reduction, 45% as having a good reduction, and 14% as having an excellent reduction). The rest of these participants reported no change in headache severity. None reported worsened headache severity. In contrast, one half of the participants in the placebo condition reported decreased headache severity (30% judged to have minor reduction in headache, 20% assessed as having good reduction). None of the participants in the placebo condition reported excellent reduction. Reports of headache severity actually worsened for 15% of the participants in the placebo condition. The rest of the participants in the placebo condition, 35%, reported no change in headache severity. Ten participants in the treatment condition received two additional weeks of treatment exposure after the initial 1-month follow-up. All showed decreased headache activity. Of these, 12% were assessed as having a minor decrease, 50% were judged as have a good decrease, and 38% were described as having an excellent decrease in headache activity). Of participants in the treatment condition that elected not to receive additional treatment exposure, 12 (92%) showed decreased headache activity by the 2nd month of treatment (20% minor decrease; 29% good decrease; 43% excellent decrease). Among participants in the placebo condition, eight chose to receive 2 weeks of treatment exposure after the initial 1-month follow-up. Their results were favorable as well, with 75% showing decreased headache activity (38% good, 38% excellent).

In one of the most rigorous studies on PEMF therapy and headache, Pelka et al. (2001) examined 46 women and 36 men between the ages of 16 and 66 in a double-blind, placebo-controlled study. Of these 82 participants, data from 77 could be analyzed. The participants were randomly assigned to an active treatment group or a control group. Most participants had either migraine (27%) or mixed migraine and tension headache (23%). Others had tension (15%), cluster (7%), weather-related (13%), or post-traumatic headache (10%). Finally, some had a headache of an origin not listed (5%). Participants were instructed to keep the PEMF device, the Reductor C (Migomed; Meteco, Berlin, Germany), no more than 12 inches away from the head on a ribbon worn around the neck. The waveform of the fields to which participants were exposed was 16 Hz in frequency and 5 μT. In the treatment group, all assessed criteria showed significant improvement at the end of the four-week study ($p < .0001$ vs. baseline vs. placebo). Seventy-six percent of treatment patients showed clear or very clear relief of their complaints. Only one patient (2.5%) in the placebo group reported feeling some relief, 8% endorsed slight relief, and 2% claimed significantly worse symptoms. Unfortunately, the researchers did not report on any follow-up assessments beyond the four-week post-treatment period.

Table 1 summarizes these studies. The table presents descriptive information, with a particular focus on the PEMF devices and waveforms used, as well as the outcomes obtained. Most of these studies, described here in further detail, were published within the past two decades. Limited information was available on four of the headache treatment studies discussed in this paper. Information for the study reported by Prusinski et al. (1988) in a symposium was gleaned from the abstract, which was the only information available to the others. The study by Young and Davey (1993) and the two headache studies by Lappin (2004) were obtained from *Bioelectromagnetic Medicine*, a secondary source. The study by Grunner (1985), published in German, was not available in English. A student of ours who speaks German as a native language assisted with the translation of this publication.

Conclusions

Some of the available studies investigating the use of PEMFs for the treatment of headache did not include a control or comparison group. Those that were placebo-controlled have not compared PEMFs to existing accepted treatments, for purposes of benchmarking. In addition to clarifying the degree to which PEMF therapy is helpful, a comparison of PEMF therapy to traditional, more common approaches, such as drug therapies, would help to determine whether PEMF therapy is an equivalent and/or a more cost-effective alternative. Furthermore, many of the studies had very brief follow-up periods. Longer follow-up periods will be needed in order to help determine whether any therapeutic benefits resulting from the use of PEMFs endure over time. Given the high cost of many traditional medical treatments, an effective, less expensive treatment with long-lasting effects could potentially contribute to a reduction in healthcare costs in the U.S. Although the studies on the use of PEMFs for the treatment of headaches are limited, they suggest that further inquiry is warranted.

None of these published studies reported any adverse events among participants. Exclusion criteria included pregnancy (Sherman et al. 1999), acute infectious or organic diseases, such as the occurrence of arteriosclerosis, diabetes mellitus, ulcer, a serious operation, or an infarction within the 12 months preceding study participation (Pelka et al. 2001) and headaches resulting from tumors (Grunner 1985). The youngest study participant reported in the PEMF-headache studies was 16 years old (Pelka et al. 2001). Das Sarkar and Bassett (1991) published a case study of a child who received PEMF treatment for a non-union bone fracture in his humerus.

The results of PEMF treatment for headache are encouraging; yet further, rigorous study is clearly merited. CAM therapies, such as PEMF, may prove to be a viable alternative to more expensive forms of traditional treatment (Institute of Medicine 2005). The Institute of Medicine (2001) issued a report asserting that conventional care is plagued by a number of issues, which include preventable errors, widespread disparities in the rates of use (even for procedures such as surgery) even within similar populations in different regions of the U.S., underutilization of effective care, and over utilization of less effective procedures. If research shows that CAM therapies such as PEMF treatment can help to alleviate problems in traditional health care by providing effective, less expensive alternatives, then the current health care system may be charged with the task of making these alternatives more readily available to patients who may benefit.

With regard to PEMF therapy in particular, future research would profit from adoption of current criteria for classifying/diagnosing headaches, greater inclusion of appropriate control or comparison conditions, incorporation of improved measures of outcome (Andrasik 2001; Andrasik et al. 2005), and performing “benchmark” comparisons (with existing, established medical and behavioral treatments). As regards headache diagnosis, greater attention needs to be given to consideration of frequency of presentation. The most current classification scheme distinguishes between (a) infrequent (at least 10 episodes occurring on less than 1 day per month or 12 days per year on average), (b) frequent (at least 10

Table 1 Research examining the use of PEMF therapy for headache

Author and date	Diagnoses	Sample size	# Female (F) & male (M) in sample	Age range	Device name	Waveform	Design	Amount of Tx	Longest follow-up	% Drop out	Outcome
Grunner (1985)	Headaches (unknown types)	40	27 F, 13 M	18–57	Magnetodiapulse 2	260 Hz, 1.9 μT, t = 3 ms	Random sequence/ assignment of active and placebo tx	0.5 h	–	–	Headache symptoms reduced
Lappin (2004) (1995 study)	Migraine	262	–	–	Enermed	–	Repeated measures, no control group	–	–	58% did not respond	94% reported severe symptoms before treatment, 21% reported severe symptoms after treatment; 63% of participants reported 50% improvement
Lappin (2004) (1999 study)	Migraine	20	–	–	Enermed	–	Double-blind, placebo-controlled	–	–	–	Mean # headaches decreased in treatment, not control; ½ of treatment and ¼ of control had at least 25% decrease in headache
Pelka et al. (2001)	Migraine, mixed headache,[a] tension, weather-related, post-traumatic, & other unspecified headaches	77	46 F, 36 M	16–66	Reductor C (Migomed)	16 Hz, 5 μT	Double-blind, placebo-controlled	4 weeks (device worn on ribbon around neck; treatment dosage unknown)	4 weeks	6.1%	Improvement in all assessed criteria; 76% treatment participants improved compared to 25% placebo participants

Table 1 continued

Author and date	Diagnoses	Sample size	# Female (F) & male (M) in sample	Age range	Device name	Waveform	Design	Amount of Tx	Longest follow-up	% Drop out	Outcome
Prusinski et al. (1988)	Migraine, tension, cervical, post-traumatic, & cluster headaches	90	68 F, 22 M	25–65	Vitanova-Automatik	–	Repeated measures, no control group	20 min/day for 15 days	1 month	9.4%	Patients with migraine, tension, and cervical headaches reported excellent to good results; those with post-traumatic or cluster headaches did not benefit
Sandyk (1992)	Migraine attacks	1	1 F	42	Ergo[r]	2–7 Hz, 7.5 pT (pico-Tesla)	Case study; placebo then treatment	7 min of exposure	<1 day	N/A	Complete relief of patient-reported symptoms
Sherman et al. (1998)	Primarily migraine, with and without auras; several with mixed headache[a]	23	19 F, 4 M	20–73	Diapulse D103	27.12 MHz in 65 µs bursts	Uncontrolled pilot study followed by double-blind, placebo-controlled study with crossover	1 h/day, 5 days/week for 2–3 weeks	14 month for open study, 6 month for controlled study	In placebo 85.7% declined to crossover from actual to placebo treatment; otherwise, 0% drop out	Open study: headaches reduced on average from about 4.03 headaches per week to 0.43 per week, with continued reduction during follow-up (about 0.14 per week); controlled study: headaches treated with PEMF reduced during exposure (from 3.32 per week to 0.67 per week) and follow-up (0.58 per week)

Table 1 continued

Author and date	Diagnoses	Sample size	# Female (F) & male (M) in sample	Age range	Device name	Waveform	Design	Amount of Tx	Longest follow-up	% Drop out	Outcome
Sherman et al. (1999)	Primarily migraine; half had migraine only; some concurrent mixed,[a] sinus, & cluster headache	42	24 F, 8 M	20–72	Diapulse D103	27.12 MHz in 65 μs bursts	Double-blind, placebo-controlled study without crossover	1 h/day, 5 days/week for 2 weeks	Up to 16 months	7.1% dropped out; 7.1% with tension headache only were removed	73% of treatment group showed decrease in headache while 50% placebo group reported decreased headache. Headaches worsened for 15% of the placebo group
Young and Davey (1993	Migraine	54	–	–	Enermed	3–12 Hz	Repeated measures, no control group	Device worn for 3 months; unknown dosages	–	–	Average number of migraines dropped by half

–, Information not available

[a] Mixed headache indicates migraine mixed with tension headache

episodes occurring on one or more but less than 15 days per month for at least 3 months), and (c) chronic forms (occurring on 15 or more days per month on average for greater than 3 months) of headache (Headache Classification Subcommittee 2004). The frequency distinction is important because, all things remaining equal, the greater the frequency the poorer the treatment response. Further, more recent research has identified certain headache types that are particularly difficult to treat (such as medication overuse, post-traumatic, and cluster headache and headaches accompanied by psychiatric comorbidities; Andrasik 2007; Grazzi and Andrasik 2006; Lake 2006; Katsarava and Jensen 2007). Also, many patients with headaches are concurrently taking various medications, which, if altered measurably during the course of treatment by PEMF, may complicate interpretation. Thus, researchers are well advised to assess for these conditions and medications and to consider their potential for confounding findings. Other helpful guidelines may be found in Penzien et al. (2005).

As with other CAM therapies, the research literature of PEMF treatment exists; however, much more research is needed to establish the efficacy of such treatments. Fortunately, the National Institutes of Health offers support for studies examining CAM therapies (Institute of Medicine 2005). The onus is upon basic and clinical scientists to avail themselves of these opportunities and open up new doors to medical and health research.

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Appendix A Table of studies exemplifying the variety of clinical applications of PEMF therapy

Authors and year (Citation)	Conditions/diagnoses	Treatment	Results
Aaron et al. (1989)[a]	Endochondral (cartilate) ossification (rats)	PEMF	PEMF promoted synthesis of cartilage molecules and bone connective tissue
Aaron et al. (1989)	Osteonecrosis of the femoral head	PEMF versus core decompression	Both PEMF and core decompression reduce the progression of the condition; PEMF was less effective with advanced lesions
Barclay et al. (1983)	Inoperable hand injuries	PEMF versus control	PEMF therapy significantly controlled swelling and pain
Bassett et al. (1982)	Nonunion fractures and failed arthrodesis (surgical procedure)	PEMF treatment after failed arthrodesis and PEMF with surgical repair after failed arthrodesis	PEMF promoted healing in most patients for whom arthrodesis could not salvage total-knee prostheses; Nonunion fractures were united in most of the patients; when PEMF alone did not promote healing, combining PEMF with surgical repair was effective
Bellossi and Desplaces (1991)[a]	Cancer: mammary carcinoma (rats)	PEMF versus control	PEMF increase the duration of survival in rats
Bigliani et al. (1983)	Knee arthrodesis (surgical procedure) after total joint arthroplasty; included patients with nonunion and delayed union	PEMF with arthrodesis	Bone bridging was achieved in most patients, healing tended to occur more quickly the earlier PEMF was used after arthrodesis
Borsalino et al. (1988)	Intertrochanteric osteotomy for hip degenerative arthritis	PEMF versus control	Greater osteotomy healing was found in treatment group
Cane et al. (1991)[a]	Metacarpal bones (horses)	PEMF versus control	PEMF stimulated bone repair at one level but not another (diaphyseal as opposed to metaphyseal level) in the metacarpal bones

Appendix A continued

Authors and year (Citation)	Conditions/diagnoses	Treatment	Results
Capanna et al. (1994)	Bone graft after tumor resection	PEMF versus control	Healing rates were similar for control and treatment groups; however, when chemotherapy was not employed, healing rates were favored treatment group; no difference in survival rates and recurrence of tumors between groups
Das Sarkar and Bassett (1991)	Nonnion fracture of the lateral condyle of the humerus	Case study of PEMF use with a child	Solid union was achieved
Di Silvestre and Savini (1992)	Spinal (lumbosacral posterolateral) fusion	Stimulation of spinal fusions using PEMF	Healing time after spinal fusion procedure was cut in half; one-third of patients healed after one month, while nearly all patients healed after 3 months
Dolgikh et al. (2005)	Essential hypertension	EMF versus control	Decreased arterial blood pressure, normalization of blood glucose levels, and arrested development of disseminated intravascular coagulation
Duma-Drzewinska and Buczinski (1978)	Bed sores	PEMF	Patients with superficial ulcers healed more quickly than expected
Fischer et al. (2005)	Osteoarthritis of the knee	PEMF	Results exclusively favored PEMF; improvements of self-reported pain measures and walking distance were documented
Ganelina (1994)	Ischemic heart disease	Electromagnetic radiation	Good to satisfactory response with regards to blood flow
Gorpinchenko (1995)	Sexual disorders (men)	PEMF versus control	A greater proportion of
Grant et al. (1994)	Cerebral ischemia (rabbits)	PEMF versus control	PEMF reduced cortical ischemia edema and ischemic neuronal damage
Gunlap et al. (1992)	Nonunion femoral, humoral, and tibial fractures	PEMF	Healing rates favored participants with certain types of patterns produced by recordings that relied on radioactive tracers (scintigraphic patterns)
Heller et al. (1997)	Cancer: Melanoma	Electrochemotherapy with bleomycin (anticancer drug)	Tumor volume was significantly reduced
Hirata et al. (2001)[a]	Cancer: Multidrug resistance in osteosarcoma (rats)	PEMF with doxorubicin	PEMF enhanced the ability of doxorubicin to bind to nuclear DNA of cancer cells and inhibited the growth of cancer cells
Ieran et al. (1990)	Skin ulcers of venous origin	PEMF versus control	Success rate higher in treatment group; no patients in treatment group worsened; therapeutic effects lasted even after stimulation is over
Ijiri et al. (1996)[a]	Bone ingrowth into ceramic implant in humerus (rats)	PEMF	When compared to an equivalent area untreated with PEMF, PEMF treated cavity with implant appeared to stimulated bone ingrowth into the ceramic implant

Appendix A continued

Authors and year (Citation)	Conditions/diagnoses	Treatment	Results
Ionescu et al. (1982)	Edema and pain in burn patients	PEMF	Prevented initial development of edema and pain
Ito and Bassett (1983)	Sciatic nerve transaction	PEMF versus control	Rate and quality of healing twice as great with PEMF
Ito and Shirai (2001)	Nonunion tibial fracture	PEMF	All tibial fractures with good blood supply to bone ends healed
Ito et al. (2000)	Congenital pseudarthrosis of the tibia	Seven-year follow-up of one case; PEMF with bone grafts	Bone healing was achieved and leg did not shorten beyond prescribed limits
Itoh et al. (1991)	Diabetic ulcers, stages II and III	PEMF added to ongoing, traditional, medical treatment	All ulcer patients healed when PEMF was added
Iurlov et al. (1989)	Bronchitis	Low-intensity EMF versus PEMF versus control; all conditions coupled with standard drug therapy	Electromagnetic therapy alleviated symptoms of bronchitis when coupled with standard drug therapy
Jorgensen et al. (1994)	Acute and chronic gynecological pelvic pain of	PEMF	Most patients experienced significant relief
Kahanovitz et al. (1994)[a]	Posterior lumbar spinal fusions (dogs)	Two PEMF groups versus control	No significant difference between either PEMF group and control dogs healing of fusions
Kaplan and Weinstock (1968)	Edema and pain in foot surgery patients	PEMF versus control	Reduced pain and edema in treatment condition; based on subjective rating scales
Karlov et al. (1991)	Functional transient and ischemic apoplexy, circulatory encephalopathy (vascular diseases of the brain)	UHF Electromagnetic field versus control	Statistical trend favoring the treatment condition; decreased arterial pressure, normalized blood glucose level, arrest in syndrome development
Karpukhin and Bogomol'nii (1996)	Sexual dysfunction: Impotence	PEMF plus vacuum therapy versus vacuum therapy alone	PEMF plus vacuum therapy was more effective, with a high proportion of participant reporting full restoration of sexual function
Kniazeva et al. (1994)	Hypertension	PEMF	Improved labile, as opposed to stable, hypertension
Krillov et al. (1996)	Vascular complications of diabetes mellitus	PEMF versus control	More PEMF patients achieved good to satisfactory results; their healing was also faster and longer-lasting
Lappin et al. (2003)	Multiple sclerosis	PEMF versus control	Significant difference favoring PEMF on measures of fatigue and overall quality of life; however, no treatment effects for bladder control and disability measure; mixed results for symptoms of spasticity
Lin et al. (1992)[a]	Ligament of the patella (rats)	PEMFs of various waveforms versus control	PEMF promoted early-stage ligament healing
Lin et al. (1993)[a]	Ligament of the patella (rats)	PEMFs of various waveforms versus control	PEMF promoted blood flow at the site of injury as well as collagen production; the process of ligament healing was accelerated
Matsunaga et al. (1996)[a]	Stimulation of osteogensis and alkaline phosphate (ALP) activity in bone marrow (rats)	PEMFs of various waveforms	PEMF stimulated osteogenesis and ALP activity; results varied depending on the waveforms used

Appendix A continued

Authors and year (Citation)	Conditions/diagnoses	Treatment	Results
Mishima (1988)[a]	Surgically produced osteoporosis (rats)	PEMF	While PEMF did not appear to affect bones loss due to factors such as age, PEMF did seem to promote bone formation activity and increase bone volume in osteoporotic hindlegs
Miyagi et al. (2000)	Cancer: Human cancer cells (cultures)	PEMF	Promoted growth in undifferentiated cells, but suppressed growth in differentiated cells at cite of malignant growths
Omote (1988)	Cancer: Drug resistance in human cancer cells (cultures)	PEMF with thymidine and methotrexate (anticancer drug)	PEMF promoted uptake of both thymidine and methotrexate; PEMF increased antitumor activity
Orlov et al. (1986)	Hypertension	"Running" impulse magnetic field versus control	Correction of arterial blood pressure
Pasquinelli et al. (1993)[a]	Cancer: multidrug resistance in mammary carcinoma (rat and human cells)	PEMF with doxorubicin (anticancer drug)	PEMF increased concentration of anticancer agents in rat and human cell lines
Pennington et al. (1993)	Edema from grades I and II ankle sprains	PEMF versus control	Edema reduced faster in treatment condition
Pienkowski et al. (1992)[a]	Surgically divided and resected fibulae (rabbits)	PEMFs of asymmetrical versus symmetrical stimulus pulse waveforms	Both asymmetrical and symmetrical wave forms stimulated bone growth and healing
Pienkowski et al. (1994)[a]	Surgically divided and resected fibulae (rabbits)	Control versus PEMF of various waveforms	Significant increase in bone stiffness for PEMF groups
Salzberg et al. (1995)	Pressure ulcers on spinal cored injured patients	PEMF versus control	More patients with grade II ulcers showed improvement in treatment condition than control condition
Sandyk (1994)	Alzheimer's disease	PEMF	Improvements in short-term memory, visual memory, spatial orientation, drawing performance, mood, and social interactions
Sharrard (1990)	Fractures of tibial shaft	PEMF versus control	Greater proportion of patients in treatment group showed healing than in control group
Sherman and Karstetter (1991)	Tibial and metatarsal stress fractures	PEMF versus control	Significantly faster improvement in treatment condition
Shimizu et al. (1988)[a]	Stimulation of bone ingrowth in ceramic (porous hydroxyapatite [HA] versus porous tricalcium phosphate [TCP]) implants in tibia (rats)	PEMF versus control	Accelerated bone formation and maturation was observed in PEMF group with HA pores but not PEMF TCP pores or control group
Sidorov and Pershin (1993)	Systemic lupus erythmatosus	EMF versus microwave therapy versus control	Complete relief of myalgia, polyarthralgia, and painful contractures
Simmons (1985)	Failed posterior lumbar interbody fusion	PEMF	A significant increase was found in bone formation and fusion in the majority of patients; treatment reduced risks associated with surgical treatment and did not require hospitalization

Appendix A continued

Authors and year (Citation)	Conditions/diagnoses	Treatment	Results
Suntsov (1991)	Otitis externa (inflammation of the external auditory canal)	PEMF versus electromagnetic waves	100% recovery rate claimed
Takayama et al. (1990)[a]	Metabolically derived osteoporosis	PEMF versus two different controls	No significant differences were observed
Varcaccio-Garofalo et al. (1995)	Chronic refractory pelvic pain	PEMF	Over half of patients experienced complete
Wilson (1972)	Inversion ankle injuries	PEMF versus control	Twice as much recovery in 3 days for treatment condition
Zienowicz et al. (1991)[a]	Peripheral nerve transaction (rats)	PEMF combined with delayed surgery versus other treatments and combinations of treatments	Improved nerve function; significant improvement in ambulation

[a] Studies using animal subjects

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