Healing of Orthopaedic Diseases by Means of Electromagnetic Field

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Abstract: The paper deals with the problem of the so called, electromagnetic medicine, namely the healing by use of electromagnetic field some of orthopaedic diseases. The main therapies are briefly signalized and the most popular magnetotherapy is shown in more detailed way. The paper presents the results of clinical investigations as well as some attempts of numerical simulation of the process.

Keywords: orthopedy, magnetotherapy, electromagnetic field

1. Introduction

Nowadays one of the main diseases is the one of movement organs especially that connected with legs and knee joints, like arthritis or pseudo-arthritis. According to American statistics about 15% of Americans suffer from orthopedic diseases and every year more than 7 million need to be hospitalized because of orthopedic dysfunctions [1]. There are many conventional methods of treatment in such cases, but for the last 20-25 years the methods which used electromagnetic field are being developed [2,3]. We call them generally as the methods of electromagnetic therapy (EMT). The orthopeadic diseases which are mostly treated by EMT are as follows:

- Arthrities
- Pseudo-arthrities (bone non-union)
- Osteoarthrities
- Osteoporosis

2. Methods of electromagnetic therapy

There are three main directions in using electromagnetic field in orthopaedic therapy:

1. magnetotherapy,
2. electrotherapy,
3. current therapy.

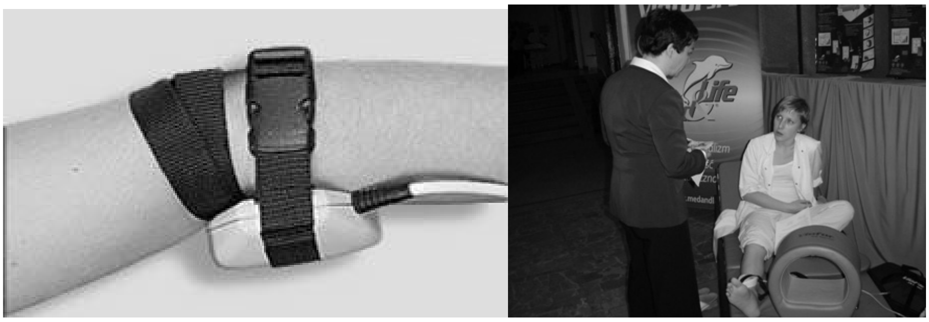

Figure1. Magnetotherapy systems

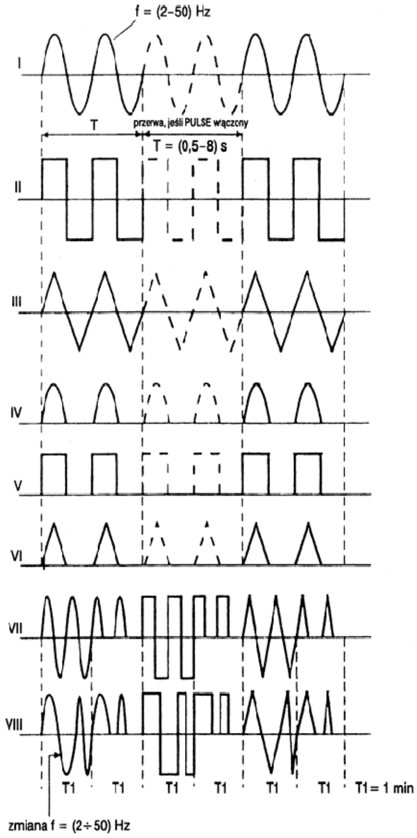

Figure 2. Time courses of excitations

Ad.1 Magnetotherapy is carried out with the electromagnetic field with magnetic component dominated and simply uses the magnetic induction phenomenon, i.e. Faraday's phenomenon. Eddy currents are generated in muscle and bone tissues due to varying in time magnetic component of applied EM field. The value of current density depends on electric conductivity and frequency of the field and its time-course.

Magnetotherapy in orthopaedics can be realized in many ways – two of them are shown in Figure 1. The technical parameters of the treatment are suited to the patient need. It is supposed that the therapeutical effect is reached for current density in a bone tissue from 2 till 20 mA/m^2. Frequency of the applied field as well as the shape of the course also diverge. Practically one uses the frequency between 10-100 Hz with various time courses (Figure 2). Time of application is from several minutes till a couple of hours.

Ad.2 *Electrotherapy* uses the effect of displacement current which flows through the dielectric material due to variation of electric component of EM field. This is electric induction phenomenon. In this case the induced current value depends on electric permeability and frequency of the field and its time course. Electrotherapy consists in using electrodes which supply the limb under tre through conducting gel. The value of supplying voltage is from 1 to 10 V with the frequency 20-200 kHz. Such parameters and the values of electromagnetic parameters of limb cause the current in the tissue in the range 5-500 mA/m^2 [2].

The method is much lesser used nowadays than the method of magnetotherapy but one can meet it in the United States and some places in Europe, e.g in Italy.

Ad.3 *Current therapy* consists in "injecting" a current directly to the bone. The method has weak connotation with EMT but it is evoked here just to complete the possible treatments. The main reason which makes the method different from the rest two is that the current therapy is invasive treatment as it requires surgical action on patient – the main feature of EMT, i.e. invasiveness, is lost.

Current therapy depends on the value of current applied *in situ*. The published results of investigation showed, that this value should not be lower than 20 mA/m^2 (no reaction), but it should not exceed 200 mA/m^2 (possible necrosis of tissue). Taking into account the upper value and regarding the parameters of a tissue one can find the applied voltage which is 2.3 V [3]. This application is made with DC current 24-hour, with negative electrode in the healing area while positive electrode can be placed little far from the limb.

The clinical tests made with the above techniques showed that the magnetotherapy is the most useful technique, since it is the most effective, non-invasive and easy in operation [2-4].

3. Clinical aspects of magnetotherapy

The method is widely used in medical practice which enforce the commercial production of special devices (applicators) shown in Fig. 3.

There are various research projects realized in medical research centres which show how magnetotherapy works in medical practice. Below some of them are quoted.

Italian project in 1982 gave the very positive results as the percentage of healing cases amounted 73%. British researchers, in turn, reached 80%- success in the healing process of pseudo-arthrisis with the parameters of therapy: frequency – 1-11 Hz, magnetic flux density 2-50 mT (see [9]). Other Italian investigation showed that the number of patients up to 84% patients were healer. This is rather believable result as the number of patients was 348. Spanish researchers tested 1170 patients and the coefficient of success reached at most 74%.

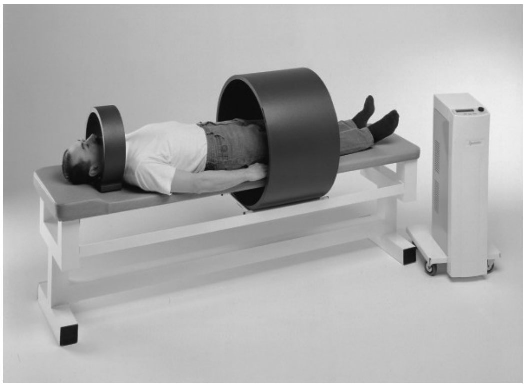

Fig.3. The commercial device for magnetotherapy

There were investigations which reported not the successes in healing pseudo-arthrosis but the time that was needed to attain the positive effects. Again Italian researchers showed that the re-union of the broken tibial bones treated by magnetic field was reached in 85 days while control group reached the same effect after 109 days.

Research on big group of patients has been made in one of Italian clinics. Magnetotherapy was used on the cohort of 3014 patients with limb inflammation of acute and chronic nature. Good results were reached for almost 79% of patients. Interesting finding is that the better results were attained for therapy that was dedicated to one joint (see [4]).

The high effectiveness of magnetotherapy was also proved for healing of sciatica. Polish researchers show that magnetotherapy (2.5-10 mT) removed the pain in 16.7% of patients totally and weakens pain in the group of 65.1% [7]. The other group of doctors report that magnetotherapy gives some promising results in the case of osteoporosis [4].

Many medical research centres announce similar results. Some researchers underline that the magnetotherapy can used as the aided (supplementary) treatment and then the effectiveness could be even better.

4. Computer simulation

As it is very difficult, if not impossible, to get the knowledge about eddy currents inside the stimulated tissues the only possibility is to make the numerical simulation. Two stimulation cases will be considered in the simulation process. The cases differ from each other with the way of magnetic stimulation: toward the bone and perpendicular to the bone (Figure 4).

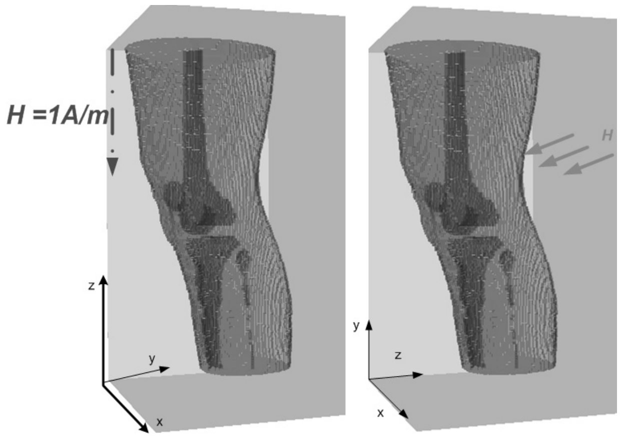

Figure 4. The geometrical models of two ways of magnetotherapy

It is assumed that the magnetic component of EM is homogenous in the area of treatment. The second assumption concerns the time-dependency and the sine wave excitation 50 Hz was taken into account. In fact, the magnetic field in a stimulator can be generated in many ways, as shown in Figure 2. Both assumptions made the case a little bit artificial but, as we look for some tendency, not for the exact values, they may be accepted. As the problem is linear the value of magnetic field strength can be taken arbitrarily, thus for the sake of simplicity the value of 1 A/m was used for the computing

The electric data of the human body used in this work (in this case the leg is stimulated) is obtained from US Air Force Research Laboratory, which represents a large male (1.8 m tall and 105 kg weight). In order to model the leg tissue response by relaxation theory, the electrical properties of human tissue were modelled using the 4-Cole-Cole approximation with parameters given in [6] (Table I).

Table 1. Parameters of biological materials

Material	**Conductivity** [S/m]	**Density** [g/cm^3]
Body fluid	1.50000e+000	1.01
Fat	2.00131e-002	0.916
Lymph	5.21683e-001	1.04
Nerve (spine)	2.76552e-002	1.038
Muscle	2.41783e-001	1.047
Blood vessel	2.64757e-001	1.04
Bone (cortical)	2.00557e-002	1.99
Skin	2.00000e-004	1.125
Bone (cancellous)	8.08320e-002	1.92

The finite-difference time-domain technique (FDTD) is a well established numerical method for modelling very complicated, inhomogeneous electromagnetic problems at high frequencies. However, bioelectromagnetic simulations at low frequencies using

FDTD method require special consideration. Frequency scaling algorithm is often used at quasi-static problems where the ***E***-field and ***H***-field are assumed to be uncoupled. Using this algorithm the actual simulation is performed at a higher frequency *(f*)* (with the quasi-static approximation being still valid) and the induced fields are scaled to the frequency of interest *(f)* after the higher frequency FDTD-simulation is finished. Assuming that the electric field in the air (E_{air}) is normal to the body surface one can write:

$$j\omega\varepsilon_0\hat{n}E_{air}(\omega) = (\sigma + j\omega\varepsilon)\hat{n}E_{tissue}(\omega) \quad (1)$$

From (1) it can be concluded that:

$$E_{tissue}(f) = \frac{\omega(\sigma^* + j\omega^*\varepsilon^*)}{\omega^*(\sigma + j\omega\varepsilon)}E_{tissue}(f^*) \cong \frac{f\sigma^*}{f^*\sigma}E^*{}_{tissue}(f^*) \quad (2)$$

Assuming that $\sigma + j\omega\varepsilon \cong \sigma$ for both *f* and *f** and σ^* and σ are close enough, the equation (2) can be simplified to:

$$E_{tissue}(f) = \frac{f}{f^*}E^*_{tissue}(f^*) \quad (3)$$

In our case the actual FDTD calculations were performed at the frequency $f^* = 10$ MHz and afterwards the induced electric field E^* at the frequency f^* was scaled to the frequency in question, i.e. $f = 50$ Hz, using equation (3). As it is obvious from (2), the permittivity of tissues does not affect the results significantly, therefore the value of $\varepsilon_r = 1$ was set for the whole environment to hasten the speed of wave propagation and to reduce the simulation time. On the surface of the simulation, volume absorbing boundary conditions were defined. In this study six perfectly matched layers (PML) boundary condition was used because it is superior to most standard absorbing boundary conditions (ABC) with regard to electromagnetic interferences with human tissues.

Since eddy currents are the main factor of therapeutic effect the results of eddy current density is presented in the form of absolute value in the cross-section of stimulated knee.

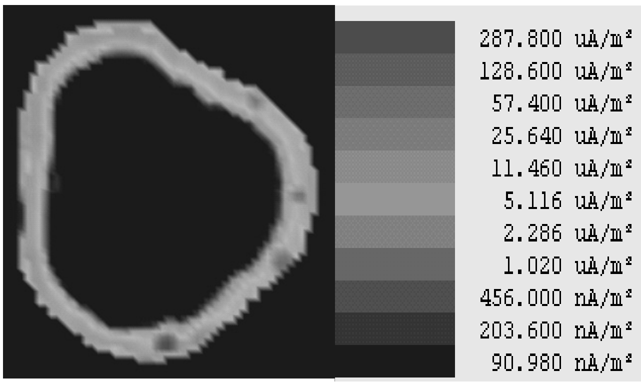

Figure 5. Eddy current distribution for toward-leg stimulation

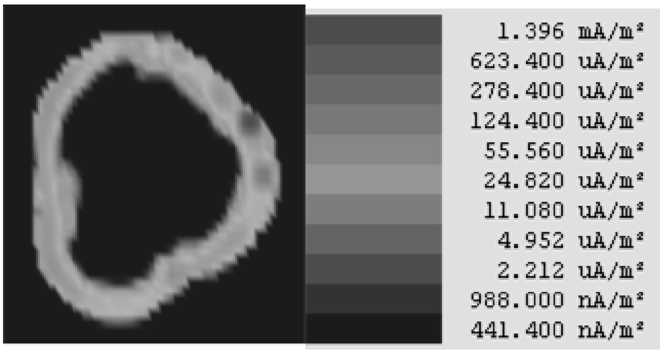

Figure 6. Eddy current distribution for under-leg stimulation

The two exemplary results show that significant part of eddy currents is evoked in the muscle surrounding a bone. It is because of the almost ten-fold discrepancy between conductivities of bone and muscle tissues. Thus, the values of magnetic field strength used in clinical practice is entirely proper if the value of eddy current density needed for therapy should be reached. The higher values of eddy currents occur in the under-leg stimulation.

5. Conclusions

All the above considerations allow to provide the medical staff with some hints that are listed below:

- the electromagnetic therapy is widely realized by various techniques but medical practice shows that magnetotherapy is mostly used – clinical research prove the satisfactory effectiveness of magnetotherapeutic technique,
- magnetic component of EM field applied to a patient can be too big as far as muscle tissues are taken into account – this problem require further research,
- therapeutic effect (if we take into account eddy current density) is much better when one uses the under-leg coil – this fact is for doctors' considerations.

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