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17 Magnetic Fields for Pain Control

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17.1 GENERAL

The issue of pain treatment is an extremely urgent health and socioeconomic 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–$15,000 per person annually. At least one in four adults in North America is suffering from some form of pain at any given moment. These estimates do not include the nearly 30,000 people that die in North America each year due to nonsteroidal anti-inflammatory drug-induced gastric lesions (Thomas and Prato, 2002).

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 (CAM) in order to reduce drug dependencies, risks of invasive procedures, and/or side effects. More than a third of American adults report using some form of CAM, with total visits to CAM providers each year now exceeding those to primary-care physicians. Annual out-of-pocket costs for CAM are estimated to exceed $27 billion (Institute of Medicine, 2005).

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. Most effective pain management strategies require multiple concurrent approaches, especially for chronic pain. It is rare that a single modality, including magnetic field (MF) therapy, solves the problem completely.

The level of evidence for the value of pulsed electromagnetic fields (PEMFs) for managing pain varies significantly. From an insurance coverage and public policy perspective, the standard for the quality of evidence even in randomized controlled trials is very demanding. From the perspective of the clinician, who lives and functions with a high degree of ambiguity, reasonable levels of evidence are all that is necessary for the clinician to make decisions and recommendations. For most clinicians, the level of evidence, relative to managing the patient's pain, is typically observational since there is very little practical, clinical value in more objective measures of pain and since the pain under management tends to be in multiple locations and in a very wide variety of types of patients. Rarely do clinicians have sufficient useful biologic (e.g., from imaging studies) or biochemical (from available laboratory studies) data to drive decision-making for pain management. Most decision-making at the clinical level resolves to physical examination of patients or the patient's own self-report.

While biologists and physicists attempt to discern and discover the mechanisms of biologic processes that may contribute to pain, measurements of these phenomena are not typically accessible to the clinician. While pharmacologists may determine that a particular biologic or cellular physiologic mechanism is a desired goal for a pharmacologic intervention, the clinician cannot typically measure this level of aspect of the problem. Therefore, the clinician relies on observable phenomena, such as physical examination, blood pressures, cholesterol levels, and C-reactive protein levels, which are not direct surrogates for the mechanism of a given medication. So, to the extent that controlled clinical trials exist, despite some of their methodological limitations, for the clinician, this is a better level of information for decision-making than mechanistic studies. Studies that report on observable physiologic parameters may be of the greatest value in the practical clinical management of pain.

Static EMFs have been used for centuries to control pain and other biologic problems. This review explores the value of magnetic therapy in managing pain, presenting the scientific basis supporting these modalities. This includes the use of MFs, produced by both static (permanent) and time-varied (most commonly, pulsed) magnetic fields (PEMFs). Fields of various strengths, waveforms, and frequencies have been evaluated, depending on the clinical conditions or aspects selected for the study. There is as yet no *gold standard*. And, it is doubtful that there ever will be because of the very nature of the complexities involved. After thousands of patient-years of use globally, very little risk has been found to be associated with MF therapies (Markov, 2004). Standards and guidelines for safety have been promulgated and published (ICNIRP, 2010). The primary precautions or contraindications relate to implanted electrical devices, pregnancy (because of lack of data), and seizures with certain kinds of frequency patterns in seizure-prone individuals.

MFs affect pain perception in many different ways. These actions are both direct and indirect. Direct effects of MFs are on neuron firing, calcium ion movement, membrane potentials, endorphin levels, nitric oxide, dopamine levels, acupuncture actions, and nerve regeneration. Indirect benefits of MFs from physiologic function enhancement are on circulation, muscle, edema, tissue oxygen, inflammation, healing, prostaglandins, cellular metabolism, and cell energy levels (Jerabek and Pawluk, 1996).

Pain relief mechanisms vary by the type of stimulus used (Takeshige and Sato, 1996). For example, needling to the pain-producing muscle, application of a static MF or external qigong, or needling to an acupuncture point all reduce pain by different mechanisms. In guinea pigs, pain could be induced by reduction of circulation in the muscle (ischemia) and reduced by recovery of circulation. 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 (Takeshige and Sato, 1996).

17.2 ALTERNATIVES FOR PAIN MANAGEMENT

In clinical practice, it is rare to manage pain with one simple approach. Usually, many approaches are used simultaneously. These include supplements and herbs (Eriksen et al., 1996; Arnold and Thornbrough, 1999; Randall et al., 2000), acupuncture (Thomas et al., 1992; Wong and

Rapson, 1999), and chiropractic adjustments or manipulations (Haldeman and Rubinstein, 1993), among others.

Both static (permanent) and time-varied (pulsed) EMFs have been studied for the management of a myriad of health conditions, including pain. Most of this review will focus on PEMFs and pain.

Since the the last half of the 20th century, a number of electrotherapeutic, magneto-therapeutic, and electromagnetic medical devices have emerged for treating a broad spectrum of trauma, tumors, and infections with static and pulsed EMFs (Jerabek and Pawluk, 1996). The current scientific literature indicates that short-term periodic exposure to PEMFs has emerged as one of the most effective and safe forms of therapy for many conditions, including pain.

Studies comparing different technologies are rare. However, the difference in the effectiveness of pain relief between pulsed radiofrequency (PRF) and electro-acupuncture (Lin et al., 2010) stimulation in patients with chronic low-back pain was evaluated. Visual analog scale (VAS) pain score, the Oswestry disability index (ODI), and Short Form 36 (SF-36) were used to assess pain relief and functional improvement effect of PRF and electro-acupuncture, in a randomized controlled trial. PRF therapy was significantly better after 1 month of treatment. But electro-acupuncture also showed functional improvement in the lumbar spine based on the ODI scores.

17.3 STATIC MAGNETIC FIELDS FOR PAIN RELIEF

While most of the evidence presented in this review relates to PEMFs, static MFs have also been found in various studies to have benefits in pain management. This review of necessity is limited in the number of studies regarding static MF benefits, and the ones presented are somewhat unique in their approach to addressing the pain problem.

Several studies found value in the use of static magnets. A review of magnets applied to acupuncture points shows that this application has variable usefulness (Colbert et al., 2008). However, an acupuncture-like action may be at least one of the explanations for the benefit of locally applied magnets. Magnetic wrist bracelets have been found helpful to decrease the pain from osteoarthritis (OA) of the hip and knee (Harlow et al., 2004). In this study, commercial neodymium magnets were tested on 194 individuals in a randomized, placebo-controlled trial for pain control in OA of the hip and knee. The magnets in group A were 170–200 mT; in group B, they were 21–30 mT; and group C used nonmagnetic steel washers. The Western Ontario and McMaster universities osteoar-thritis index (WOMAC A) was measured at entry, 4 and 12 weeks. Secondary outcomes included changes in WOMAC B and C scales and a VAS for pain. Mean pain scores were reduced more in the standard magnet group (group A) than in the sham control group (mean difference 1.3 points). The intriguing result is that even with nonlocal application of a magnetic therapy for pain from OA of the hip and knee, pain in these remote joints decreases when wearing magnetic wrist bracelets. A lower-intensity magnet group (group B) was used as a low *dose* control. The assumption here is that the lower-intensity magnetic therapy is expected to be more likely to be comparable to the sham group than the higher-intensity magnetic therapy. However, in this study, even the weaker magnets produced a measurable benefit, although it was not statistically different from the stronger magnets. Still, there was a trend for the stronger magnets to produce better results than the weaker magnets. The mean reduction in WOMAC A scores in the intervention group of 2.9 (27% change from baseline score) and the difference above placebo (1.3 points) is similar to that found in trials of conventional medical OA treatments.

A uniquely designed static magnetic system was also studied in rheumatoid arthritis (RA) and knee pain (Segal et al., 2001) in a randomized, double-blind, controlled, multisite clinical trial in 64 patients. Four static magnets enclosed in a molded plastic circular case (group A) or a control magnetic device with only one magnet (group B) was taped to the knee of each subject to be worn continually for 1 week. A greater reduction in reported pain in the A group was sustained through 1-week follow-up (40.4% versus 25.9%), supported by twice-daily pain diary recordings, $p < 0.0001$ for each treatment period versus baseline. Between-group comparisons found no

significant difference ($p < 0.23$), which shows no difference in pain reduction results between the stronger four-magnet unit versus the one-magnet unit enclosures. Subjects in group A reported an average decrease in their global assessment of disease activity of 33% over 1 week, as compared with a 2% decrease in the control group ($p < 0.01$). After 1 week, 68% of the treatment group reported feeling better or much better, compared with 27% of the control group, and 29% and 65%, respectively, reported feeling the same as before treatment ($p < 0.01$). Despite what appear to be clinically relevant differences between the stronger and weaker magnetic groups, the lack of statistical significance may well be due to an underpowered study or the treatment time was not carried on long enough. Because even weaker magnets may still show significant clinical benefits, studies using them as controls are likely to need larger numbers of subjects in order to detect meaningful differences. A similar issue occurred in the Harlow study (Harlow et al., 2004).

Several studies reported less positive results. These are instructive for potential methodological considerations for future static magnet studies. A static magnetic foil placed in a molded insole for the relief of heel pain was used for 4 weeks to treat heel pain (Caselli et al., 1997). Sixty percent of patients in the treatment and sham groups reported improvement. The magnetic foil offered no advantage over the plain insole. This study, like others with low numbers of patients, may have had significant design limitations, including not having had a large enough sample to show differences, especially when considering dosimetry at the target tissue. Flexible static magnetic shoe insert foils produce fairly weak fields. Since MFs, especially from static magnets, drop off in strength very rapidly from the surface of the applicator (Pilla, 1998), the MF *dose* delivered to the target tissue is usually much lower than assumed or theoretical values. The depth of penetration of the desired MF intensity is, therefore, critical to achieve clinically meaningful results (Markov, 2004). As a result, desired outcomes may never be seen for the magnetic device, and changing conditions to be studied or much longer treatment times may be necessary to achieve even any meaningful results.

Chronic pain frequently presented by post-polio patients can be relieved by application of static MFs applied directly over trigger points using 300–500 G static magnets for 45 min (Vallbona and Richards, 1999).

Treatment with a flexible permanent magnetic pad for 21 days reduced chronic muscular low-back pain six times more than placebo (Preszler, 2000). This has also been effective for herniated lumbar disks, spondylosis, radiculopathy, sciatica, and arthritis. Pain relief is sometimes experienced as early as 10 min or in some cases takes as long as 14 days.

17.4 PEMFs AND PAIN MANAGEMENT

Several authors have reviewed the experience with PEMFs in Eastern Europe (Jerabek and Pawluk, 1996) and elsewhere (Trock, 2000) and provided a synthesis of the typical physiologic findings of practical use to clinicians, resulting from magnetic therapies. These include, at a minimum, reduction in edema and muscle spasm/contraction, improved circulation, enhanced tissue repair, and natural antinociception. These are the fundamentals of the repair of cell injury. PEMFs have been used extensively in many conditions and medical disciplines, being most effective in treating rheumatic or musculoskeletal disorders. PEMFs produced significant reduction of pain, improvement of spinal functions, and reduction of paravertebral spasms. In clinical practice, PEMFs have been found to be an aid in the therapy of orthopedic and trauma problems (Borg et al., 1996).

The ability of PEMFs to affect pain is at least in part dependent on the ability of PEMFs to positively affect human physiologic or anatomic systems. The human nervous system is strongly affected by therapeutic PEMFs (Prato et al., 2001). Animals exposed to static and extremely low-frequency (ELF) MFs are also affected by the presence of light, which strengthens the effects of PEMFs (Prato et al., 1999).

One of the most reproducible results of weak ELF MF exposure is an effect upon neurologic pain signal processing (Thomas and Prato, 2002). This evidence suggests that PEMFs would also be an effective complement for treating patients suffering from both chronic and acute pain.

The placebo response may explain as much as 40% of an analgesia response from any pain treatment (Colloca et al., 2013), and needs to be accounted for in research design to assure adequate sample sizes. However, aside from this aspect of accounting for the placebo effect, the central nervous system mechanisms responsible for the placebo response, that is, central cognitive and behavioral processes, can be addressed directly in managing pain and include medications, hypnosis, mindfulness meditation, and psychotherapy. In addition, these placebo response–related central processes appear to be an appropriate target with magnetic therapies for managing pain. Amplifying MF manipulation of cognitive and behavioral processes has been evaluated in animal behavior studies and in humans, affecting at the very least opiate receptors (Del Seppia et al., 2007). Therefore, amplifying the placebo response with centrally focused MFs would generally be expected to be additive to pain management using MF therapies elsewhere on the body. One particular application considering this approach is rapid transcranial magnetic stimulation (rTMS). rTMS is being increasingly evaluated for this purpose and already found effective in reducing centrally and peripherally caused pain (Lefaucheur et al., 2004). A review of the rTMS technology is available at Aleman (2013).

Current transcranial magnetic coil stimulators can activate brain neural structures without deep electrode placement and the discomfort associated with transcutaneous electrical stimulation used in pain control. The possibility of reducing pain in patients with localized musculoskeletal processes is by applying repetitive magnetic stimulation (rMS) on tender noncentral body regions (Pujol et al., 1998). Thirty patients were randomized to receive 40 min of real or sham magnetic stimulation. After a single session, real magnetic stimulation significantly exceeded the sham effect, decreasing VAS scores, using a 100 mm scale, by 59% in the treated group and 14% in sham-treated patients ($p = 0.001$). Pain relief regularly persisted several days. Results indicate that powerful magnetic coil stimulation can efficiently reduce pain originating from localized musculoskeletal injuries.

In the opposite situation of the placebo response, not all circumstances involving pain respond equally well to any management approach, including PEMFs. The time it takes to heal the underlying cause contributing to pain is an important variable. To elucidate one possible mechanism of pain reduction with PEMFs, a randomized, double-blind, placebo-controlled, crossover experiment was conducted with human volunteers (Fernandez et al., 2007). Pain was caused by infusion of hypertonic 5% saline into the forearm. Subjects received active or sham PEMF. There were no significant differences in mean VAS pain scores between the two machines. There are many possible explanations for this lack of apparent benefit in this experimental model, including inadequate PEMF dosing.

17.5 POTENTIAL MECHANISMS OF MAGNETIC FIELD EFFECTS ON PAIN

Cell injury itself involves multiple processes (Kumar, 2007), which, if mitigated, can be expected to reduce the perception of pain and limit the results of the cell injury. Therefore, this is the goal of clinical management. If the cause of pain cannot be reduced or eliminated, then the goals of pain management shift to reducing the perception of pain or blocking the pain signal traffic otherwise.

Research on the use of PEMFs for pain management focuses on the multiple mechanisms of the production of pain. The primary mechanisms of the production of pain in local tissue in response to cell injury include, to varying degrees, edema, apoptosis or necrosis, diminished vascular supply, reduced cellular energy production, and impaired repair processes. PEMF therapies address many of these different aspects of cell injury (Jerabek and Pawluk, 1996).

Magnetic therapy increases the threshold of pain sensitivity (Thomas and Prato, 2002) and activates the anticoagulation system (Khamaganova et al., 1993), which increases circulation to tissue. PEMF treatment stimulates production of opioid peptides, activates mast cells and increases electric capacity of muscular fibers, helps with edema and pain before or after a surgical operation (Pilla, 2013), increases amino acid uptake (De Loecker et al., 1990), and induces changes

in transmembrane energy transport enzymes, allowing energy coupling and increased biologic chemical transport work.

Healthy humans normally have reduced pain perception and decreased pain-related brain signals (Prato et al., 2001). Biochemical changes in the blood of treated patients are found that support the pain reduction benefit. PEMFs cause a significant improvement in normal standing balance in adult humans (Thomas et al., 2001). PEMFs couple with muscular processing or upper-body nervous tissue functions, which indicate CNS sensitivity that likely improves central pain processing.

Various kinds of PEMFs have been found to reduce pain. For example, various MFs applied to the head or to an extremity, for 1–60 min, with intervals between exposures from several minutes to several hours, randomly sequenced with sham exposures allowed the study of brain reactions by various objective measures (Kholodov, 1998). EEGs showed increased low-frequency rhythms. Low-frequency EEG rhythms may explain the common perception of relaxation and sleepiness with ELF EMFs. Even weak AC MFs affect pain perception and pain-related EEG changes in humans (Sartucci et al., 1997). A 2 h exposure to 0.02–0.07 mT ELF MFs caused a significant positive change in pain-related EEG patterns.

The benefits of PEMF use may last considerably longer than the time of use. This is a common clinical observation. In rats, a single exposure produces pain reduction both immediately after treatment and even at 24 h after treatment (Cieslar et al., 1994). The analgesic effect is still observed at the 7th and 14th day of repeated treatment and even up to 14 days after the last treatment. Repeated presentation of painful stimuli in rats can significantly elevate the threshold of response to painful stimuli. One group (Fleming et al., 1994) investigated the ability of magnetic pulse stimuli to produce increases in pain thresholds, simulating thalamic pain syndrome. Exposure to the PEMFs increased the pain threshold progressively over 3 days. Pain suppression was maintained on the second and third days relative to other treatments. The pain threshold following the third MF exposure was significantly greater than those associated with morphine and other treatments. Brain-injured and normal rats both showed a 63% increase in mean pain threshold. The mechanism may involve endorphins, having important implications for clinical practice and the potential for a reduction in reliance on habit-forming medications.

PEMFs promote healing of soft tissue injuries by reducing edema and increasing resorption of hematomas (Markov and Pilla, 1995), thereby reducing pain. Low-frequency PEMFs reduce edema primarily during treatment sessions. PEMFs at very high frequencies applied for 20–30 min cause decreases in edema lasting several hours following an exposure session. PRFs induce vasoconstriction at the injury site, probably a primary mechanism in the anti-edema effect. PRFs also displace negatively charged plasma proteins found in the traumatized tissue. This is expected to increase lymphatic flow, an additional factor contributing to edema reduction.

PEMF signals induce maximum electric fields in the mV/cm range at frequencies below 5 kHz. PRF fields are typically shortwave band, 13–40 MHz range, carrier waves. Modulation, for example, consisting of modulated sinusoidal waves of lower frequencies, will prevent heating in target tissues. Higher-intensity PRFs have many applications involving tissue ablation, through heating destruction of tissue. PRFs considered in this review do not include the ablative PRFs.

Chronic pain often occurs from aberrant small neural networks with self-perpetuated neurogenic inflammation. It is thought that high-intensity pulsed magnetic stimulation (HIPMS) noninvasively depolarizes neurons and can facilitate recovery following injury (Ellis, 1993). HIPMS, intensity up to 1.17 T, was used to study recovery after injury in patients with posttraumatic/postoperative low-back pain, reflex sympathetic dystrophy (RSD), neuropathy, thoracic outlet syndrome, and endometriosis. The outcome VAS difference was 0.4–5.2 with sham treatments versus 0–0.5 for active treatments. The author proposed that the pain reduction was likely due to induced eddy currents.

In normal subjects, a magnetic stimulus over the cerebellum reduces the size of responses evoked by cortical electrical stimulation (Ugawa et al., 1997). Magnetic stimulation over the cerebellum

produces the same effect as electrical stimulation, even in ataxic patients, and may be useful for the pain associated even with peripheral muscle spasticity. Direct electrical stimulation of the brain is an accepted clinical procedure (Levy et al., 2010). Since electrical stimulation is generally uncomfortable and often invasive, PEMF stimulation, whether with lower-intensity PEMF systems or higher-intensity rTMS (Lefaucheur et al., 2004), is being seen to be a safer and equally effective alternative.

Even when magnetic field stimulation (MFS) of high enough intensity is used to cause quadriceps muscle contractions (Han et al., 2006), it appears to cause less pain at similar peak muscle torque levels than neuromuscular electrical stimulation (NMES). The VAS was compared at the same peak torque reached by each method of stimulation. The mean tolerable maximum peak torque was higher, almost double, with MFS versus NMES. So, magnetic stimulation produced less pain at the same isometric peak torque. MFS may even be effective in reducing pain in the presence of high-intensity muscle contractions.

Effects on the tissues of the body and the symptoms of pain have been found across a wide spectrum of electromagnetic frequencies, including high-frequency PEMFs. For example, significant reductions in pain were found in individuals with acute whiplash injuries using 27.12 MHz PEMF stimulation (Foley-Nolan et al., 1992). The same group (Foley-Nolan et al., 1990) had previously found that individuals with persistent neck pain lasting greater than 8 weeks had statistically significantly greater improvement in their pain compared to controls. The controls were then crossed over onto PEMF treatment and had similar results.

For more detailed discussion of the potential mechanisms of action of MFs to treat pain, see Markov (2004). The author discusses some of the parameters that may be necessary to properly choose a therapeutic MF with respect to the target tissue to be stimulated. The research literature on magnetic therapies for pain management is very variable in describing the particular parameters of the magnetic therapy apparatus being studied. This leaves the clinician at a significant disadvantage in determining which MFs produce the best results for the given condition being treated. Further, the author states, “during the past 25 years more than 2 million patients have been treated worldwide for a large variety of injuries, pathologies and diseases. This large number of patients exhibited a success rate of approximately 80%, with virtually no reported complications.” The author goes on to describe a number of mechanisms of cellular action of EMFs that may be deemed responsible for the therapeutic benefit in improving pain.

In another study, Shupak et al. (2004) looked at possible mechanisms or influencing factors for the effects of PEMFs on pain, especially on sensory and pain perception thresholds. It appears that MF exposure does not affect temperature perception but can increase pain thresholds, indicating an analgesic effect.

Based on the review by Del Seppia et al. (2007), it appears that at least one of the mechanisms involved in PEMF effects on pain and nociception is the opiate receptor. Another study in rats (Fleming et al., 1994) found that there was an analgesic effect comparable to more noxious tactile stimulation, that is, stress-induced analgesia. There was an approximately 50% increase in the pain threshold in response to electrical current stimulation.

In a study to gain a better understanding of pain perception (Robertson et al., 2010), a functional magnetic resonance imaging study was done to assess how the neuromodulation effect of MFs influences the processing of acute thermal pain in normal volunteers. ELF MFs (from DC to 300 Hz) have been shown to affect pain sensitivity in snails, rodents, and humans. Because of this research, it is unlikely that a pure placebo response is involved. This neuroimaging study found changes in specific areas of the brain with pain stimuli that are definitely modified by low-intensity PEMF exposure.

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 (Guseo, 1992). Pain syndromes due to muscle tension and neuralgias improve.

17.6 NEUROPATHY

Peripheral neuropathy can be an extremely painful condition that is very challenging to manage. Two randomized controlled studies failed to show significant results in diabetic peripheral neuropathy (DPN) (Wróbel et al., 2008; Weintraub et al., 2009). Another two studies showed significant improvements in DPN (Cieslar et al., 1995; Graak et al., 2009). There were significant methodological differences among the studies.

A large study (Weintraub et al., 2009) was conducted to determine whether repetitive and cumulative exposure to low-frequency PEMF to the feet can reduce neuropathic pain (NP) and influence nerve regeneration. Two-hundred and twenty-five patients with DPN stage II or III were randomized in a double-blind, placebo-controlled parallel study, across 16 academic and clinical sites in 13 states to PEMF or sham (placebo) devices. They applied their treatments 2 h per day to their feet for 3 months. Pain reduction scores were measured using a VAS, the neuropathy pain scale (NPS), and the patient's global impression of change (PGIC). A subset of subjects underwent serial 3 mm punch skin biopsies from three standard lower-limb sites for epidermal nerve fiber density (ENFD) quantification. There was a significant dropout rate of 13.8%. The PEMF versus sham group had reductions in DPN symptoms on the PGIC (44% versus 31%; $p = 0.04$). There were no significant differences in the NP intensity on NPS or VAS. Of the 27 patients who completed serial biopsies, 29% of the PEMF group had an increase in the distal leg ENFD of at least 0.5 SDs, while none did in the sham group ($p = 0.04$). Those with increases in distal thigh ENFD had significant decreases in pain scores. The conclusion was that PEMF at this dose was not effective specifically in reducing NP. However, neurobiological effects on ENFD, PGIC, and reduced itching scores were hopeful and suggest that future studies should be attempted with higher PEMF intensities 3000–5000 G, longer duration of exposure, and a larger biopsy cohort. Since most of the therapeutic approaches to DPN have poor success rates, relying mostly on the suppression of pain with medications, this study is encouraging in actually demonstrating potential nerve regeneration improvements.

Another randomized, placebo-controlled, double-blind study (Wróbel et al., 2008) was conducted to assess an ELF PEMF effect on pain intensity, quality of life and sleep, and glycemic control in patients with painful diabetic polyneuropathy. Sixty-one patients were randomized into a study group of 32 patients exposed to a low-frequency, low-intensity MF or a sham control group of 29 patients. Pain durations were greater than 2 years in both groups. Treatments were for 3 weeks, 20 min a day, 5 days a week. Questionnaires, completed at the beginning, after 1–3 and 5 weeks, included SFMPQ-VAS (pain evaluation), EuroQol EQ-5D, and MOS Sleep Scale. Significant reductions in pain intensity were seen in both the study group, VAS 73 mm at baseline versus 33 mm after 3 weeks, and controls, VAS 69 mm at baseline versus 41 mm after 3 weeks. The extent of pain reduction did not differ significantly between the groups at any time. The conclusion was that this low-intensity ELF PEMF, used for only 3 weeks, had no advantage over sham exposure in reducing pain intensity. In the Weintraub study, patients were treated for 3 months, providing a longer opportunity to produce sustainable changes in the tissues. Since neuropathy is a very stubborn problem to treat, it is likely that both of these neuropathy studies were too short for the severity of neuropathy present, treatment protocols, measures, and equipment used.

In another study (Graak et al., 2009) on NP, using low-power, low-frequency PEMF of 600 and 800 Hz, 30 patients, 40–68 years of age with DPN stages N1a, N1b, N2a, were randomly allocated to three groups of 10 in each. Groups 1 and 2 were treated with low-power 600 and 800 Hz PEMF, respectively, for 30 min for 12 consecutive days. Group 3 served as control on usual medical treatment. Pain and motor nerve conduction parameters (distal latency, amplitude, nerve conduction velocity) were assessed before and after treatment. They found significant reduction in pain and statistically significant ($p < 0.05$) improvement in distal latency and nerve conduction velocity in experimental Groups 1 and 2. Using this particular protocol, low-frequency PEMF was seen to reduce NP as well as for retarding the progression of neuropathy even when applied for only a short span of time. What could happen with longer-term treatment remains to be determined.

Thirty-one patients with diabetes mellitus (type I and II), with intense symptoms of neuropathy, were treated (Cieslar et al., 1995). They had 20 exposures to variable sinusoidal PEMF, 40 Hz, 15 mT, every day for 12 min. Reduction of pain and paresthesias, vibration sensation, and improved muscle strength was seen in 85% of patients, all significantly better than sham controls.

Carpal tunnel syndrome is another form of neuropathy, affecting the median nerve at the wrist. There are many different approaches to the treatment of carpal tunnel syndrome, including surgery, with varying success. In a randomized, double-blinded, placebo-controlled trial (Weintraub and Cole, 2008), a commonly commercially available combination of simultaneous static and dynamic, rotating time-varying dynamic MFS was used to treat the wrist. There was a significant reduction of *deep* pain. Ten months of active PEMF resulted in improvement in nerve conduction and subjective improvement on examination (40%), pain scores (50%), and a global symptom scale (70%).

The neuropathy of postherpetic neuralgia, a very common and painful condition, often medically resistant, responded to PEMF (Kusaka et al., 1995). A combination static and pulsed MF device was placed on the pain/paresthesia areas or over the spinal column or limbs. Treatments continued until symptoms improved or adverse side effects occurred. Therapy was effective in 80%. This treatment approach shows that treatment for pain problems may either be localized to the area of pain or over the spinal column or limbs, away from the pain. Treatment over the appropriate related spinal segment offers the opportunity to interrupt the afferent pain signal traffic to the brain. This approach has been frequently used with success in Eastern European studies (Jerabek and Pawluk, 1996). Another author reported a more general clinical series in postherpetic pain in which better results happened in patients simultaneously suffering from neck and low-back pain (Di Massa et al., 1989).

Posttraumatic, late-stage RSD, or now called regional complex pain syndrome (CRPS), a form of neuropathy, is very painful and largely untreatable by standard medical approaches. In one report, ten 30 min 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 (Saveriano and Ricci, 1989). There was no further improvement at 20 days. The author had a personal case treated with a 27.12 MHz PEMF signal, in a nurse who was almost completely disabled in her left upper extremity. She used her device for about an hour a day. Within about 1 month, she had about 70% recovery, and within 2 months, she had essentially normal function with no further sensitivity to touch, changes in temperature, etc. She maintained her recovery with continued treatments in the home setting.

rTMS has been reported for the treatment of RSD in a sham-controlled trial (Picarelli et al., 2010) and one case series (Pleger et al., 2004). In the controlled trial, the active treatment group of five patients, during treatment, had a significant reduction in pain intensities. Reduction in the mean VAS scores was 4.65 cm (50.9%) versus 2.18 cm (24.7%) in the sham-rTMS group. The highest reduction occurred at the 10th session. In the earlier reported case series, patients were treated in the motor cortex contralateral to the affected side. Seven out of ten patients reported decreased pain intensities. Pain relief occurred 30 s after stimulation, with a maximum effect at 15 min later. Pain re-intensified up to 45 min after rTMS. Sham rTMS did not alter pain perception. Both of these studies appear to indicate that the benefit of even rTMS may be limited in RSD to the time of treatment. This may well relate back to an earlier point regarding the need to heal the underlying cause in order to achieve sustainable results. Short-term rTMS treatments are unlikely to more durably impact the underlying cellular and physiologic dysfunctions but, in some cases, may have a definite value in short-term management.

17.7 ORTHOPEDIC OR MUSCULOSKELETAL USES

Musculoskeletal conditions, especially with related pain, are most frequently treated with MF therapies. Among these, one of the most common conditions is lumbar arthritis, as a cause of back pain. Chronic low-back pain affects approximately 15% of the US population during their lifetime (Preszler, 2000). Given the current treatment options available through conventional medical

therapy, with their attendant risks, there is a large unmet need for safe and effective alternative therapies (Institute of Medicine, 2005).

PEMFs of 35–40 mT give relief or elimination of pain about 90%–95% of the time for lumbar OA, improve results from other rehabilitation therapies, and secondarily, additionally improve related neurologic symptoms (Mitbreit et al., 1986). Even PEMFs of 0.5–1.5 mT used at the site of pain and related trigger points also help (Rauscher and Van Bise, 2001). Some patients remained pain free 6 months after treatment.

Using peripherally applied ELF high-intensity magnetic stimulation (rMS), with an rTMS device, benefits were found in musculoskeletal pain from 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 arthritis, osteochondral lesions of the heel, posterior tibial tendinitis, upper back muscle spasms, and rotator cuff injury (Pujol et al.,1998).

In a series of 240 patients treated in an orthopedic practice with PEMFs, patients had decreased pain (Schroter, 1976) from rheumatic illnesses, delayed healing process in bones, and pseudo-arthritis, including those with infections, fractures, aseptic necrosis, venous and arterial circulation, RSD (all stages), osteochondritis dissecans, osteomyelitis, and sprains and strains and bruises. The clinically determined success rate approached 80%. About 60% of loosened hip prostheses have subjective relief of pain and walk better, without a cane. Even so, x-ray evidence of improvement was seen periodically, as evidenced by cartilage/bone reformation, including the joint margin. If the goal in pain management is to heal the underlying tissue, not just manage symptoms, evidence, typically from imaging studies, can drive the duration of treatment to obtain the most long-lasting and more permanent results.

To further expand on these points, in both research and clinical settings, a determination always needs to be made regarding the length of the course of treatment. This needs to take consideration of the objectives of the treatment. Patients are often happy simply by having a reduction in their symptoms and improvement in their function. On the other hand, the clinician may be aware that better and more long-standing results can be obtained by extending the treatment program. In the case of arthritis, an ideal situation could include resolution or improvement of the bony or cartilage changes, so the pain does not recur. This can best be determined through imaging studies. In the case of fractures, clinically, the person is considered released from care when there is a sufficient callus formed, allowing immobilization casting to be removed and full rehabilitation initiated. On the other hand, these fractures are at risk of breaking down full healing, leading to various levels of nonunion or delayed union, not uncommon problems in orthopedics. Therefore, continued x-ray evaluation of the bone may be necessary to know how long the course of magnetic treatment should be extended to prevent the possibility of union issues. Similar situations apply to other clinical conditions. So, in the earlier situations, simply managing the pain or other symptoms without adequate consideration of the ultimate goals would potentially lead to less than optimal results. The constraints of the research and clinical settings and other practical considerations most often drive the decisions to terminate treatment or the research. Because of these constraints, we do not commonly have adequate information about the proper length of treatment courses to guide clinical practice. If patients had unlimited access to PEMF systems, preferably in the home setting, better information would be able to be obtained to determine optimal courses of treatment.

The use of PEMFs is rapidly increasing and extending to soft tissue from its first applications to hard tissue (Pilla, 2013). EMF in current orthopedic clinical practice is frequently used to treat delayed and nonunion 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 upward of a year in the case of nonunion fractures. PRF applications appear to be best for the reduction of pain and edema. The acute tissue inflammation that accompanies the majority of traumatic and chronic injuries is essential to the healing process; however, the body often over-responds in the chronic lesion situation, and the resulting edema causes delayed healing and chronic pain. Edema reduction is an important target for PRF and PEMF applications.

Double-blind clinical studies have now been reported for chronic wound repair, acute ankle sprains, and acute whiplash injuries. PRFs have been found to accelerate reduction of edema in acute ankle sprains by up to fivefold (Pennington et al., 1993). Some of the best responses to PRFs appear to be during or immediately after the treatment of acute soft tissue injuries. For bone repair, while not commonly used for this purpose, limited experience shows that responses to PRFs are significantly slower. 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.

Even chronic musculoskeletal pain treated with MFs for only 3 days, once per day, can eliminate and/or maintain chronic musculoskeletal pain (Stewart and Stewart, 1989). Small, battery-operated PEMF devices with very weak field strengths have been found to benefit musculoskeletal disorders (Fischer, 2002). Because of the low strength used, treatment at the site of pain may need to last between 11 and 132 days, between two times per week, 4 h each, and, if needed, continuous use. Use at night could be near the head, for example, beneath the pillow, to facilitate sleep. Pain scale scores are significantly better in the majority of cases. Conditions that can be considered for treatment are arthritis, lupus erythematosus, chronic neck pain, epicondylitis, patellofemoral degeneration, fracture of the lower leg, and RSD/CRPS.

Back pain or whiplash syndrome treated with a very low-intensity (up to 30 uT) PEMF twice a day for 2 weeks along with usual pain medications relieves pain in 8 days in the PEMF group versus 12 days in the controls (Thuile and Walzl, 2002). Headache is halved in the PEMF group, and neck and shoulder/ arm pain improved by one-third versus medications alone.

Cervical spine-related nerve pain affects approximately 1 in 1000 adults per year. A prospective audit done initially on the effect of PRF treatment of the cervical dorsal root ganglion found satisfactory pain relief for a mean period of 9.2 months. The research group then went on to do a randomized sham-controlled trial (Van Zundert et al., 2007). At 3 months, the PRF group showed a significantly better outcome with regard to the global perceived effect (>50% improvement) and VAS (20-point pain reduction). The need for pain medication was significantly reduced in the active group after 6 months. Another application of PRF, using low field amplitude pulsed short-wave 27.12 Hz diathermy, has successfully treated persistent neck pain and improved mobility (Foley-Nolan et al., 1990). This system used a miniaturized, 9 V battery-operated, diathermy generator fitted into a soft cervical collar, for 3–6 weeks, 8 h daily. Seventy-five percent of improved range of motion (ROM) and pain were seen within 3 weeks of treatment.

Other PEMFs have been found (Kjellman et al., 1999) to have more benefit in the treatment of neck pain in some research, compared to physical therapy, for both pain and mobility.

A blinded randomized study was conducted to compare European spa therapy (ST) with PEMF therapy in chronic neck pain (Forestier et al., 2007a). There was significantly greater improvement in the PEMF group than the ST group ($p = 0.02$). As part of the earlier study, the authors also did a cost–benefit analysis (Forestier et al., 2007b). It is rare to find cost–benefit research on the use of PEMFs. The main outcome measure of the cost–benefit part of the research was the cost required to achieve an increase in health dimension scores on the MOS SF-36 comparing care in the 6 months preceding to 6 months after the start of the study. They found that the overall health care costs were less for the PEMF group than the ST and control groups. A gain of one physical MOS SF-36 unit over 1 year cost €3,400 for the PEMF group as a whole, €29,000 for the ST group, and €95,076 for the control group. It appears that the cost–benefit to society of the PEMF treatment group compared to ST or standard therapy produces a substantial cost savings.

One group evaluated pain and swelling after distal radius fractures after an immobilization period of 6 weeks (Cheing et al., 2005). Eighty-three patients were randomly allocated to receive 30 min of either ice plus PEMF (group A), ice plus sham PEMF (group B), PEMF alone (group C), or sham PEMF for 5 consecutive days (group D). All had a standard home exercise program. Outcome

measures included a VAS for recording pain, volume displacement for measuring the swelling of the forearm, and a handheld goniometer for measuring the range of wrist motions. They were assessed, before treatment, and on days 1, 3, and 5 during treatment. At day 5, a significantly greater cumulative reduction in VAS as well as improved ulnar deviation ROM was found in group A than the other three groups. For volumetric measurement and pronation, participants in group A performed better than subjects in group D but not those in group B. The end result was that the addition of PEMF to ice therapy produces better overall treatment outcomes than ice alone, or PEMF alone, in pain reduction and ulnar ROM. This study points out the cumulative benefit of using both PEMFs and standard therapy, at least in radial fractures.

Treatment of lateral epicondylitis (tennis elbow) can be frustrating and challenging. Many therapeutic approaches have been used, including local steroid injection and surgery. This condition tends to recur regardless of the therapies used. Steroid injections carry their own risks, and so alternative methods of therapy that are less invasive and potentially harmful need to be developed. PEMFs have been found as a useful and safe candidate therapy. One group tested the efficacy of PEMF compared to sham PEMF and local steroid injection (Uzunca et al., 2007). Sixty patients with lateral epicondylitis were randomly and equally distributed into three groups as follows: group I received PEMF, group II sham PEMF, and group III a corticosteroid + anesthetic agent injection. Pain levels during rest, activity, nighttime, resisted wrist dorsiflexion, and forearm supination were investigated with VAS and algometer. All patients were evaluated before treatment, at the third week, and the third month. VAS values during activity and pain levels during resisted wrist dorsiflexion were significantly lower in group III than group I at the third week. Group I patients had lower pain during rest, activity, and nighttime than group III at the third month. PEMF appears to reduce lateral epicondylitis pain better than sham PEMF. Corticosteroid and anesthetic agent injections can be used in patients for rapid return to activities, along with PEMFs to produce a longer-standing benefit.

Another randomized sham-controlled study (Devereaux et al., 1985) on lateral humeral epicondylitis (tennis elbow) involved 30 patients with both clinical and thermographic evidence of tennis elbow. PEMF treatment, consisted of 15 Hz, delivering 13.5 mV and using a figure of eight coil with the loops over each epicondyle for 8 h a day in one or two sessions, for a minimum period of 8 weeks. They were significant improvements in grip strength at 6 weeks, with a slight decrease in difference at 8 weeks. There was little difference in the first 4 weeks. Since there were only 15 subjects in each treatment group, this study was probably underpowered for most of the other measurement indices used.

17.8 OSTEOARTHRITIS PAIN

OA affects about 40 million people in the United States. OA of the knee is a leading cause of disability in the elderly. Medical management is often ineffective and creates additional side-effect risks. Many patients with OA of the knee/s undergo many soft tissue and intra-articular injections, physical therapy, and many, eventually, arthroscopies or joint replacements.

An ELF sawtooth wave, 50 uT, whole-body and pillow applicator system has been in use for about 20 years in Europe. In one study using the system, applied 8 min twice a day for 6 weeks, it was shown to improve knee function and walking ability significantly (Pawluk et al., 2002). Pain, general condition, and well-being also improved. Medication use decreased. Plasma fibrinogen, C-reactive protein (a sign of inflammation), and the sedimentation rate all decreased by 14%, 35%, and 19% respectively. Sleep disturbances often contribute to increased pain perception. It was found to improve sleep, with 68% reporting good/very good results. Even after 1 year follow-up, 85% claim a continuing benefit in pain reduction. Medication consumption decreases from 39% at 8 weeks to 88% after 8 weeks.

A randomized double-blind controlled study on early knee OA (Nelson et al., 2013) found an almost 60% reduction in mean VAS pain scores within the first 5 or so days for the active treatment group. This improvement held and persisted for the 42 days of the study. The sham group mean VAS

scores were not significant at any time point. The mean VAS score change for the active treatment group was about threefold better than the sham group. A portable 6.8 MHz sinusoidal signal with a peak-induced electric field of 34 V/m was applied for 15 min twice a day for 14 days. The majority of the pain relief happened in the first 5 days and maintained stable for 42 days, till the end of the study. Pain relief persisted after the 14th day when the PEMF was discontinued. Pain relief decreased from a mean baseline VAS score of 6.85 to just under 4, after day 5.

A major limitation of magnetic therapy research studies is that they are often terminated too soon. This is not the case typically in clinical practice, when these therapies are often applied for extended periods of time, typically when symptoms have improved to a goal target. My own clinical practice experience has been that when individuals discontinue their therapies prematurely, for OA in particular, their pain eventually returns. So, they should either continue therapy over extended periods of time or get periodic retreatments. Other than clinical practice experience, we do not have good research-based data to guide clinical practice. By necessity, this study also did not evaluate clinical measures of function, effusion, and inflammatory markers or have evidence by physical imaging, such as MRI, of actual physical changes to the joint. Other knee arthritis research, using other ELF low-intensity signals (Pawluk et al., 2002), found functional improvements in objective knee scores. We continue to await imaging evidence for longer-term changes to the structure of the knee itself.

In another randomized, placebo-controlled study (Ay and Evcik, 2009), PEMF of 50 Hz, 105 uT, applied for 30 min, was used in 55 patients with grade 3 OA for only 3 weeks for pain relief and enhancing functional capacity of patients with knee OA. Pain improved significantly in both groups relatively equally ($p < 0.000$). However, there was significant improvement in morning stiffness and activities of daily living (ADL) compared to the control group. They did not find a beneficial symptomatic effect of PEMF in the treatment of knee OA in all patients.

In a rheumatology clinic study of knee OA (Pipitone and Scott, 2001), 75 patients received active PEMF treatment by a unipolar magnetic device or placebo for 6 weeks. The 9 V battery-operated device was <0.05 mT with a low-frequency coil of 2 kHz plus harmonics up to 50 kHz modulated on a 3, 7.8, or 20 Hz base frequency and an ultrahigh frequency coil with a 250 MHz modulated frequency plus harmonics of the same modulation as the LF coil. Patients were instructed to use the magnetic devices three times a day. The 7.8 Hz modulation frequency was prescribed for the morning and afternoon treatments, while the 3 Hz modulation frequency was prescribed for the evening. Baseline assessments showed that the treatment groups were equally matched. Analysis at follow-up showed greater between group improvements in global scores of health status. Paired analysis showed significant improvements in the actively treated group in objective function, pain, disability, and quality of life at study end compared to baseline. These differences were not seen in the placebo-treated group.

In another randomized, double-blind, placebo-controlled clinical trial of knee OA in Denmark (Thamsborg et al., 2005), 83 patients had two 2 h of daily treatment, 5 days per week for 6 weeks. They were reevaluated at 2 and 6 weeks after treatment. Again, objective standardized measures were used. There was a significant improvement in ADL, stiffness, and pain in the PEMF-treated group. In the control group, there was no effect on ADL after 2 weeks and a weak change in ADL after 6 and 12 weeks. Even the control group had significant reductions in pain at all evaluations and in stiffness after 6 and 12 weeks. There were no between-group differences in pain over time. ADL score improvements for the PEMF-treated group appeared to be less with increasing age. When groups were compared, those <65 years of age had significant reduction in stiffness. While this tended to be a negative study, when looking at between-group comparisons, there were indications of improvement in ADLs and stiffness, especially in individuals younger than 65.

Twenty-seven OA patients treated with PEMF in a tube-like coil device for 18 half-hour exposures over 1 month had an average improvement of 23%–61% compared to 2%–18% in the placebo group (Trock et al., 1993). They were evaluated at baseline, midpoint of therapy, end of treatment, and 1 month later. The active treatment group had decreased pain and improved functional

performance. Another study reported by the same group (Trock et al., 1994), including 86 patients with OA of the knee and cervical spine, showed significant changes from baseline for the treated patients at the end of treatment and at 1-month follow-up. Placebo patients also showed improvement but with less statistical significance at the end of treatment and had lost significance for most variables at 1-month follow-up. The study patients showed improvements in pain, pain on motion, patient overall assessment, and physician global assessment.

Using PEMFs to prevent the development or progression of OA may be another target for PEMFs. Meniscal tears of the knee frequently, whether operated or not, lead to arthritic changes, which can take place over long periods of time. In a longer-term 21-year follow-up study (Roos et al., 1998) of post-meniscectomy patients looking for x-ray signs of OA, mild x-ray changes were found in 71% of the knees, while more advanced changes were seen in 48%. The corresponding prevalence values in the control group were 18% and 7%, respectively. Knee symptoms were reported twice as often in the study group as in the controls. Surgical removal of a meniscus following knee injury is still a significant risk factor for knee OA development on x-ray, with a relative risk of 14.0 after 21 years. A 5-year x-ray follow-up study (Covall and Wasilewski, 1992) was done post arthroscopic meniscectomy. In this follow-up study, some 61% of the knee joints showed changes postoperatively, with about 15% showing significant progression. When these joints were compared to the nonoperated joint (serving as a self-control), only 40% of the operative knees showed relative progression and only 4% had significant progression.

Because of the relatively high frequency of OA in patients with meniscal tears or occurring post-meniscectomy, it appears that PEMFs could be indicated for routine use to prevent onset or progression. Of course, it remains to be proven that PEMFs can in fact slow down progression. At the moment at least, the evidence seems to indicate that PEMFs may be helpful in the function and pain aspects of existing OA of the knee. The ability to do longer-term comparisons is becoming contaminated by the significant increases in the numbers of people getting early joint replacements. We may well have to rely on clinicians using therapies like PEMFs to provide us with reports of the long-term benefits of MF therapies on preventing OA, until more formal and well-funded studies are available.

One study (Sutbeyaz et al., 2006) looked at the effect of PEMFs on pain, ROM, and functional status in patients with cervical osteoarthritis (COA). Thirty-four patients were included in a randomized double-blind study. PEMF was administrated to the whole body using a 1.8 × 0.6 m size whole body mat. They were on the mat for 30 min per session, twice a day for 3 weeks. Pain levels in the PEMF treatment group decreased significantly after therapy ($p < 0.001$), with no change in the sham group. Active ROM, neck muscle spasm, and disability (NPDS) scores also improved significantly after PEMF therapy ($p < 0.001$). No change was seen in the sham group. This study shows that PEMFs can give significant pain reduction in neck arthritis and can be used alone or with other therapies to give even greater benefits.

A 50 Hz pulsed sinusoidal MF, 35 mT field PEMF for 15 min, 15 treatment sessions, improves hip arthritis pain in 86% of patients. Average mobility without pain improved markedly (Rehacek et al., 1982). Forty-seven patients with periarthritis of the shoulder who were receiving outpatient physical therapy were randomized using a controlled triple-blind study design to conventional physical therapy or conventional physical therapy with pulsed MF therapy (Leclaire and Bourgouin, 1991). They received treatments three times a week for a maximum of 3 months. PEMF therapy was applied 30 min at a time at three different frequencies 10/15/30 Hz with matched intensities of 3/4/6 mT over the course of the therapy program. This study showed no statistically significant benefit from magnetotherapy in the pain score, ROM, or improvement of functional status in patients with periarthritis of the shoulder. There appeared to be a trend toward slightly worse baseline function of the magnetic therapy group. This would therefore suggest that treatment was not carried out for a sufficient time. An improvement in the design of the study would have been to follow the individuals until they had achieved either goal recovery or full recovery, as would happen in clinical practice. Another possibility for the lack of benefit for the pulsed magnetic therapy group

is that the frequencies and intensities used are not optimized for this particular condition, given the length and the frequency of treatments per week.

17.9 FIBROMYALGIA

Fibromyalgia (FM) is a complex syndrome, primarily affecting women. There is still no adequate standard conventional medical approach to this problem. While there is an approved medication for this condition, it is not always effective, because it does not deal with the underlying cause and has significant side effects. PEMFs can frequently be very helpful. In one study (Sutbeyaz et al., 2009), 56 women with FM, aged 18–60 years, were randomly assigned to either PEMF or sham therapy, 30 min per session, twice a day for 3 weeks. Treatment outcomes were assessed after treatment and at 4 weeks, showing significant improvements in test scores at the end of therapy and at 4-week follow-up. The sham group also showed improvement at this time on all outcome measures except the specific FM questionnaire. So, low-frequency PEMF therapy can improve at least some general FM symptoms.

A low-intensity PEMF (400 .tT) in a portable device fitted to their head was found to help FM. In a randomized, double-blind, sham-controlled clinical trial (Thomas et al., 2007), patients with either chronic generalized pain from FM (n = 17) or chronic localized musculoskeletal or inflammatory pain (n = 15) were exposed in treatments twice daily for 40 min over 7 days. A VAS scale was used. There was a positive difference with PEMF over sham treatment with FM, although not quite reaching statistical significance ($p = 0.06$). The same level of benefit was not seen in those without FM. In patients with other causes of chronic, nonmalignant pain, either longer periods of exposure are necessary or other approaches need to be considered.

The effect of specific PEMF exposure on pain and anxiety ratings was investigated in two patient populations (Shupak et al., 2006). A double-blind, randomized, placebo-controlled parallel design was used on the effects of an acute 30 min MF exposure (less than or equal to 400 uT; less than 3 kHz) on VAS-assessed pain and anxiety ratings in female RA and FM patients who received either the PEMF or sham exposure treatment. A significant pre–post effect was present for the FM patients, $p < 0.01$. There was no significant reduction in VAS anxiety ratings pre- to post-exposure.

Lying on a mattress pad embedded with static magnets at night for 16 weeks reduced pain in FM patients (Colbert et al., 1999). This was a randomized double-blind study, with 25 females sleeping on *magnetic* mattress pads or a nonmagnetized pad. Each pad had 270 comparable looking domino size (2 × 4.5 cm) ceramic pieces that were either magnetized or not. The magnets were measured to be about 1100 G on their surface. However, having in mind compression properties of the foam in the mattress pad, the actual MF at the body surface was in the range of 500–600 G depending on patient body mass. The women sleeping on the experimental mattress pad experienced a statistically significant decrease in total myalgic pain of 12%, improved physical functioning of 30%, an average pain score decrease of 38% on VAS, and improvement in sleep of 37%. The control group had a 1% decrease in total myalgic score, 3% decrease in physical functioning, 8% decrease in pain score, and 6% improvement in sleep. It certainly appears that field intensity with static MFs can be very important in achieving adequate results, with higher field intensities likely producing better results. On the other hand, this FM study also indicates that MF density, that is, the number of MFs applied to the whole body simultaneously, may be a significant factor as well and may be the preferred approach given that it is often not clear where the, actual versus assumed, pain generators are.

17.10 POSTOPERATIVE PAIN

Postoperative pain is to be expected, with variable severity depending on the patient and the type of surgery. Surgeons seek new methods of pain control to reduce side effects and speed postoperative recovery. Several studies were found evaluating the value of MFs of postoperative pain.

An in vivo study of PEMFs (Shafford HL, et al. 2002) was done in dogs postoperatively after ablation of ovaries and uterus to see how pain is affected and interacts with postoperative morphine analgesia. Sixteen healthy dogs were examined within 6 h postoperatiion at eight different time points. There were four groups: (1) control group (NaCl administration), (2) postoperative PEMF exposure (NaCl administration), (3) postoperative morphine application, and (4) postoperative morphine application plus PEMF exposure. The PEMF was 0.5 Hz, exposure intermittent, 20 min field on/20 min field off for 6 h, whole-body exposure. At 30 min, the total pain score for group 4 was significantly less than for the control group, but not significantly different from group 2 or 3. The results suggest that PEMF may augment morphine analgesia or be used separately postoperatively after invasive abdominal procedures.

After breast augmentation surgery, patients (Hedén and Pilla, 2008) applied a portable and disposable noninvasive, high-frequency and low-intensity PEMF device in a double-blind, randomized, placebo-controlled study. Healthy females undergoing breast augmentation for aesthetic reasons were separated into three cohorts: (n = 14) receiving bilateral PEMF treatment, (n = 14) receiving bilateral sham devices, and (n = 14) an active device to one breast and a sham device to the other breast. Pain levels were measured twice daily through the seventh day after surgery (POD 7), and postoperative analgesic use was also tracked. VAS scores decreased in the active cohort by almost three times the sham cohort by POD 3 ($p < 0.001$) and persisted at this level to POD 7. Postoperative pain medication use decreased nearly three times faster in the active versus the sham cohorts by POD 3 ($p < 0.001$). These results can be extended to include the use of this form of PEMF for the control of almost any situation of postoperative pain, especially involving surgery on superficial physical structures.

In another surgical study, this time post breast reduction for symptomatic macromastia, PEMFs were studied, not only on their results on postoperative pain, but also on potential mechanisms, including changes to cytokines and angiogenic factors in the wound bed (Rodhe et al., 2010). Twenty-four patients were randomized in a double-blind, placebo-controlled, randomized fashion to a sham control or a low-intensity 27.12 Hz PEMF configured to modulate the calmodulin-dependent nitric oxide signaling pathway. Pain levels were measured by VAS, and narcotic use was recorded. The PEMF used produced a 57% decrease in mean pain scores at 1 h ($p < 0.01$) and a 300% decrease at 5 h ($p < 0.001$), persisting to 48 h postoperatively in the active versus the control group, along with a concomitant 2.2-fold reduction in narcotic use in active patients ($p = 0.002$). Mean IL-1β in wound exudates was 275% lower ($p < 0.001$), suggesting fairly rapid reductions in acute posttraumatic inflammation.

On the other hand, some research has found a lack of benefit of PEMFs postoperatively. Pain after elective inguinal hernia repair was evaluated in a double-blind randomized, non-PEMF controlled trial using a high-frequency low-intensity portable PEMF device (Reed et al., 1987). The device had an output rate of 320 Hz, pulse width of 60 µs, and maximum power output of 1 W. Treatment was 15 min twice a day, over and under the thigh. VAS at 24 and 48 h postoperatively showed no difference between treated and untreated groups. This study most likely used treatment times that were too short for the intensities used, and the electrodes were placed remote to the actual wound, not over the surgical site.

Severe joint inflammation following trauma, arthroscopic surgery, or infection can damage articular cartilage; thus, every effort should be made to protect cartilage from the catabolic effects of proinflammatory cytokines and stimulate cartilage anabolic activities. A pilot, randomized, prospective, and double-blind study (Zorzi et al., 2007) was done to evaluate the effects of PEMFs (75 Hz, rectangular) after arthroscopic treatment of knee cartilage. Patients with knee pain were recruited and treated by arthroscopy with chondroabrasion and/or perforations and/or radiofrequencies. There were two groups: lower-intensity control (MF at 0.05 mT) and active (MF of 1.5 mT). PEMFs were used for 90 days, 6 h per day. Objective measures were used before arthroscopy, and after 45 and 90 days, the use of anti-inflammatories (NSAIDs) was recorded. Three-year follow-up interviews were also used (n = 31). Knee score values at 45 and 90 days were higher in the active group at 90 days ($p < 0.05$). NSAID use was 26% in the active group and 75% in the control group ($p = 0.015$). At 3-year follow-up, the percent completely recovered was higher in the active group ($p < 0.05$).

Anterior cruciate ligament reconstruction, now a common surgical procedure, is usually performed by a minimally invasive arthroscopic approach. Even so, arthroscopy may elicit an inflammatory joint reaction detrimental to articular cartilage. PEMFs would be expected to mitigate some of these inflammation reactions. To study this possibility, a prospective, randomized, and double-blind study was done on 69 patients with a 75 Hz, 1.5 mT device, 4 h per day for 60 days versus sham device (Benazzo et al., 2008). At follow-up, active treatment patients showed a statistically significant faster recovery ($p < 0.05$). The use of anti-inflammatories was less frequent ($p < 0.05$). Joint swelling and return to normal ROM occurred faster ($p < 0.05$). The 2-year follow-up did not show statistically significant difference between the two groups. In addition, a subset analysis of 29 patients (15 in the active group; 14 in the placebo group) who concurrently had meniscectomy, function scores between the two groups were even larger than observed in the whole study. So this particular PEMF signal is expected to shorten postoperative recovery time and limit joint inflammation.

17.11 SHOULDER PAIN

Shoulder pain is the third most common musculoskeletal problem and accounts for 5% of visits in primary care. Although many treatments are described, there is no consensus on optimal treatment, and up to 40% of patients still have pain 12 months after initially seeking help for pain. Previously, the effect of transcutaneous PRF was evaluated in a retrospective audit (Taverner and Loughnan, 2014) that showed good pain relief for a mean 395 days and justified this randomized sham-controlled trial. In this follow-on study, 51 patients had evaluations at 4 and 12 weeks by a blinded observer and compared with baseline. There were reductions in pain at night, pain with activity, and functional improvement with active but not sham. Active treatment showed significant reductions of 24/100 in pain at night and 20/100 with activity at 4 weeks and 18/100 and 19/100, respectively, at 12 weeks from baseline. Pain at both rest and shoulder elevation were not improved by active treatment.

Shoulder overuse, subacromial impingement syndrome, is a frequent and commonly disabling type of shoulder pain. A double-blinded, PEMF randomized, and controlled study was done along with other standard conservative treatment modalities in acute rehabilitation (Atkas et al., 2007). Forty-six patients received a standard program for 3 weeks of pendulum exercises and cold packs five times a day, restriction of shoulder extension, daily activities, and meloxicam 15 mg daily. One group was given PEMF of 50 Hz, 3 mT with a U-shaped applicator, 25 min per session, 5 days per week for 3 weeks. The other group was given sham PEMF. A VAS, total constant shoulder function score, and ADL were measured, before and after treatment. When compared with baseline, significant improvements were seen in all these variables at the end of the treatment in both groups ($p < 0.05$). The active PEMF group had a higher baseline resting VAS with rest pain and activity pain and a 0.8 VAS difference from baseline to post-treatment assessments, with significantly higher standard deviations. So, it appears that this study was underpowered to be able to detect differences using the treatment protocols applied. Because both groups received standard therapies as well, including ice packs and medication, it would be expected to be harder to find a statistically significant difference with this small number of study patients, and given the duration of the study, for the additional benefit of PEMFs. It is quite probable that for short-term studies like this, a much higher-intensity PEMF system would be needed to demonstrate significant differences in benefit.

17.12 PELVIC PAIN SYNDROME

Noninflammatory chronic pelvic pain syndrome (CPPS) can be quite disabling in both men and women, frequently with no adequate treatment options. A study (Leippold et al., 2005) was designed to prospectively evaluate sacral magnetic stimulation as a treatment option

for patients with noninflammatory CPPS (CPPS, category IIIB). Fourteen men were treated with sacral magnetic stimulation, 10 treatment sessions once a week for 30 min at a frequency of 50 Hz. Twelve of fourteen men reported improvement but only during the time of stimulation. Inventory scores before and after treatment did not change. There was no sustained effect beyond the time of stimulation on the mean scores for pain, micturition complaints, or quality of life. Sacral magnetic stimulation in patients with CPPS IIIB reduces pain only during stimulation. The fact the pain relief is obtained during treatment is notable and valuable. Because this level of frequency of treatments is less likely to induce healing in the tissues causing the pain syndrome, it may be reasonable to expect only a reduction in pain during the treatment course and not a more enduring benefit. While this treatment approach does not appear to be useful, it remains to be seen whether a change in the protocol may produce more enduring results.

Gynecologic pelvic pain may also benefit from PEMFs. A high-voltage, high intensity, pulsed stimulation (1-30 pulses/second) system (Jorgensen et al., 1994) was used in the setting of ruptured ovarian cysts, postoperative pelvic hematomas, chronic urinary tract infection, uterine fibrosis, dyspareunia, endometriosis, and dysmenorrhea. Ninety percent of patients experienced marked rapid relief from pain, with pain subsiding within 1–3 days after PEMF treatment, eliminating supplementary analgesics. Unfortunately, longer-term data are not available to determine the durability of the therapeutic response.

17.13 MISCELLANEOUS PAIN APPLICATIONS

In dentistry, periodontal disease may cause bone resorption severe enough to require bone grafting. Grafting is followed by moderate pain peaking several hours afterward. Repeated PEMF exposure for 2 weeks eliminates pain within a week. Even single PEMF exposure to the face for 30 min of a 5 mT field and related conservative treatment produce much lower pain scores versus controls (Tesic et al., 1999).

Results of PRF PEMF in a case series either eliminates or improves, even at 2 weeks following therapy, pain 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 (Punnonen et al., 1980).

PEMFs have been found to be helpful in headaches. For migraine headaches, high-frequency (53-61 gHz) PEMFs applied to specific acupuncture points on the inner thighs for at least 2 weeks are effective short-term therapy (Sherman et al., 1999). Longer exposures lead to greater reduction of headache activity. One month after a treatment course, 73% of patients report decreased headache activity versus 50% of placebo treatment. Another 2 weeks of treatment after the 1-month follow-up gives an additional 88% decrease in headache activity. Patients with headache treated with a PEMF for 15 days after failing acupuncture and medications get effective relief of migraine, tension, and cervical headaches at about 1 month after treatment (Prusinski et al., 1987). They have at least a 50% reduction in frequency or intensity of the headaches and reduction in analgesic drug use. Cluster and posttraumatic headaches do not respond as well.

17.14 SUMMARY

PEMFs of various kinds, strengths, and frequencies included have been found to have good results in a wide array of painful conditions. There is little risk when compared to the potential invasiveness of other therapies and the risk of toxicity, addiction, and complications from medications. This creates an ideal setup for clinicians to attempt PEMFs before other more potentially harmful treatments are attempted, especially for long-term treatment of chronic pain conditions. Clearly, more research is needed to elaborate mechanisms and optimal treatment parameters and the best MF systems for given applications. While it is the goal of the researcher to find the optimal system for a particular indication, the goal is opposite for clinicians, that is, to have the most

generalizable system for the most problems. This latter situation is expected to be the best, most cost-effective approach, not only for patients but also for the health care system.

Most magnetic systems used in the research setting have never been commercially available. On the other hand, a large percentage of commercially available systems have been inadequately studied. Most PEMF systems typically available to the clinician are the commercial systems. Most clinicians using PEMF systems rely on the general body of knowledge of PEMF effects on biology as being clinically useful, bolstered when possible with evidence from clinical trials. Ultimately, as with any other therapy, including pharmaceuticals, clinical experience will guide variations in treatment protocols, and whether only one PEMF system or multiple systems are needed. Because of the range of effects of different PEMF systems, it may be best clinical practice to have several different PEMF systems to achieve desired results for the widest majority of clinical presentations. These could include, but are not limited to, for example, high-intensity local systems; lower-intensity, whole-body complex signal systems for health maintenance or very sensitive individuals; medium-intensity local and/or whole-body systems that allow selection of individual frequencies; or systems with extremely low intensities that provide a broad spectrum of frequencies.

Many studies that have been reported in this review have been controlled trials, and many have been randomized double-blind placebo. Many studies have small sample sizes and therefore are often underpowered, often yielding negative or conflicting results. Negative results do not necessarily indicate the lack of potential for the technology and are simply the probability of an inadequate research design. This reflects the very complex nature of clinical practice across a large spectrum and variety of pain conditions.

There are very few studies comparing different PEMF systems or other treatment modalities directly. There is no consistency in the device design even for the same clinical category, such as OA of the knee. Even though a device may have been found to have statistically significant benefits in a given condition, it is not predictable that it would be equally effective in other situations. What works well in vitro may not work well in vivo. The reverse is also true that what might not work well *in vitro* may work well *in vivo* in living systems, because of harmonics, biologic amplification, and the much more complex *in vivo* physiologic systems. Also, what works well in animals may not work well in humans.

The reasons for apparent inconsistency of results are that the issues being treated are by themselves complex and at the very least include different demands and responses for biologic windows for frequencies, intensities, and waveforms. This is not even to consider the effects of the durations of individual treatments or courses of treatment. Understanding the dose delivered at the target tissue is critical and is one of the main reasons that static MFs have not been more widely accepted, that is, often being of insufficient intensities to reach deeper tissues. Clinical experience has shown that deeper problems, or those that are chronically more severe, respond better with higher-intensity MFs, regardless of whether static or time varied, independent of considering waveform and frequency.

Medical practitioners are becoming gradually aware of the potential of MFs to successfully treat or significantly benefit the myriad of problems presented to them, reducing risks of conventional medical approaches when feasible. A major decision for clinicians remains whether to do in-office treatment or encourage patients to purchase their own systems for home use. Experience demonstrates that longer-term, daily, in-home use produces the most durable results. In-office treatments can provide some indication of responsiveness of the condition to magnetic therapy. In some circumstances, a course of treatments in the office setting may resolve pain for a considerable period of time. After 25 years of clinical use of MF therapies, it has been my experience that long-term home use works best, especially for chronic pain, almost regardless of the system purchased.

While very few PEMF systems have been US Food and Drug Administration (FDA) approved, it is even more rare for a system to be FDA approved specifically for pain and then become covered by Medicare or other health insurance. So, regardless of whether treatments are in-office or home-based, they are highly unlikely to be covered by insurance.

It may be reasonable enough to conclude that the body of evidence for the use of PEMFs for pain management is sufficiently robust to provide some degree of credibility and confidence for the clinician to be able to consider this technology in the management of their pain patients, especially considering the risk-benefit ratio vis-à-vis other available therapies. Knowing which systems to use, understanding how to adjust or select stimulation parameters, understanding the clinical dimensions of the problems needed to be treated, and selecting appropriate conditions for pain management using PEMFs will provide the clinician and the patient the most useful results.

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