Review Article

# The Use of Magnetic Field for the Reduction of Inflammation: A Review of the History and Therapeutic Results

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## ABSTRACT

Interest in magnetic field (MF) therapy has increased rapidly in recent years as research shows that this noninva-sive, cost-effective modality might be safer than drugs and surgical procedures for reduction of inflammation. Inflammation is a signal-mediated response to tissue invasion by pathogens or toxins or to injury or physical stresses. The immune response plays a pivotal role in reac-tion to insult, which triggers an inflammatory response almost immediately. Commonly, pharmaceuticals are used to suppress inflammation, although some evidence shows that suppressing inflammation can hinder wound healing. Immunological studies show that MF therapy, even low-intensity MF, interacts with cells and tissues, and the use of MF as an alternative or complement to cur-rently prescribed therapies could lead to a faster reduction in the inflammatory response. This review highlights past and present outcomes in bioelectromagnetic therapies and some of the more promising findings on the effect that MF therapy plays in inflammatory responses. (*Altern Ther Health Med.* 2013;19(2):##-##.)


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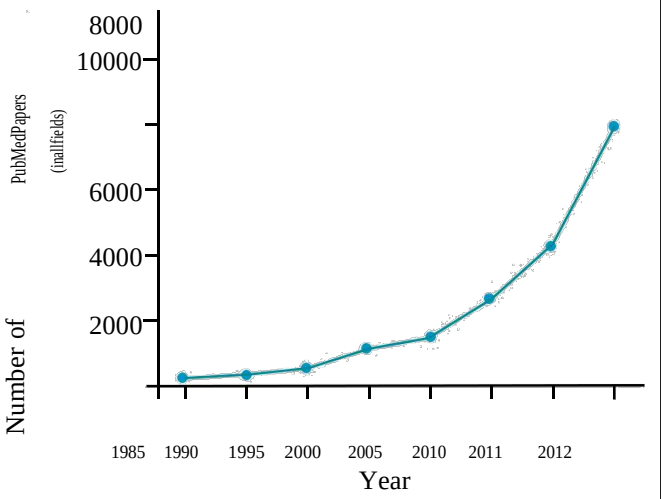
Interest in magnetic field (MF) therapy has increased in the past several years, as researchers have suggested its use as an alternative or complementary treatment to control the inflammatory response (Figure 1).[1-3] Immunological studies show that MF, even low-intensity MF, interacts with cells and tissues.[4-7] In particular, interest in the effect of MF on phagocytotic cells has attracted a lot of attention due to the role that extremely low-frequency, electromagnetic fields (ELF-EMF) play in decreasing the growth rate of tumors.[8-10] Research examining the effect of a whole-body magnetic field on cancer patients has shown that MF therapy has overall beneficial effects, particularly with respect to improved immune status and postoperative recov-ery.[11]

**Figure 1.** The Increase in Number of Peer-reviewed Published Articles Showing Interest in Magnetic Field Therapies (from 1985 to 2012)



For many years it was thought that electromagnetic-field (EMF) exposure would cause only harmful effects in the body, but it is now understood that the amount of energy (field strength or amplitude) and the frequency of the field is what determines whether MF is harmful, therapeutic, or benign.[12] In particular, ionizing radiation has been shown to cause harmful effects by breaking the electron bonds that hold molecules like DNA together.[13,14] Fields capable of gen-erating ionizing fields include alternating current (AC) that is produced by power lines, electrical wiring, and electrical equipment. Some epidemiological studies have suggested that an increased risk of cancer is associated with magnetic-field exposure near electrical power lines.[12,15,16]

The energy in nonionizing radiation, however, is not strong enough to break ion bonds in atoms and molecules.[17,18] Depending on the frequency and amplitude, beneficial nonionizing EMF has been reported to decrease calcium-transport alterations in human lymphocytes,[19,20] support natural killer cells fighting cancer and viruses,[21-27] modulate traumatic brain injury,[28] and reduce postoperative infections as well as bacterial and viral-related inflammatory responses that are major complications in today's medicine.[29-31] Tissue-permeating interventions, such as pulsed electromagnetic fields (PEMF), increase healing rates immediately after injury[3] due to their ability to quickly restore the equilibrium between free radicals and antioxidants as they work to stop the cascade of inflammatory progression and biochemical degradation in the traumatized tissue.[32] PEMF therapies not only potentially restore equilibrium in reactive oxygen spe-cies (ROS) related to free radical/antioxidant chemistry, they also induce currents that stabilize cytosolic $Ca^{2+}$ that is acti-vated by oxidative stress, upregulate classes of protective and restorative gene loci, and down-regulate dysregulatory and apoptotic gene loci.[3]

ELF-EMF has been reported to prohibit bacterial growth and improve immune response against bacterial infection.[33] Antibiotics have proved to be very effective in the treatment of bacterial infections, but the way in which antibiotics are administrated orally and distributed systemically throughout the body can create a lag time between the administration of the drug and its absorption at the site of insult. The time it takes an antibiotic to reach therapeutic levels can be significantly longer if the vascular system is compromised. During the time it takes a pharmaceutical to reach the site of injury, MF treatment can be applied and can penetrate even poorly vascularized tissue. Pending the deliv-ery of an antibiotic, bacteria can multiply[34]; therefore devel-oping treatments that can stimulate the efficacy of the immune system while waiting for antibiotics to take effect, could prevent septic shock. An urgent need also exists to address the lack of effective treatments to meet the increasing public-health burden caused by multidrug-resistant bacteria, in particular gram-negative bacteria.[35]

Inflammation initializes as a response to prevent the spread of damaging agents to nearby tissues, dispose of cell debris and pathogens, and set the stage for the repair and regenerative process.[36] The regeneration of tissues and organs is highly dependent on the ability of cells to keep inflammation under control so that the acute inflammatory response does not become chronic. Acute inflammation allows the tissue to regenerate through cell proliferation, while chronic inflammation continuously destroys the tissue after it has been rebuilt. A stable inflammatory response depends on the release of proper amounts and types of immune inflammatory and anti-inflammatory cells and their cytokines.[37]

When inflammation subsides, the damaged tissue may not be completely repaired, depending on the severity of the inflammation and the type of tissue involved. In minor inflammation of the skin, for example, the tissue is capable of complete regeneration, whereas in cardiac tissue, regeneration is more limited, and the damaged cells are often replaced by scar tissue.[29,31] It is during the time in which an acute-phase inflammatory response becomes chronic that the need for a noninvasive treatment is so critical. After the inflammatory response has been initiated and the immune system activated, adding pharmacological treatments— either orally, by injection, or topically, all of which have damaging side effects—can easily lead to further harm such as gastrointestinal trouble,[38] yeast overgrowth,[39] and anaphylactic or anaphylactoid reactions.[40] MF therapies, however, have shown few, if any, side effects in the treatment of inflammatory responses.[41]

The immune response is a signal-mediated reaction to tissue invasion by pathogens or toxins or to injury or physical stresses. It is triggered by signal transduction, which is the conversion of cell information from one form to another.[42] Cell signaling is part of a complex system of communi-cation that governs basic cellular activities and coordinates cell actions. The ability of cells to perceive and correctly respond to their environment is the basis of development, tissue repair, and immunity as well as normal tissue homeo-stasis.

In addition to fighting pathogens, the immune system monitors the health of cells and disposes of cells that have been injured or killed.[43] When microbes such as bacteria or viruses breach epithelia and enter the tissues or blood stream, they are attacked by specialized lymphocytes called phagocytes and by several plasma proteins.[42,43] Immediately following microbial invasion or tissue trauma, certain lymphocytes known as monocytes leave the blood and mature into macrophages that enter the tissue around the injured or infected site. Macrophages are widely distributed, bone-marrow-derived leukocytes that phagocytose foreign particles. They either stimulate inflammation or suppress it by releasing chemical signals that alter the behavior of other cells.[44] Macrophages are second only to hepatocytes in the amount of protein molecules they release after phagocytos-ing antigens and other particulates as well as destroying pathogens such as bacteria.[45,46] Resident macrophages are migratory cells that are found in connective tissues and in every organ in the body.[47] They migrate to extravascular sites

of infection by binding to endothelial adhesion molecules in response to chemical attractants that are produced when they encounter microbes.

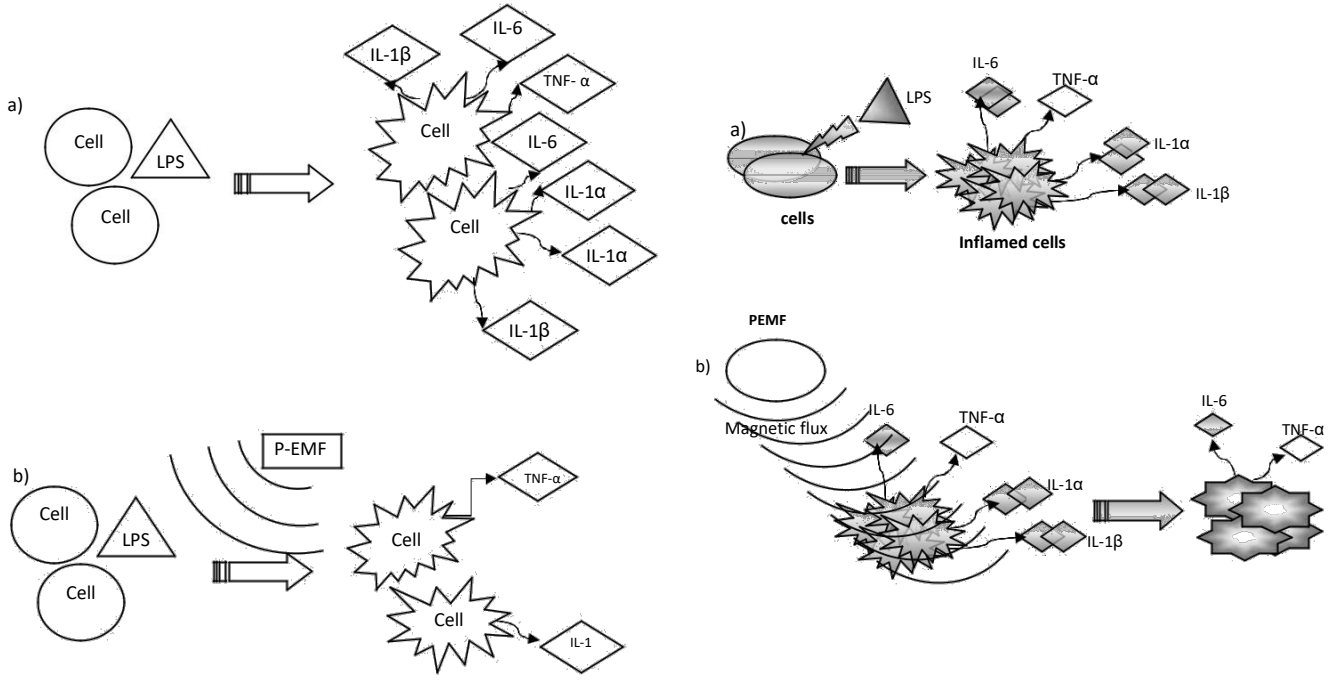
Macrophages are activated by binding to the invading pathogens, the result of which is the release of locally produced cytokines.[48] Cytokines are inflammatory proteins that react to tissue injury and infection and are synthesized in a wide range of biological actions in various tissues.[49-51] They are cell-signaling messengers that have specific effects on the interactions between cells, on communication between cells, or on the behavior of cells. The signaling mechanism of the proinflammatory cytokine cell is responsible for the initia-tion of the inflammatory response. Immune responses can be broken down into individual signal-transduction events through which changes in the extracellular environment elicit altered gene expression at the cellular level.[52,53]

Because EMF is able to influence cell communication, it is capable of attenuating inflammation even at genomic levels (Figure 2).[54,55] Errors in cellular information processing are responsible for inflammatory diseases,[56] autoimmunity,[57] irritable bowel syndrome,[58] and diseases such as cancer,[59] diabetes,[60] and even Alzheimer's disease.[61] Inflammation is also a key characteristic of pain and edema.[62] Research has shown that certain inflammatory-cell signals are involved in the initiation and persistence of pathologic pain through activated nociceptive sensory neurons.[63]

Current therapies used to reduce inflammation can cause adverse side effects. Treatments such as nonsteroidal, anti-inflammatory drugs (NSAIDs), used primarily to treat inflammation and associated pain, are designed to effect a specific biochemical target; however, they have an analgesic-dose ceiling and can cause gastric bleeding, renal toxicity, cardiovascular concerns, and occasional central nervous system effects, including loss of short-term memory and decreased attention span.[64] In addition, NSAIDs can cause many other side effects, the most common being nausea, vomiting, diarrhea, constipation, decreased appetite, rash, dizziness, headache, and drowsiness. They can also cause fluid retention, leading to edema. The most serious side effects of prescription NSAIDs are kidney failure, liver fail-ure, ulcers and prolonged bleeding after an injury or surgery, heart attacks, and strokes.[65]

Other options for treating inflammation include heat therapy, which may be applied to the body's surface or to deep tissues. Hot packs, infrared heat, paraffin (heated wax) baths, and hydrotherapy are inexpensive and easily accessible methods of treatment, but too much heat can cause burns.[66] Cold therapy is dosed in the form of ice packs in direct contact with the skin. When ice is applied, it lowers the skin temperature and helps to reduce swelling and inflammation. Ice can also numb nerve endings, stopping the transfer of impulses to the brain that register as pain. Although readily

**Figure 2.** (a) Shows cells after 3 hours of induction of LPS-cells aggregate to amplify signaling for TNF-α, IL-1α, IL-1β and IL-6. (b) Shows cells after 1 hour of exposure to PEMF; cell signaling is dampened, and cells become less inflamed.



available, if not closely monitored, cold therapies can cause frostbite or cell necrosis, nerve damage, reflex sympathetic dystrophy, tissue death, amputation, loss of use of a limb, and complex regional pain syndrome.[67-69] In contrast to these standards of treatment, MF therapies have few if any side effects and have a major advantage in their affordability over both pharmaceuticals and the cost of surgery.[41,70,71] Other benefits include ready availability, ease of localized applica-tion, and indefinite shelf life.[41]

## BIOPHYSICS

Bioelectromagnetics is the study of how living organ-isms interact with electromagnetic fields (EMFs). This inter-action takes place because all living matter is made of elec-trons, atoms, ions, and molecules. Faraday's Law explains the interchange between electricity and magnetism—that is, how voltage can be generated by changing the magnetic environment and how a magnetic field can be altered by changing voltage. Faraday's Law can be applied to electrical currents that already exist in the body (heart, brain, etc). These cur-rents are capable of producing magnetic fields outside the body[72] and can be measured by electrocardiograph (ECG), electroencephalograph (EEG), and magnetoencephalogra-phy (MEG), which is a technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain. These fields can be affected by exogenous EMF stimulation,[72] as can organs and cells in the body.[4] Research shows that the cell membrane is one of the main locations where applied EMF acts on the cell.[73,74] EMF at the membrane's outer surface can alter the ligand-receptor interactions,[75] also known as mechanically gated ion channels.[76] A low-frequency EMF passes unobstructed through living tissue, and in some cases, weak EMFs have resonant patterns that are close to the frequencies of $Ca^{2+}$, $Na^{+}$, and other ions.[73]

## MAGNETIC FIELD THERAPIES

In 1982, a PEMF device was approved by the US Food and Drug Administration (FDA) for bone repair, although it remains widely unused due to physicians' misunderstanding and lack of knowledge concerning the treatment.[77] PEMF therapeutic devices can be applied in two different ways, either by capacitive or inductive coupling. In capacitive cou-pling, no contact occurs with the body, whereas direct cou-pling requires the placement of opposing electrodes in direct contact with the surface of the skin of the targeted tissue.[71] Inductive coupling does not require electrodes to be in direct contact with the skin because it produces a field (see Faraday's Law of Induction) that emanates in all directions.

Research has shown that therapeutic applications at ELF-EMF (1-300 Hz) levels stimulate the immune system by suppressing inflammatory responses at the cell-membrane level. [78] Double-blind, placebo-controlled clinical trials[79] show that MF passes through the skin into the body's con-ductive tissue,[79-81] reducing pain and the onset of edema shortly after trauma.[82,83] Where edema is already present, treatment exhibits significant anti-inflammatory effects.[84] In a study of the effect of MF therapy on arthritis, 3 hours of exposure to a 50-Hz magnetic field revealed that experimen-tally induced inflammation in rats was significantly inhibit-ed as a result.[85] Strong beneficial effects have also occurred using 75-Hz frequency, MF treatment in patients suffering from fractures of the ankle joints.[86] In a randomized, double-blind, sham-controlled clinical study, low-frequency PEMF therapy at 0.1 to 64 Hz was shown to improve mobility, pain, and fatigue in fibromyalgia patients.[87]

MF-field treatment has been shown to enhance health and wellness by increasing blood flow[88] and aiding the effi-ciency of DNA repair.[89] In addition, researchers have sug-gested that the use of therapeutic EMFs can protect the myocardium from ischemia reperfusion injury[90] and can treat neurodegenerative disorders such as Alzheimer's dis-ease.[91] Depending on the dose (field strength and frequency) and duration of treatment, the EMF exposure can be harm-ful or induce a cytoprotective cellular response.[92] At 75 Hz (1.5 mT), EMFs display anti-inflammatory effects in human osteoarthritis synovial fibroblasts, by modulating inflamma-tory and anti-inflammatory parameters.[93] At 50 Hz (1 mT), ELF-EMF modulates chemokine production and keratino-cyte growth through inhibition of the NFκB signaling path-way, and thus, may inhibit inflammatory processes.[94] A 27.12 MHz, radio-frequency PEMF was shown to modulate an inflammatory cytokine after traumatic brain injury,[95] while repeated 915-MHz irradiation could cause DNA breaks in renal and liver cells in rats but did not affect the cell genome at the higher extent compared to the basal dam-age.[96]

Findings from preclinical and clinical studies suggest that psychiatric illness, particularly major depressive disor-der (MDD), is associated with inflammatory processes.[97] High-frequency (53 GHz) radiation was used to treat 53 neurotically depressed patients. Full recovery was observed in over 50% of cases, considerable improvement in over 40%, and some improvement in over 8%. [98] at 42.2, 51.8, and 65 GHz. In addition to decreased pain, edema, and infec-tion, other therapeutic benefits include an increase in ATP production,[100] normalization of cellular-membrane poten-tials,[101] and oxygenation of tissues and removal of toxins from the cells,[102] with few if any side effects.

Medical risks associated with posttraumatic stress dis-order (PTSD) have an underlying inflammatory pathology suggesting that inflammation contributes to these health declines.[103] In one study, 12 patients with PTSD and major depression underwent PEMF treatment of either 1 Hz or 5 Hz as an adjunct to antidepressant medications. Seventy-five percent of the patients had a clinically significant, antide-pressant response after treatment, and 50% had sustained that response at a 2-month follow-up. Comparable improve-ments were seen in anxiety, hostility, and insomnia.[104]

While pharmaceutical approaches commonly are used to suppress the inflammatory response, evidence exists that suppressing inflammation can hinder wound healing.[105,106]

**Table 1.** Examples of Different Magnetic Therapies Applied in the Identified Research Studies to Treat Inflammatory-related Conditions

| Condition | B or Freq* | Treatment Duration | Treatment Number | Key Finding |
|---|---|---|---|---|
| Alzheimer's[91] | 5–8 Hz | 30 min | 2x daily for 9 months | Significant improvement of cognitive function |
| Arthritis[1] | 60 Hz | 90 min | 3x daily until condition improves | Reduction of pain and inflammation |
| Back pain[107] | 64 Hz | 16 min | Until pain stopped | Statistically significant potential for reducing pain |
| Bacterial infection[33] | 50 Hz | 4–6 h | 1x | Increased immune response against bacteria |
| Cancer (breast, colon, and prostate tumors)[8] | 0.1 Hz–114 kHz | 60 min | 2x/week for 4 months | Significant decrease in size of tumor with tumor-specific frequencies |
| Carpal tunnel syndrome[108] | 20 Hz | 4 h | Daily for 2 months | Statistically significant short- and long-term pain reduction |
| Chronic bronchitis[109] | 30 mT | 15–20 min/ day | 15x for 6 months | Effective treatment in patients suffering from chronic bronchitis when coupled with standard drug therapies |
| Cognitive function[110] | 900 MHz | 2 h/week | 55 weeks | Significant reduction in cognitive impairment in rats |
| Edema[84] | 70 mT | 15–30 min | 6x in 3 h | Significant reduction of acute edema |
| Fibromyalgia[87] | 0.1–64 Hz | 30 min | 2x day/3 weeks | Improved function, decreased pain and fatigue, and improved global status in FM patients |
| Gastroduodenitis[111] | 100 Hz | 6–10 min | 8–10x for 2 weeks | Elimination of gastro-esophageal and duodenogastral refluxes for 77% of treated patients compared to 29% of controls |
| Glial cells[112] | 900 MHz | 15 min daily | 2–10 days | Induction of glial reactivity and biochemical modifications in the rat brain |
| Mastitis[103,113] | 10–25 Hz | 60 min | 2x/week for 3 months | Significant reduction in postop inflammation |
| Multiple sclerosis[114] | 1–25 Hz | 2–24h/day | Up to 5 weeks | Significant alleviation of symptoms with PEMF device |
| Migraine headache[115] | 27.12 Hz | 1 h/day | 5 days/week for 2 weeks | Effective, short-term intervention for migraine but not for tension headaches |
| Nerve regeneration[116] | 2 Hz/0.3mT | 1 h/day | 10 days | Suggested indirect influence on regeneration for pre- and postinjury exposure with PEMF |
| Neuritis[116,117] | 7.5 picoT | 20 min | 10–12x until vision improved | Production of beneficial effects in 93% of patients suffering from nerve problems |
| Oral surgery preop[118] | 5mT/30Hz | 30 min | 3–5 days prior to surgery | Significant reduction in inflammation in clinical trials |
| Osteoarthritis[119] | 10 G–25 G/ 5–24 Hz | 9 h | 18x in 1 month | Rapid improvements of immunological indices and alleviation of symptoms |
| Pain and edema[120] | 1mT or 5 mT | 6 h/day | 90 days | Significant aid to clinical recovery |
| Post traumatic stress disorder[104] | 1Hz or 5Hz | 15 min daily | 10 consecutive days for 20–30 days | A clinically significant antidepressant response for 75% of patients |
| Rheumatoid arthritis[121] | 30 mT | 30 min | 15–20x | Reduction of pain in chronic-pain populations |
| Septic shock[122] | 50 Hz/2mT | 6 h | 1x | Greater sensitization of *E coli* to antibiotics |
| Skin ulcers[123] | 75 Hz/2.7 mT | 4 hr/day | for 3 months | Positive effects but only in small lesions |
| Tendonitis[124] | 30 mT | 60 min | 10–20x for 8 weeks | Significant beneficial effects |
| Whiplash[125] | 64 Hz | 8 min | 4x in a 2 week period | Considerable and statistically significant pain reduction |
| Wound healing in diabetic mice[126] | 15 Hz | 8 h/day | 24 days | Significant reduction in postoperative pain for a decrease in the need for analgesic resolve |

Abbreviations: B = magnetic field; G = gauss; T = tesla; Hz = hertz; 1 mT = 10 gauss

Studies show that PEMF treatments can promote cell activa-tion and endothelial-cell proliferation through the cell mem-brane. Endothelial cells contribute to vasculogenesis. Neovascularization is essential for the survival of growing, injured, and ischemic tissue.[127]

ELF levels can increase the rate of formation of epithe-lial cells in partially healed wounds and also quicken the healing time of skin wounds that were surgically created on the backs of rats.[128] Fields at 15 Hz were used to significantly accelerate wound healing in diabetic mice.[129] The electric field of a wound has been measured as 177 ± 14 mV/mm immediately after trauma. Field lines point away from the wound in all directions instantaneously after injury, and these field lines are the first signals indicating skin damage. This electric field is generated at the outer surface of the epi-dermis by the outward flow of the current of injury. An equal and opposite current must flow within the multilayered epi-dermis to generate an intraepidermal field within the nega-tive pole at the wound site.[128] These skin wounds have electri-cal potentials that can be stimulated by ELF-EMF to aid in the healing process by dedifferentiating cells near the wound, thereby accelerating cell proliferation.[78] Pennington et al[130] used a double-blind study among active-duty, military per-sonnel, treating 50 grade-1 and grade-2 ankle sprains with one 30-minute, postinjury PEMF therapy, and reported a statistically significant difference in the outcomes, promoting reduced time loss in these military personnel.[130]

Various types of magnetic fields exist, such as static and time-varying as well as continuous and pulsed, with a wide range of frequencies. Most doses of time-varying and pulsed MF therapies run between 1 Hz and 75 Hz, with ranges of intensity between 1 microtesla (μT) and 250 millitesla (mT), though significant results have been seen with high-frequen-cy treatments. Durations of treatments range between 10 minutes and 48 hours with the number of treatments varying between 10 sessions spaced over several weeks up to three months, depending on the condition (Table 1).

Though many trials have been run in vitro and in vivo, clinical dosimetry needs further research. Of important note is the lack of standardized nomenclature and experimental protocols. Like most pharmaceuticals, where dosages vary from patient to patient, MF therapies are dose dependent per patient and also per individual tissue(s).[131,132] It has been sug-gested that at least ten different dosing parameters should be required for all practitioners using MF therapies.[133] These parameters would include specifying (1) the targeted tissue(s), (2) the site of MF application, (3) the distance of magnetic surface from targeted tissue(s), (4) the MF strength,
(5) the material composition of the magnet, (6) the magnet's dimensions (size, shape, and volume), (7) the magnetic polar configuration, (8) the magnetic support device, and (9) the frequency and duration of MF application. Contraindications include pregnancy or pacemaker implants.

## CONCLUSION

The use of MF for anti-inflammatory and wound-heal-ing applications is well known.[1,134,135] Because MF can be applied almost immediately after injury and can penetrate even poorly vascularized tissue, the benefits of using MF as a complement or alternative to anti-inflammatory treatments can be advantageous. Growing interest in this noninvasive, low-cost therapy is stimulating a lot of research in MF treat-ments. Studies show no discomfort occurs and few known risks are associated with the use of MF therapy. The presence of implanted metal does not appear to affect the therapeutic ability of MF.[81] When compared to the standard of care, MF therapies are a viable complement or alternative to treating inflammation in most patients.

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