Key Words
Pulsed electromagnetic fields, pain, osteo-arthritis, joints, human, articular cartilage, bone.

Pulsed Electromagnetic Fields for Treating Osteo-arthritis

by J van Nguyen
R Marks

Summary

Background Osteo-arthritis, a painful joint disorder involving degenerative changes of the articular cartilage and subchondral bone, often results in progressive functional impairment and disability. One particular modality used by physiotherapists that shows very promising results in reducing the joint damage and pain found in osteo-arthritis is pulsed electromagnetic fields.

Objective The present objective was to examine the rationale for, and the potential efficacy of, applying pulsed electromagnetic fields for reducing joint pain and other related symptoms of osteo-arthritis.

Methods The related English language literature was extensively reviewed to examine whether changes in pain might be expected from the application of pulsed electromagnetic fields to an osteo-arthritic joint, and why.

Results The basic and clinical research in this field, while somewhat limited, supports the insightful application of pulsed electromagnetic fields to ameliorate pain and disability due to osteo-arthritis.

Conclusion Further basic and clinical research to validate the use of pulsed electromagnetic fields in facilitating function and possibly in facilitating joint reparative processes in osteo-arthritis, as well the lessening of osteo-arthritic joint pain and joint dysfunction is indicated.

Van Nguyen, J and Marks, R (2002). 'Pulsed electromagnetic fields for treating osteo-arthritis', *Physiotherapy*, **88**, 8, 458-470.

Introduction

Osteo-arthritis, the most common form of arthritis, is usually accompanied by focal destruction of the articular cartilage lining of synovial joints, plus extensive subchondral bone remodelling and possible bone necrosis. It affects men and women equally, particularly in later life, and may involve one or more large peripheral joints and/or joints of the spine. The primary signs and symptoms of osteo-arthritis include pain and stiffness, weakness, joint instability, joint inflammation, joint deformity and a decreased range of joint motion. A general decrease in the ability to function physically occurs over time and may lead to impaired psychological function and social isolation, in addition to economic hardships.

Because there is no cure for osteo-arthritis, individuals with this disease, particularly those who have little benefit from prescribed medications or cannot use these drugs without hazard, are sent to physiotherapists for treatment to alleviate their symptoms and to restore optimal functional capacity.

Physical therapies commonly advocated for treating the symptoms of osteo-arthritis include exercise and a wide variety of electrotherapeutic modalities. Each shows some promise in improving one or more osteo-arthritic signs and symptoms even though adequate research in this field is sorely lacking.

In this respect, one electromagnetic modality constituted by low-frequency low-energy pulsed electromagnetic fields of single or pulse burst quasi-rectangular or triangular waveforms, which originated in its application to bone and wound healing, has been found to have promising applications in this respect.

How effective pulsed electromagnetic fields are for treatment of joint pain, inflammation, bone damage and healing of articular cartilage and soft tissue lesions, which may all occur in people with osteo-arthritic joint disease, is the subject of this literature review. In particular we examine:

- Existing rationale underlying the application of pulsed electromagnetic fields for treatment of painful osteo-arthritic joints.

- Clinical effectiveness of therapeutic pulsed electromagnetic fields for treatment of osteo-arthritis and related conditions.
- Possible mechanisms to explain how exposure of articular tissue to pulsed electromagnetic fields may yield beneficial clinical results for people with osteo-arthritic joint disease.

Rationale

Articular Cartilage

Under normal conditions, articular cartilage – the joint structure most affected by osteo-arthritis – is constituted by cells known as chondrocytes, which account for less than 10% of its volume. These cells manufacture, secrete and maintain the organic component of the extracellular compartment, or cartilage matrix, composed of a dense collagen fibril network enmeshed in a concentrated solution of proteoglycans and water. The importance of these structural interactions is that they determine the biomechanical behaviour of the tissue in response to dynamic loading (Mow *et al*, 1989; Mow and Wang, 1999). Their malfunction or destruction, however, which is often related to a decrease in proteoglycan concentration, in addition to underlying bone damage, bone necrosis, and bone remodelling, usually leads to disruption of the cartilage collagen-proteoglycan matrix, and a decreasing ability of cartilage and the surrounding joint tissues to absorb compressive stresses. Loading pressures are hence transmitted increasingly to the underlying bone where pain receptors reside (Mow *et al*, 1989; Wong *et al*, 1987).

Numerous animal studies have shown that articular cartilage exposed to an electrical field can increase its proteoglycan content (Aaron and Ciombor, 1993), as indicated by an increase in sulphate incorporation. The biological explanation for this outcome is not clear, but may involve information transferred to the chondrocytes concerning the nature of their mechanical environment and the state of the extracellular matrix which modifies transcription and synthesis (Aaron and Ciombor, 1993).

Alternatively, pulsed electromagnetic fields may interact with ligands on the chondrocyte cell surface membrane, and this interaction may lead to changes in internal calcium concentrations that trigger proteoglycan production (Granziana *et al*, 1990; Lee *et al*, 1993). The fields themselves may also increase chondrocyte synthesis of proteoglycans directly (Aaron and Ciombor, 1993). This response, which may be cell specific (Binderman *et al*, 1985), may depend upon the electrophysical parameters of the applied pulsed electromagnetic fields, including: amplitude, duration and frequency, in addition to the density of the cells themselves, and as indicated by Sakai *et al* (1991), intermittent exposure of cartilage cells to pulsed electromagnetic fields may be superior to continuous exposure.

In terms of duration, Brighton *et al* (1984) found the incorporation of sulphate into cartilage macromolecules was increased within five days of pulsed electromagnetic field application to chondrocyte cell cultures and that this increased even further, after 12 days. Furthermore, the cultures exposed to the electrical fields retained 95% of their newly formed proteoglycans compared to 70% of those assayed in control cultures (Aaron and Ciombor, 1993), hence suggesting catabolism was slower in the treated tissue cultures.

Similar findings have been reported by Smith and Nagel (1983) and although cartilage collagen content tends to remain unchanged during exposure to pulsed electromagnetic fields (Aaron and Ciombor, 1993), cartilage proteoglycan molecules that are synthesised in response to pulsed electromagnetic fields appear to be normal in size and composition. Pulsed electromagnetic field treatments might also help to preserve extracellular matrix integrity in early stages of osteo-arthritis, where excessive proteoglycan is laid down, by down-regulating proteoglycan synthesis and degradation in a co-ordinated manner without affecting structural integrity (Ciombor *et al*, 2001; Liu *et al*, 1997), and by increasing the proliferation of available chondrocytes (Pezzetti *et al*, 1999), and their DNA synthetic mechanisms (Pezzetti *et al*, 1999; Rodan *et al*, 1978).

Baker *et al* (1974), who applied an electrical signal to full-thickness defects created on the weight-bearing surface of the lateral femoral condyles of rabbits by means of an implanted bimetallic silver platinum electrochemical device placed at

Authors

John van Nguyen BSc BScPT is a clinical physiotherapist from Ontario, Canada.

Ray Marks EdD PT is director of clinical research at the Osteo-arthritis Research Center, Toronto, Canada.

Address for Correspondence

R Marks,
PO Box 1153,
Adelaide Postal Station, Toronto
M5C 2K5, Ontario, Canada.

e-mail
rm226@columbia.edu

the surface of the defect, showed that the defects exposed to the electrical current had a greater tendency to heal with hyaline cartilage than the control defects, which healed mostly by fibrocartilage. A later study in which circuitry was modified and inserted into the full thickness defects demonstrated chondrocytes and matrix compatible with normal articular cartilage.

More recently, pulsed electromagnetic fields applied to guinea pigs which develop arthritis that bears similarity to osteo-arthritis, demonstrated that the

Table 1: Musculoskeletal conditions and conditions of the integument where pulsed electromagnetic fields have been found to produce significant clinical effects (adapted from Bassett, 1993)

Condition	*Type of study*	*Treatment time*	*Success rate (%)*
Fracture non-union	Prospective double blind	3-6 months	75-95
Failed joint fusions	Prospective	3-6 months	85-90
Spinal fusions	Prospective	3-6 months	90-95
Congenital pseudarthrosis	Prospective double blind	6-12 months	70-80
Osteonecrosis (hip)	Prospective	6-12 months	80-100
Osteochondritis dessicans	Prospective	3-9 months	85-90
Osteoporosis	Prospective	Life	85-90
Chronic tendinitis	Double blind	3 months	85-90
Chronic skin ulcers	Double blind	3 months	85-90
Loose hip prostheses	Double blind	6 months	53

Table 2: Pulsed electromagnetic field effects in medical conditions and situations that might have a bearing on osteo-arthritic related symptomology (adapted from Bassett, 1993)

Condition	*Pathology*	*Pulsed electromagnetic fields cellular effects*
Fracture non-union	Soft tissues in gap, failure of mineralisation, calcification, bone formation and vascularisation	↑ Mineralisation and angiogenesis ↑ Collagen, glycosaminoglycans production, and endochondral ossification
Failed joint fusions	As above	As above
Congenital pseudarthrosis		As above, plus ↓ osteoclasis
Spine fusions	Unincorporated bone grafts	↑ Angiogenesis, osteoblastic activity
Osteonecrosis	Dead bone, rapid osteoclasis	↑ Angiogenesis, ↓ osteoclasis, ↑ Osteoblastic activity
Osteoporosis	↑ Bone removal ↓ Bone formation	↓ Osteoclasis ↑ Osteoblastic activity
Chronic tendinitis	Avascular, hyalinised, fibrillated collagen	↑ Angiogenesis ↑ Collagen and glycosaminoglycans production
Chronic skin ulcers	Poor vascular supply and healing	↑ Angiogenesis ↑ Collagen and glycosaminoglycans production
Ligament/tendon damage		↑ Collagen and glycosaminoglycans production ↑ Angiogenesis
Peripheral nerve damage		↑ Protein and nerve growth factor synthesis, axon migration and function

experimental animals which were exposed for one hour per day for six months to the electromagnetic fields demonstrated a retarded onset of the disease (Ciombor *et al*, 2001).

Since mature articular cartilage cells do not mount at all readily a repair response that results in adequate matrix reconstitution (Aaron and Ciombor, 1993; Trock, 2000), these aforementioned experimental observations may be of great importance in their application to the treatment of osteo-arthritic joint disease, where cartilage degeneration and its attendant disability is usually a progressive process. Bone repair, which can also be readily amplified by the application of pulsed electromagnetic fields, may likewise have an equally beneficial effect on cartilage integrity, in addition to its having direct effects on cartilage reconstitution and proteoglycan synthesis (Norton, 1985; Trock, 2000). The additionally documented effects of pulsed electromagnetic fields on ligamentous tissue healing (Lin *et al*, 1992; Wilson, 1972), nerve regeneration (Wilson *et al*, 1974), inflammation (Weinberger *et al*, 1996), and pain (Warnke, 1983) may have a beneficial influence on the structure and function of articular cartilage, and its ability to reconstruct a functional matrix (Aaron and Ciombor, 1993).

In summary, although results of *in vitro* studies must be extrapolated with some caution, many suggest pulsed electromagnetic fields applied to an osteo-arthritic joint might promote favourable transcriptional, cellular and sub-cellular molecular effects within damaged cartilaginous and bony tissues. In addition, because secondary bone repair is mediated by cartilage (Pezzetti *et al*, 1999), and bone cells in turn foster cartilage repair, pulsed electromagnetic field applications which can stimulate favourably both bone and cartilage cells could prove highly beneficial (Radin and Burr, 1984; Threlkeld, 1984).

Along with improved joint function and joint integrity due to improved bone and cartilage maintenance and repair, other anticipated benefits of pulsed electromagnetic field stimulation that could influence favourably the osteo-arthritic disease process are temporary pain relief, ligament and tendon healing, nerve regeneration, and decreased inflammation (Darendeliler *et al*, 1997; Lee *et al*, 1997; Trock, 2000).

In the following section, results of controlled trials published as full reports and directly related to the application of pulsed electromagnetic fields and osteo-arthritic disability and published in English are described. To this end a literature search of the Medline (1985-2001), Embase (1982-2001) and Cinahl (1980-2001) databases – using the key words 'arthritis', 'osteo-arthritis', 'physiotherapy', 'pulsed electromagnetic fields', 'joints', 'articular cartilage', 'inflammation' and 'pain' – was implemented and a narrative of the results of pertinent studies and their methods was undertaken.

In addition, the available randomised controlled studies specifically reporting on osteo-arthritis and pulsed electromagnetic field treatments were assessed for completeness of information and effectiveness of the intervention using the methods described by van der Heijden *et al* (1997). These criteria for internal validity are:

- Enrolment of homogeneous populations by explicit selection criteria.
- Adequate randomisation procedures.
- Subject similarity at baseline is confirmed.
- Withdrawals are less than 10% and equal for all groups.
- Missing values at outcome assessment are less than 10%.
- Co-interventions are standardised.
- Interventions and assessments are blinded.

Results

The present search method revealed 15 relevant articles, but one was not clearly related to the application of electromagnetic therapy (Zizic *et al*, 1995). Another used an animal model (Ciombor and Aaron, 2001), one was not published as a full-length study (Perrot *et al*, 1998) and one was a retrospective study (Hershler and Sjaus, 1999). The remainder related to the use of pulsed electromagnetic fields for bone healing or relief of pain and inflammation. Only two randomised controlled trials reporting specifically on pulsed electromagnetic fields and osteo-arthritis were found.

Table 3: Comparative clinical studies outlining the use of pulsed electromagnetic fields for the treatment of osteo-arthritis

Authors	*Sample and design*	*Methods*	*Outcome measures*	*Results*	*Limitations*
Hersher and Sjaus (1999)	45 people with osteo-arthritis were compared retrospectively for their response to pulsed electromagnetic fields to 35 cases with soft tissue injuries	Data were extracted from standard pulsed electromagnetic fields evaluation forms	Self-reported pain on a visual analogue scale for pain intensity and frequency	Using a matched pair t-test, significant changes from baseline scores were found within both groups at 6 weeks and 6 months after treatment. The extent of the improvement was similar for both groups at the 6-week and at the 6-month follow-up periods	This was not a controlled study. The data were collected retrospectively and were based on self-reports documented by nurses or therapists Unknown treatment parameters
Perrot *et al* (1994)	40 patients, 32 women and 8 men, average age 68.8 years, were randomised to an active treatment or a placebo group	Experimental group received 1 hour of pulsed electromagnetic fields for 9 consecutive days Placebo group received the same treatment sequence	Visual analogue pain scale Lequesne's algofunctional index Number of responders	Pain improved in the active treatment group after day 9 There were more responders in pulsed electromagnetic fields group at 1 month Pain and function improved in the treated group 3 months after the end of treatment ($p < 0.05$)	This work was published only in abstract format Unknown treatment parameters
Trock *et al* (1994)	86 patients with knee osteo-arthritis and 81 with cervical osteo-arthritis identified radiographically were studied	Each diagnostic group was randomly assigned to an active treatment or a placebo group	Visual analogue scale to record pain at affected site over the last week Activities of daily living questions and a score for pain at night on a 0-24 scale	The pain score of the osteo-arthritis knee and cervical spine treated groups improved at all assessments after treatment Activities of daily living, pain on motion, and tenderness scores were generally improved to a greater extent among treated patients	There was a strong placebo effect and the reliability of the assessment procedures is unknown
Trock *et al* (1993)	27 patients with osteo-arthritis of the knee were randomised to an active treatment or a placebo control group	Treatments were administered by an extremely low frequencyof pulsed waves for 30 minutes, 3-5 sessions per week for a total of 18 treatments	Visual analogue scale to record pain at affected site over the last week Activities of daily living questions and a score for pain at night on a 0-24 scale	Improvements occurred in each variable to a greater degree in the treatment group	The sample size was small and no objective measures were conducted

Table 3: Comparative clinical studies outlining the use of pulsed electromagnetic fields for the treatment of osteo-arthritis (continued)

Authors	*Sample and design*	*Methods*	*Outcome measures*	*Results*	*Limitations*
Mammi *et al* (1993)	40 consecutive patients with valgus tibial osteotomy for knee joint osteo-arthritis were studied in a randomised controlled trial	After surgery, patients were assigned to a control or an active stimulation group	Four orthopaedic surgeons, unaware of the experimental conditions, evaluated radiographs taken 60 days post-operatively and rated the osteotomy healing according to four categories	In the control group 73.6% of patients were categorised in the first and second healing categories In the stimulated group 72.2% were categorised in the third and fourth categories, indicating more advanced healing (< 0.006)	Lack of intent to treat analysis for 3 patients who did not complete protocol
Borsalino *et al* (1988)	32 consecutive patients with hip joint osteo-arthritis treated with femoral inter-trochanteric osteotomy were studied in a double blind placebo controlled prospective evaluation of pulsed electromagnetic fields therapy	Post-operatively, two groups of patients were treated with either an active or a placebo electromagnetic device for 8 hours a day for three months	Blinded evaluators evaluated patients clinically and radiographically	Statistically significant improvements in healing were seen in the active group when compared to the control group	Lack of intent to treat analysis for 1 patient who did not complete study

Randomised Trials

Trock *et al* (1993) were the first to investigate the effect of pulsed electromagnetic fields with respect to osteo-arthritis. In that study, 27 persons with definitive osteo-arthritis of the knee were randomly assigned to either a placebo or a treatment group according to standardised procedures. The treatment group received 18 half-hour periods of electromagnetic field exposure over one month using a specially designed non-contact, aircoil device that delivered three signals in stepwise fashion, ranging from 5 Hz to 12 Hz frequency at 10 G to 25 G of magnetic energy. The two primary outcome measures were pain and an activities of daily living inventory. Although both groups were similar at baseline, the results showed a 23-61% improvement in the measured variables for the treatment group and a 2-18% improvement for the placebo group. While there were too few cases in the treated group to permit meaningful analysis of the response according to radiological criteria, five patients with grade 3 or 4 disease obtained excellent responses according to the physician assessment made at last visit. The results of this small study seem reasonable in light of the fact that the eight criteria for internal validity were all met and the results were later substantiated in a follow-up study by Trock *et al* (1994) and in a randomised study published as a brief report by Perrot *et al* (1998) (see table 3).

In the follow-up study by Trock *et al* (1994), the investigators studied the efficacy of pulsed electromagnetic fields for treating both osteo-arthritis of the knee and osteo-arthritis of the cervical spine. Here, the authors conducted a double-blind randomised and placebo-controlled trial, which involved 86 patients with osteo-arthritis of the knee, and 81 with osteo-arthritis of the cervical spine using the same treatment device as mentioned above. The device generated extremely low pulsed electromagnetic fields. The system used a coiled current and was applied in a stepwise fashion to the area of the joint being treated. The pain levels of the subjects evaluated using a 10 cm visual analogue scale, and their activities of daily living levels, measured using questionnaires, were evaluated at baseline, midway, and at the end of the treatment period, as well as one month after completion of the treatment. These data showed that the mean pain and activities of daily living scores of the treated group of patients with osteo-arthritis of the knee were greater in relation to to their baseline values than those of the placebo group by the end of treatment and at the one month follow-up observation period. The treated patients with osteo-arthritis of the cervical spine also showed greater improvement from baseline than the placebo group for most outcome variables at the end of treatment and at the one-month follow-up observations, and these differences reached statistical significance at one or more observation points for pain. Although the internal validity of the study may have been compromised by the fact that the data were pooled and difficulty in activities of daily living was lower at baseline for the controls with neck osteo-arthritis, there were marked and clinically significant improvements among both diagnostic groups in terms of their pre- and post-treatment outcomes, and this favoured the actively treated groups.

In both studies by Trock *et al*, the validity criteria were met with few exceptions, and the active treatment appeared superior to the placebo applications. However, the studies were not designed to delineate mechanisms of action, and thus the authors could only speculate upon the mechanisms that led to the observed improvements in the participants' pain levels and their ability to carry out activities of daily living after treatment. They were fairly certain, however, that the outcomes were not due to any heating effect since the pulsed electromagnetic field parameters used in both experiments were not sufficient to produce heat.

Non-randomised Trials

More recently, Hershler and Sjaus (1999) conducted a retrospective study to establish the effectiveness of pulsed electromagnetic fields in the treatment of chronic pain. They divided the patients into an osteo-arthritic and a soft tissue injury group. Data were extracted from standard evaluation forms detailing the medical histories and diagnoses of the patients. The outcome was self-reported symptom evaluations of pain intensity and pain frequency using a five-point visual analogue scale. The measures were conducted before treatment, and at nine-day and six-week follow-up sessions. In both groups pain declined at six weeks and this reduction was maintained for both groups at six months. Although this was not a double-blind clinical trial, and was based on data collected by a nurse/therapist from charts, patients had previously not responded to conventional therapy, regardless of group.

Related Clinical Studies

In a related study, osteonecrosis of the femoral head, which generally progresses to osteo-arthritis within two or three years (Aaron *et al*, 1989), was treated by applying pulsed electromagnetic fields of single-pulse configurations at a frequency of 72 Hz to the affected hip joints. The coil was held in place over the greater trochanter in specially fabricated shorts. Patients wore the coil for eight hours a day for 12 to 18 months after intra-capsular hip fracture. The clinical outcomes assessed were pain relief and the degree of conservation of the femoral head, and the minimum follow-up time was 24 months.

In relation to these outcome measures, Aaron *et al* found that for 39 patients (23 men and 16 women, mean age 43±3 years) pulsed electromagnetic field therapy significantly reduced both the incidence of clinical, as well as the radiographic progression of osteonecrosis. In addition, the exposure to pulsed electromagnetic field therapy was more effective than core compression in this respect, and its impact was evident for an average of up to three years after treatment, as determined by roentgenograms.

In a similar study of 95 patients conducted by Bassett *et al* (1989), the effect of coil-delivered pulsed electromagnetic fields on femoral head osteonecrosis using the Steinberg rating system as the outcome measurement was investigated. This rating system quantifies increases in femoral head and joint involvement and is based on direct measurements of standardised radiographs of the hip by grids.

In this respect, the authors found that the exposure of osteonecrotic patients to pulsed electromagnetic fields over an average period of four years yielded no observable progression of the disease process. Moreover, patients in the early stages of the disease actually showed improvements in their bone content.

Although this study was not double-blind, and relied heavily on radiographic readings, which can vary depending on the physician who reads the results, and the precise pulsed electromagnetic field parameters and dosages were unclear, it supported the efficacy of electromagnetic stimulation in treating adults with osteonecrosis.

In a further study conducted by Marks (2000), 61 randomly selected patients who had previously failed to respond to pre-operative conservative treatments and underwent lumbar fusion surgeries for discogenic low back pain between 1987 and 1994 were studied retrospectively. Forty-two had received pulsed electromagnetic field stimulation, and 19 had received no electrical stimulation. After an average follow-up time of 15.6 months post-operatively, the fusions were found to have succeeded in 97.6% of the pulsed electromagnetic field group and in 52.6% of the unstimulated group ($p < 0.001$). The observed agreement between clinical and radiographic outcome was 75% and showed that the use of pulsed electromagnetic field stimulation enhanced bony bridging in lumbar spinal fusions and afforded a good clinical outcome in patients with chronic discogenic low back pain.

Beneficial effects of pulsed electromagnetic field applications for hip degenerative arthritis treated with femoral inter-trochanteric osteotomy have been reported by Borsalino *et al* (1988). Here low-frequency pulsing electromagnetic fields were applied to 32 patients in a double-blind randomised trial. Radiographic evaluation and callus density measurements performed with an image analyser after use of either an active or a placebo magnetic device for eight hours a day for three months showed a statistically significant difference ($p < 0.01$) between controls and stimulated patients in favour of osteotomy healing. The only significant limitation of this study was the lack of an intent-to-treat analysis, however 31 of the 32 patients completed the protocol.

Similarly, 40 patients with degenerative knee arthritis undergoing valgus tibial osteotomy who were randomly assigned to an active pulsed electromagnetic field stimulation group for eight hours a day for three months had more advanced healing on blinded radiographic evaluations after 60 days than controls who received placebo stimulation (Mammi *et al.* 1993). Thus this study, which had few limitations, provided additional evidence that bone healing after osteotomy seems to be significantly affected by electromagnetic stimulation. Other research indicates that pulsed electromagnetic field applications may stimulate osteogenesis in post-menopausal women who might be susceptible to hip joint osteo-arthritis (Giordano *et al*, 2001) and may help to delay revision hip surgery (Kennedy *et al*, 1993), in addition to reducing osteonecrosis and surgical pain in adults.

Electromagnetic stimulation may also produce beneficial effects in inflammatory and painful conditions that can lead to the development of osteo-arthritis or replicate the osteo-arthritic clinical situation (see table 1). Three controlled studies have been performed in this regard to support this view.

In the first study, Binder *et al* (1984) investigated the value of pulsed electromagnetic field applications for the treatment of persistent rotator cuff tendinitis on 29 patients, whose symptoms were refractory to steroid injection and other conventional conservative measures. The results of this double-blind controlled study showed that the treatment group (15 patients) had significant improvements compared to the placebo group (14 patients), during the first four weeks of study. In the second four weeks, when both groups received active treatments, no significant differences were observed among the two groups. In the next eight weeks, where both groups received no active treatments at all, no significant differences were observed among the two groups. The outcome variables used in this study were pain scores using a horizontal visual analogue scale, pain on resisted movement, pain on active arm abduction, and active shoulder range of motion.

At the termination of the study, 19 subjects were symptomless and five were much improved. This encouraging result showed that pulsed electromagnetic field therapy may be useful in the treatment of rotator cuff tendinitis and other chronic tendon lesions that do not respond readily to medical treatments, as can occur in osteo-arthritis (Binder *et al*, 1984).

However, patients with chronic lateral humeral epicondylitis treated for eight weeks with pulsed electromagnetic fields did not improve to a greater extent than controls (Deveraux *et al*, 1985), and

LeClaire and Bourgouin (1991) found no benefit from magnetotherapy in pain, range of motion or functional status in periarthritis of the shoulder.

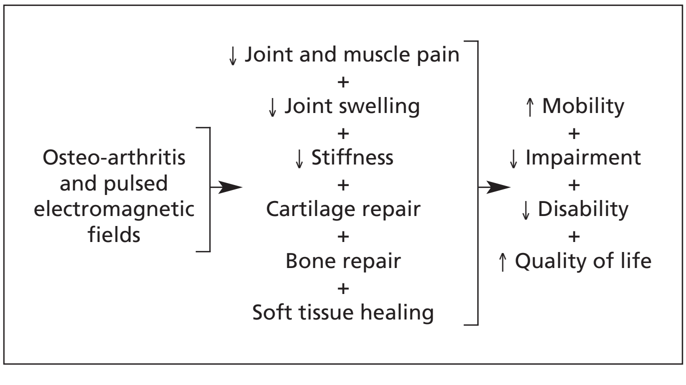
In another double-blinded study, Foley-Nolan *et al* (1992) investigated the effect of low energy high frequency pulsed electromagnetic fields on acute whiplash injuries among 40 subjects over the age of 18 years. Subjects were randomly divided into placebo and treatment groups and all were given instructions to wear a pulsed electromagnetic field coil for eight hours a day at home and advised to move their necks. The current was set at 27 MHz with pulse burst widths of 60 microseconds and a repetition frequency of 450 cycles per second that produced a pulsed magnetic field in the treatment area with a mean power of 1.5 milliwatts/cm^2 at the skin surface.

At both two- and four-week follow-up examinations, the active treatment group showed significant improvements in terms of pain when assessed using the visual analogue scale, but less improvement occurred in range of motion. This study of low energy pulsed electromagnetic fields did yield greater mobility improvements for the active group when applied over a longer period of 12 weeks. Although patients could attend regular physiotherapy at four weeks if they were unhappy with their progress, the mode of pulsed electromagnetic field employed was one that created thermal effects, and this may have helped to control the associated inflammatory processes and to speed up the healing process.

However, there may have been a significant placebo effect as observed by Hong *et al* (1982), who found no post-treatment benefits for the active group when objective pain assessments were conducted using electrodiagnostic procedures for active and placebo groups of subjects after three weeks of magnetic necklace therapy applied 24 hours per day.

Vallbona *et al* (1997) noted that the application of a 300-500 Gauss magnetic device to pain trigger points in post-polio patients reporting muscular or arthritic pain significantly reduced pain over these points and did so promptly. In this double-blind randomised clinical trial of 50 post-polio patients, active or placebo magnetic devices were applied to the affected area for 45 minutes. Those with the active device experienced a greater score decrease on the McGill pain questionnaire and more patients in the active group reported a pain score decrease.

Potential benefits of application of pulsed electromagnetic fields to osteo-arthritic joints



Discussion

In general, most clinical reports reviewed in this paper indicate that positive results, over and above a strong placebo effect, can occur in terms of pain reduction and bone healing by the application of pulsed electromagnetic fields to damaged or painful tissues and osteo-arthritic joints, regardless of method of stimulation. This was also the recent conclusion of Quittan *et al* (2000) who examined all categories of usage of pulsed electromagnetic field therapy that have been documented in the clinical literature. Although caution must be used in accounting for these positive results, alone, or in combination, these could reflect the beneficial *in vivo* effects of electromagnetic fields *vis-à-vis* joint blood flow, joint inflammatory processes, soft tissue repair, bone and cartilage healing, and augmentation of peripheral nerve regeneration (Kort *et al*, 1980). That is, they may reflect the potential for favourable restorative transcriptional and biochemical effects of applied fields on the cells of bone and cartilage and their surrounding tissue structures as outlined in table 2 and shown in the figure.

General problems with related clinical studies employing pulsed electromagnetic fields that were presently examined were that even though factors that might affect pain were well controlled for in the studies cited in this paper, assessment of pain simply as a subjective experience on a visual analogue scale may not fully capture or measure the individuals' pain states at all accurately, unless modified carefully. In all studies, at least one participant dropped out on finding that he/she was assigned to the control group. Also, in at least one study, information regarding treatment was circulated among the experimental, as well as the control groups, which led to the eventual withdrawal of two subjects from the control group.

Thus, greater control and separation of treatment and control groups in future studies is indicated, as is the addition of other outcome measures which might better capture overall functional status and quality of life, and pain and/or anti-inflammatory or anti-oedema effects. More information is also needed on the parameters that might prove most, and least, useful for treating various joint sites, and acute *versus* chronic pain states, plus what stages of the disease process might be most amenable to improvements from pulsed electromagnetic field therapy. The mechanisms underpinning those clinical improvements observed following the administration of pulsed electromagnetic field therapy and the extent of the placebo response also need clarification.

However, given that osteo-arthritis is a ubiquitous disabling disease and that some of this disability in which articular cartilage proteoglycan loss is usually progressive, might be ameliorated by its insightful application, due its chondro-protective and bone repair effects, this modality certainly seems worthy of further exploration as indicated by findings of Liu *et al* (1997) and Trock *et al* (1994). It is also noteworthy that in studies where inflammation was present, as might be the case in osteo-arthritis, the clinical effects of pulsed electromagnetic fields were markedly promoted (Yonemori *et al*, 1996).

In contrast to other physiotherapy modalities which may invoke hyper-thermia and proteolytic enzyme activity which increases cartilage destruction, and potentially induces swelling, pulsed electromagnetic field applications may be applied athermally and because they may closely mimic the effects of mechanical stimuli could be especially useful for those individuals who cannot exercise readily without pain. In addition, it is possible that its insightful application using athermal or thermal doses could relieve pain and muscle spasm, which may accompany the disease, and thereby potentiate a positive outcome *vis-à-vis* the attenuation of cumulative joint stresses believed to contribute to the disease progression.

Second, its application could enhance chondrocyte activation in such a way so as to promote proteoglycan and collagen synthesis and its limited but inherent reparative capacity.

Third, its application could help with repair of bone damage, which may be causing or perpetuating the disease to some extent.

Importantly, unlike studies where results comparable to pulsed electro-magnetic field applications have been achieved by medication, but these have been found to continue only as long as the drugs were taken, pulsed electro-magnetic field effects may be prolonged, as well as efficacious. Konrad *et al* (1996) for example, reported that the benefits of applying pulsed electromagnetic field therapy to ameliorate aseptic loosening of total hip prostheses were still noticeable one year after completion of treatment.

Also, unlike drugs, no side-effects of pulsed electromagnetic fields have been reported in the literature, and the effects on bone osteogenesis have been found comparable to those produced by normal functional activity (Rubin *et al*, 1993).

Thus, the application of pulsed magnetic fields to an osteo-arthritic joint, which might mediate even small changes in chondrocyte biosynthesis, in addition to bone and soft tissue repair, without causing adverse side-effects or undue physical strain to patients, could be extremely important over long periods of time in attempts to preserve optimal joint function. Its anti-inflammatory and pain reducing properties might prove equally valuable in preserving joint integrity.

Further studies that investigate pulsed electromagnetic field effects in relation to osteo-arthritis and the cellularity of cartilage and bone, plus its surrounding structures and their biomechanical properties, may hence prove helpful. Its application in osteotomy treatments for osteo-arthritis, and in preventing aseptic loosening after prosthetic replacement of diseased joints, also merits study.

In addition, its efficacy when combined with other physiotherapy modalities, especially appropriate joint-sparing techniques, as well as its effect on drug consumption also warrant further investigation. To this end, rigorously designed double-blind controlled studies of larger more diverse samples, where three groups of patients are randomised and compared, one with active stimulation, one with sham stimulation and a control group which receives standard treatment are needed to determine the unique effects of the stimulation. In addition to clinical measures that are reliable and valid, measures that seek to explain the mechanisms of any clinically observed treatment effects are required.

Finally, comparative studies that compare methods of stimulation objectively (Vodovnik and Karba, 1992) and which wave-form characteristics provoke specific tissue responses are needed.

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Key Messages

- Pulsed electromagnetic fields can promote tissue healing and relieve pain and inflammation.
- Individuals with osteo-arthritis may benefit from the application of pulsed electromagnetic fields to their affected joints.
- This review examined the basic and clinical studies supporting the application of pulsed electromagnetic fields to treat osteo-arthritis.
- The literature strongly suggests pulsed electromagnetic field therapy may prove beneficial in the treatment of painful osteo-arthritis.
- Further clinical and basic research studies in support of this modality in treating osteo-arthritis appear warranted.