MAGNETIC FIELD BIOEFFECTS

A Synopsis of Published Peer-Reviewed Studies

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1. Introduction

It is now well established that application of weak non-thermal electromagnetic fields (EMF) can result in physiologically meaningful in vivo and in vitro bioeffects. Time-varying electromagnetic fields consisting of rectangular waveforms (pulsing electromagnetic fields, PEMF), sinusoidal waveforms (pulsed radio frequency fields, PRF), particularly in the 15–40 MHz range, and static magnetic fields (1-3000 Gauss) are clinically beneficial when used as adjunctive therapy for a variety of musculoskeletal injuries.

2. Pulsed Magnetic Fields: Clinical Studies

The development of modern therapeutic devices was stimulated by the clinical problems associated with non-union and delayed union bone fractures, and started in the 1960s. The early work of Yasuda, Fukada, Becker, Brighton, and Bassett (1-5) suggested that an electrical pathway may be the means through which bone adaptively responds to mechanical input. The first therapeutic devices used implanted and semi-invasive electrodes delivering direct (DC) current to the fracture site (6). This was followed by the development of non-invasive technologies using electrical and electromagnetic fields. These modalities were originally created to provide non-invasive no-touch means of inducing an electrical/mechanical waveform at the cell/tissue level (7). Clinical applications of these technologies in orthopaedics has led to approved applications by regulatory bodies worldwide for treatment of fractures (non-unions and fresh fractures) and spine fusion (8-11). Additional clinical indications for these technologies have been reported in double blind studies for the treatment of avascular necrosis (12,13), tendinitis (14), and osteoarthritis (15). At present several EMF devices constitute part of the standard armamentarium of orthopaedic clinical practice for the treatment of difficult to heal fractures. The success rate for these devices has been reported as approximately 75% for hundreds of thousands of treatments, equivalent to that for the first bone graft. This represents a huge advantage to the patient since EMF therapy is non-invasive and is performed on an out-patient basis. EMF therapy also provides significant reductions in the cost of health care since no operative procedures are involved and it is performed on an out-patient basis.

Non-thermal PRF signals were originally utilized for the treatment of infections in the pre-antibiotic era (16) and are now widely employed for the reduction of post-traumatic and post-operative pain and edema. Double-blind clinical studies have been reported for chronic wound repair (17,18), acute ankle sprains (19,20), and acute whiplash injuries (21,22).

3. Pulsed Magnetic Fields: Cellular Studies

Cellular studies have addressed effects of weak low frequency electromagnetic fields on both signal transduction pathways and growth factor synthesis. The resulting working model is EMF stimulates secretion of growth factors after a short, trigger-like, duration. Ion/ligand binding processes at the cell membrane are generally considered the initial EMF target pathway, as originally proposed in 1972 (44-45). The clinical relevance to, e.g., bone repair is upregulation (modulation) of growth factor production as part of the normal molecular regulation of bone repair. The cellular level studies which support this working model have shown effects on calcium ion transport (46), cell proliferation (47), IGF-II release (48), and IGF-II receptor expression in osteoblasts (49). Effects on IGF-I and II have also been demonstrated in rat fracture callus (50). Stimulation of transforming growth factor beta (TGF-β) mRNA with PEMF in a bone induction model in the rat has been reported (51-52). Studies (53) have also demonstrated upregulation of TGF-β mRNA by PEMF in the human osteoblast-like cell line MG-63, wherein increases in TGF-β1, collagen, and osteocalcin synthesis were noted. PEMF stimulated an increase in TGF-β1 in both hypertrophic and atrophic cells from human non-union tissue (54). Further studies (55,56) suggested the increase in both TGF-β1 mRNA and protein in osteoblast cultures results from a direct effect of EMF on a calcium/calmodulin-dependent pathway. Other studies on cartilage cells, have reported similar increases in TGF-β1 mRNA and protein synthesis from EMF, suggesting a therapeutic application to joint repair (57-63).

4. Static Magnetic Fields

Static magnetic fields (SMF) in the 1-3000G range have been reported to have significant therapeutic benefit, particularly for treatment of pain and edema from musculoskeletal injuries and pathologies. This report will summarize what is currently known about SMF bioeffects.

5. Static Magnetic Fields: Basic Studies

At the molecular level ambient range fields (≤ 2G) modulated Ca^+ binding to calmodulin (CaM) which accelerated phosphorylation of a muscle contractile protein in a cell-free enzyme assay mixture, provided the target was in a receptive metabolic state, such as that which may be caused by injury (23). This study has recently been repeated for CaM dependent cyclic nucleotide phosphodiesterase activity, again by modulating Ca^+/CaM binding with a 2G field (40). Fields ranging from 23-3500G have been reported to alter the electrical properties of solutions as well as their physiological effects (24). At the cell level, 300G doubled alkaline phosphatase activity in osteoblast-like cells. Fields between 4300 and 4800G significantly increased the turnover rate and synthesis of fibroblasts, but had no effect on osteoblasts (25). Neurite outgrowth from embryonic chick ganglia was significantly increased using 225-900G (26). Rat tendon fibroblasts exposed to 2.5G showed extensive detachment of pre-attached cells, as well as a temporarily altered morphology (27). A minimum magnetic field gradient of 15 G/mm was required to cause approximately 80% action potential blockade in an isolated nerve preparation (28,29). A series of elegant studies showed 10G fields could significantly affect cutaneous microcirculation in a rabbit model (30,31). One of these studies showed a biphasic response dependent upon the pharmacologically determined state of the target.

6. Static Magnetic Fields: Clinical Studies

A necklace containing small 1300G magnets had no influence on chronic neck and shoulder pain (42). A single 45 min treatment with 300-500G bipolar (alternating poles per face) magnets reduced pain in post-polio patients by 76% in a double-blind study (32). Interestingly, the magnets were placed on pain pressure points and not directly on the pain site. A clinical study (not blinded) showed magnetic foil (no field level reported) had no effect on plantar heel pain syndrome (43). The magnetic foil was added to a molded insole designed for treatment of plantar foot pain. Discoloration, edema and pain were reduced by 40-70% over 7 days post suction lipectomy in a double-blind study (33). Pads containing arrays of 150-400G ceramic magnets (single pole per face) were placed over the liposuction site immediately post operative and left in place for 14 days. The outcome measures of fibromyalgia (pain, sleep disorders, etc) were reduced by approximately 40% in patients who slept on a mattress pad containing arrays of 800G ceramic magnets (single pole per face) over a 4 month period (34) in a double blind study. A second, more recent, double blind study on fibromyalgia confirmed significant pain reduction. This study employed arrays of magnets in mattress pads which were either single-pole per face or alternating poles per face (35). Only the former provided sufficient dosage to significantly reduce pain from fibromyalgia. Approximately 90% of patients with diabetic peripheral neuropathy received significant relief of pain, numbness and tingling using 475G alternating pole magnetic insoles in a randomized, placebo-controlled, crossover study (36). Only 30% of non-diabetic subjects showed equivalent improvement. Chronic lower back pain was not affected by application of a pad over the lumbar region having a geometric array of alternating pole 300G fields for 6 hrs/day, 3 times per week for one week in a double blind study (37). This study used magnets which did not deliver sufficient magnetic field dose to the deep tissue sites in the lower back. Peripheral blood circulation in healthy individuals was not affected by SMF (38). Chronic pelvic pain and disability were significantly decreased using 300-500 G bipolar (concentric circle) magnets over pain pressure points (39). A large (375 subjects) multicenter double blind study showed 450G multipolar magnets (shoe insoles) significantly reduced neuropathic pain and increased quality of life in patients with symptomatic diabetic peripheral neuropathy (41). The effective magnetic field from the insole surface was reported to be 20 mm (250G at 1 mm, 90 G at 3 mm, 1.5G at 13mm and equal to the earth's field at 20 mm).

7. References

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