Do magnetic field applications lead to improved bone union in light of Evidence-Based Medicine principles? Analysis of the scientific evidence from basic science to clinical research

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Abstract

Background: One of the widespread indications for using magnet therapy is impaired bone union or an attempt to accelerate the physiological process of osteogenesis. However, it must be noticed that the practical use of magnetic fields in patients after bone fractures overtakes clear clinical recommendations and indisputable scientific evidence.

Aims: This article attempts to estimate the current state of knowledge on the effectiveness of magnetotherapy in the claimed range of injuries to the movement system.

Material and methods: The critical literature review analyzed bibliographic data for the past ten years. The resources of the following medical search engines were used – PubMed, MEDLINE, Physiotherapy Evidence Database (PEDro), and Web of Science Core Collection.

Results: Both basic and clinical studies confirm the effectiveness of these physical treatments after bone fractures. However, it is difficult to say that the strength and level of evidence is high and satisfactory. According to our findings, the average PEDro score for the cited papers is 5.56, which could be a more satisfactory result. Randomized clinical trials with the highest rate (7-10 points on the Physiotherapy Evidence Database scale) are still needed. Magnetic field treatments can be used, although they only support standard management.

Conclusions: At this stage, it seems that for clinical purposes such as stimulating bone union and reducing pain, the most recommended is the use of a magnetic field with treatment parameters – magnetic induction of 1-10 mT, frequency up to 50 Hz, rectangular or sinusoidal waveform, single treatment time of 20-30 minutes, 5-7 treatments per week for several to several weeks.

Key words

magnetic field, pulsed electromagnetic field (PEMF), fracture, bone healing.

Introduction

Physical treatments using alternating magnetic fields are common in modern physiotherapy [1–3]. The most common values of magnetic induction (intensity) in therapeutic practice are from 0.1 to 20 mT and frequencies up to 10 Hz. In turn, the course of changes in the value of magnetic induction in a given time interval, the so-called shape (waveform) of the magnetic field, can be triangular, sinusoidal, or rectangular [4,5].

One of the common indications for the use of magnet therapy is a complicated bone union or an attempt to accelerate the physiological process of osteogenesis. The therapeutic mechanism in this regard is believed to be an increase in calcification within the cartilage located between bony structures, as well as stimulation of blood flow in bone tissue due to vasodilation of blood vessels and the formation of new capillaries. It also seems that a significant effect is shown by the activation of the activity of osteoblasts involved in the phenomenon of bone remodeling [6].

However, it cannot be overlooked that the practical use of magnetic fields in patients after bone fractures predates clear clinical recommendations and indisputable scientific evidence. Therefore, this article attempts to assess the current state of knowledge on the effectiveness of magnetotherapy in the cited range of musculoskeletal injuries.

Aims

The presented publication reviews the most recent literature on the area of using magnetic fields in bone unions concerning the principles of Evidence-Based Medicine.

Material and methods

The critical literature review utilized an analysis of bibliographic data for the past ten years. The resources of the following medical search engines were used – PubMed, MEDLINE, Physiotherapy Evidence Database (PEDro), and Web of Science Core Collection.

Results

Animal experiments and trials conducted in vitro and in vivo

In 2021, an article was published in the journal Biomed Research International as a systematic review and meta-analysis [7], where 92 scientific reports of in vitro studies conducted to date were included. An analysis of medical databases such as PubMed and Web of Science for the years 1999-2019 was performed. Based on the data obtained, in particular, a significant effect of exposure to an alternating magnetic field on selected varieties of human cells, for example, osteoblast-like MG-63 type ($p<0.001$) and bone marrow mesenchymal stem cells ($p<0.001$) was demonstrated. In contrast, a significantly smaller effect was found for the SaOS-2-type osteoblastic lineage ($p<0.001$) and adipose tissue-derived AD-MSC mesenchymal stem cells. Interestingly, the Iranian researchers concluded that the following treatment parameters were most effective in stimulating the cellular response - magnetic induction from 1 to 10 Hz, frequency above 100 Hz, while treatments should be carried out daily for a period of ten days using rectangular-shaped pulses. The recommended duration of a single treatment has not been established.

Suryani et al. [8] presented a study in 2019 on the effects of pulsed magnetic fields on cranial osteoblast precursor cells in rats in terms of their growth, survival time, and ability to differentiate. The authors performed in vivo exposures to magnetotherapy with the following physical parameters - rectangular pulse, intensity of 0.6 mT, and frequency of 50 Hz for periods of 0, 15, 30, and 60 minutes. After the experiment, it was determined that the exposure time of 15 minutes had the most significant effect on the proliferation of MC3T3-E1 type cells, while exposure lasting more than 30 minutes could cause adverse stimulation of the activity of the bone turnover marker sialoprotein I and II, which characterizes the processes of adhesion and stimulation of osteoclasts. Thus, the results could indicate the need to set a specific time of magnetic field exposure, since treatments that are too long are capable of inhibiting normal bone union. However, the above hypothesis was rather abandoned based on the results of other works.

Chinese researchers [9] evaluated a 40-minute exposure to an alternating magnetic field with an induction of 3.8 mT and a frequency of 8 Hz on cultured rat bone marrow stem cells over a period of three weeks. The treatments were performed daily, once a day. The proliferation effect of these cells was noted after 7, 14, and 21 days ($p<0.05$).

Similarly, Fu et al. [10] observed in vivo no cytotoxic effect (an intensity of 10 mT was applied for 25 consecutive days) of magnetotherapy on necrotic human bone graft. Moreover, they found bone regeneration and significant revascularization as early as days 2 and 4. Regarding the control group (sham treatments), favorable bone mineralization was noted in measurements at 10, 15, 20, and 25 days after the start of physical treatments. This means that these authors clearly negate the view of magnetic field-induced inhibition of bone union.

In an interesting animal experiment, Oltean-Dan et al. [11] subjected 20 Wistar rats to magnetotherapy treatments after surgical fixation with titanium nails of a femoral fracture. One group (n=10) received actual treatments (10 mT, 10 minutes, rectangular pulses), while the other group (n=10) received sham procedures. After two weeks, in the magnetic field-exposed group, the osteonecrosis was at a significantly more advanced stage of fibrocartilage remodeling, and the ratio of bone volume to total tissue volume in this area was significantly higher compared to the control group ($p=0.047$). Serum alkaline phosphatase and osteocalcin levels were significantly higher in the experimental group ($p=0.026$ for phosphatase, $p=0.006$ for osteocalcin) than in the placebo group. Mechanical strength in the femur was also better ($p=0.03$). After eight weeks, femurs from the magnetic field-exposed group had fully formed bone tissue with dense bone beads and very metabolically active bone marrow ($p=0.01$ relative to the control group).

It is intriguing that, as it turns out, for much lower magnetic induction values, a beneficial clinical effect can be obtained at the level of animal experiments. Researchers from Lanzhou University [12] – like Suryani et al. [8] previously – noted that magnetotherapy (0.6 mT, 50 Hz), but after a very prolonged, daily 90-minute exposure (the Iranian authors, after all, argued that action beyond 30 minutes could be detrimental) was effective in stimulating healing of femur fractures in rats. Physical treatments have been found to stimulate bone formation by increasing the metabolic pathways of adenylyl cyclase, adenosine monophosphate, protein kinase type A, and cAMP response element binding protein.

On the other hand, Wang et al. [13] made comparisons between different magnetic field strengths (1, 2, 5 mT) at 75 Hz and very prolonged exposures for 3 hours a day to animal osteoblasts in vitro, and after one month, noted a favorable stimulation of proliferation, although the effect was most pronounced for the lowest magnetic induction, a value of 1 mT.

Thus, as can be seen from the above rationales, it is difficult at the level of basic research to determine the optimal value of magnetic field strength for promoting bone union. For example, He et al. [14] suggest beneficial effects under magnetic induction of 0.6 mT, Benya et al. [15] 1.18 mT, Ma et al. [16] 2 mT [16], and Lin et al. [17] even more than 10 mT, showing a lack of consensus in this regard.

Similarly, the time for a single treatment is a wide spectrum, ranging from 10 minutes to as much as several hours [8-17]. However, other technical parameters seem to be similar, i.e., rectangular shape of the field, and the treatment series is 14-30 days.

Clinical trials

According to a 2014 systematic review and meta-analysis [18], the use of pulsed magnetic fields to accelerate the healing of acute bone fractures is expedient, although the authors note the paucity of scientific evidence and the fact that the belief in the significant effectiveness of this physical stimulus is based mainly on preclinical studies and professional practice.

In a somewhat more recent 2019 systematic review, Massari et al. [19] postulate the use of magnetotherapy as a beneficial adjunct to the conservative treatment of bone fractures while calling for further well-designed clinical work with high reference.

It must be admitted that in recent years, one can observe an increasing number of interesting randomized clinical trials in the field discussed.

Martinez-Rondanelli et al. [20] included 63 patients randomly assigned to one of the comparison groups after a femoral shaft fracture. The primary procedure was surgical fixation. Patients in the first group were additionally subjected to daily magnetic field treatments (0.5-2 mT, 5-105 Hz, sinusoidal waveform) for a period of 6 months. In contrast, sham treatments were applied to participants in the second group. Follow-up radiographs were performed in both groups at 6, 12, 18, and 24 weeks after injury. At each stage, there was an advantage for participants in the first group over those in the second group in terms of the advancement of bone healing.

In 2019, the prestigious Journal of Dentistry, Oral and Maxillofacial Surgery published fascinating results from a randomized clinical trial involving patients after mandibular fractures [21]. The study included 32 patients who were randomly assigned to two comparison groups (16 participants in each). Patients in the second group received magnetotherapy (1 mT, 40 Hz, rectangular waveform) in addition to primary surgical treatment. In the first group, no physical treatments were provided. Bone union was assessed using conventional X-ray imaging, and the severity of clinical symptoms for a period of 4 weeks after surgery. At the end of the project, there was no significant difference in mean bone density values between the two groups ($p>0.05$), although there was a magnetic field advantage on days 14 and 28 compared to the control group ($p<0.05$). The researchers conclude that magnet therapy in the postoperative period leads to increased bone density, faster recovery, improved oral mobility, and reduced pain.

In contrast, Liu et al. [22] conducted a study involving women with advanced osteoporosis. They found that magnetic field treatments (3.82 mT, 8 Hz, rectangular waveform, five times per week, 30 minutes) were effective in supporting healing after fractures in the tibia and radius. These authors observed faster bone union (osteogenesis), reduced pain at the site of injury, and improved quality of life indicators.

Dutch researchers [23] found that recovery time can be shortened in metacarpal bone fractures. The estimated number of days lost from work was 3.25 days less in patients undergoing physical therapy and magnetotherapy compared to those doing exercise therapy (kinesitherapy) alone. However, the differences were not statistically significant ($p=0.651$). The authors recommend a magnetic induction of 10 mT, a frequency of 50 Hz, a rectangular field shape, and a treatment time of 20 minutes.

Discussion

A review of the literature showed that there are indications that the use of magnetic fields in promoting bone healing after fractures is valid. Both basic and clinical studies seem to confirm the effectiveness of these physical treatments after bone fractures. However, it is difficult to say that the strength and level of evidence are high and satisfactory. According to our findings, the average PEDro score for the cited papers is 5.56, which could be a more satisfactory result. Randomized clinical trials with the highest rate (7-10 points on the PEDro scale) are still needed. The above hypothesis is consistent with the conclusions of a recent systematic review and meta-analysis, where it was found that the level of evidence for increased healing rates and pain reduction was medium, while the evidence for accelerated healing was rated as low [24]. In summary, the treatments in question can be used, although they are only adjunctive to standard management. A separate shortcoming is the need for a uniform protocol with recommended treatment parameters; there are still differences between different authors.

Study limitations

The main area for improvement of the present paper is that it does not constitute a comprehensive systematic review but only a narrative review publication. Indeed, the above limitation carries a greater risk of subjectivity than in the case of an independent assessment by an organized group of experts subjected to a process of blindness during the methodological and substantive evaluation of the articles cited in the paper.

Conclusions

At this stage, it seems that for clinical purposes such as stimulating bone healing and reducing pain, the most recommended is the use of a magnetic field with treatment parameters – magnetic induction of 1-10 mT, frequency up to 50 Hz, rectangular or sinusoidal waveform, single treatment time of 20-30 minutes, 5-7 treatments per week for several to several weeks.

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