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Determination of safety zones in the context of the magnetic field impact on the surrounding during magnetic therapy

***Abstract**. The impact of pulsating magnetic field in the vicinity of applicators used in magnetotherapy is important in the context of the influence of this field on the environment, especially when there are people with cardiac pacemakers nearby. The authors assess the safety zones mentioned in labor laws, depending on the design of the applicator.*

***Streszczenie.** Oddziaływanie pulsującego pola magnetycznego aplikatorów stosowanych w magnetoterapii jest istotne w aspekcie wpływu tego pola na otoczenie, zwłaszcza w przypadku, gdy w pobliżu znajdują się osoby ze stymulatorami pracy serca. Autorzy przeprowadzają ocenę zasięgu stref bezpieczeństwa wymienianych w przepisach prawa pracy, w zależności od konstrukcji aplikatora. (**Wyznaczenie stref bezpieczeństwa w kontekście oddziaływania pola magnetycznego na otoczenie w trakcie terapii magnetycznej**).*

Keywords: magnetotherapy, magnetic field, security requirements, safety zones, biomedical engineering.
Słowa kluczowe: magnetoterapia, pole magnetyczne, wymogi bezpieczeństwa, strefy bezpieczeństwa, inżynieria biomedyczna.

Introduction

In case of many diseases and ailments, application of pulsating magnetic field contributes to acceleration and improvement of treatment conditions. In some circumstances (e.g. lack of bone adhesion), it may be the last opportunity, that remains in the arsenal of methods used by orthopaedists in injury treatment.

In 2009, diseases of bone and joint, muscle and connective tissue were the reason for 12.1% of sickness absence in Poland [1].

Among the effects that improve treatment conditions there is e.g. pain relief. Another advantage of magnetic therapy is the patient's high tolerance to it – as a noninvasive and painless method, it does not cause any immediate ailments. Short exposure time during treatments – just a few minutes a day for the duration of treatment (several days on average) – causes no side effects (e.g. carcinogenic) over a longer period of time after healing the injury.

The above mentioned problems concern patients. However, another group of people associated with the magnetotherapy is the staff of the centers in which this form of therapy is used. The doctors, nurses and physiotherapists supervising patients, stay close to the equipment, which induces magnetic field. It is therefore important to determine the effect of individual devices on the environment in the context of existing labor laws.

Types of applicators

Applicators are devices used to induce magnetic field employed in the therapy. There are several designs of applicators. In figure 1, three types of applicators are shown. The type most widely used in offices, solenoid applicator (fig.1a), designed for treatment of orthopaedic injuries – due to its large size, weight and lack of portability – is most often used to treat limb injuries. Another device is an elliptical applicator (fig.1b). It can be carried and used locally, including TMS (Transcranial Magnetic Stimulation) [2].

The latter example is a portable applicator with adjustable shape, which is allowed by the casing of a flexible material (fig.1c). It may then be fitted to the size of the patient's limbs or trunk [3, 4].

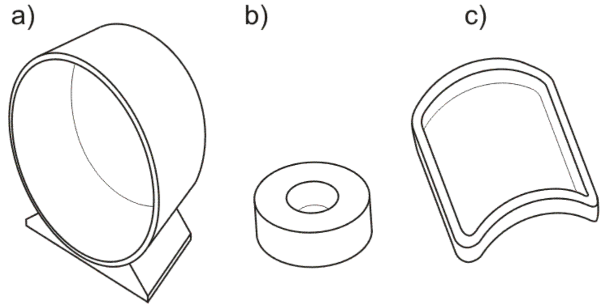

Fig.1. The types of applicators used in the magnetotherapy: (a) solenoid, (b) portable elliptical, (c) a portable with the possibility of adjusting the shape

The induction of magnetic field used in magnetotherapy ranges from 1 μT (0,8 A/m) to 20 mT (16 kA/m) and, if the method of supporting treatment for depression – TMS (Transcranial Magnetic Stimulation) – is to be considered, the upper boundary must be shifted significantly, up to 3 T (2400 kA/m) [5]. The frequency of the magnetic field used in the treatment does not exceed 50 Hz.

Applicators work in sets. Each kit consists of a driver, that allows the adjustment of the appropriate treatment parameters arrangement, and with an applicator - a certain number of winding turns encased in the housing protecting the patient against electric shock in whose surrounding, magnetic field of specific distribution is induced. The course, shape and number of turns in the applicator depend on its type.

Safety requirements related to the magnetotherapy

Safety requirements relating to the use of magnetic fields in medicine can be divided as follows [6]:

1. protection of patients and staff against electric shock,
2. protection of persons who operate the equipment for magnetic stimulation and magnetic therapy against the harmful effects of magnetic field,
3. contraindications to the use of magnetic fields in specific diseases,
4. possible contraindication due to the potential emergence of side effects.

The first requirement is clear. Because of the materials used nowadays, the possibility of shock is not taken into account. The third and the fourth requirement relate to the specific and detailed conditions and the decision to admit a patient to treatment with magnetic field depends on the doctors [7, 8, 9].

The paper focuses on the second of the listed points, i.e. an assessment of the safety of workers and the area of impact of applicators, which requires the protection of workers handling facilities.

In May 2004, the European Directive on occupational exposure to electromagnetic fields was published [10]. The Directive lays down limit values of the fields in the workplace (tab.1). It does not impose specific values of the standards adopted for each country, with the assumption that they can not be less restrictive. All values precised in cited standards are Root Mean Square.

Table 1
The maximum magnetic field strength depending on the frequency according to the standards of the European Union (5 of 13 specified ranges) [10]

Frequency range [Hz]	Magnetic component [A/m]
0-1	163000
1-8	$163000/f^2$
8-25	$20000/f$
25-820	$20/f$
820-2500	24,4

f- frequency in units of the column "Frequency range"

Polish regulations and standards on occupational safety and health, determine the conditions and time spent in the electromagnetic field of the frequency range from 0 to 300 GHz. Assessment of exposure to magnetic fields (but also in other conditions of the electric field) is based on the determination of security zones in which the permissible values of the fields acting on the environment are specified.

Due to the influence of magnetic field, the following zones are separated [11]:
- **safe**, where workers are permitted to stay without any limitations,
- **protective**, where it is allowed to stay on condition of shortening the length of exposure or use of protective clothing.

Within the protection zone, there are three zones, depending on the magnetic field strength:
- **intermediate** (66 - 200 A/m),
- **threat** (200 - 2000 A/m),
- **danger** (above 2000 A/m) - employees are not allowed to stay in this zone.

Considering the data given above, it can be concluded that restrictions being in force in Poland are more restrictive than in other EU countries.

In the intermediate zone, workers are being allowed to stay for a single shift.

Within the threat zone, the maximum acceptable time of work depends on the strength of the magnetic field and according to the rules in the frequency range from 0.5 to 50 Hz may not exceed the values defined in the regulations as the acceptable dose of magnetic field. This value is calculated by multiplying the square of field strength and the time of stay:

$$(1) \qquad Dd_H = H^2 h$$

where: Dd_H – acceptable dose of magnetic field [$(kA)^2/h$], H – magnetic field strength [A/m], h – time spent in threat zone [hours].

Value of acceptable dose is at 0,32 $(kA)^2/h$, while the maximum time that cannot exceed 8 hours [11].

Within the threat zone, both the upper limit of the magnetic field strength and the value of the dose limit of magnetic field change along with the range of frequencies. Quoted level relates to the limit dose in the range of frequencies from 0.5 to 50 Hz, since such frequencies are used in the magnetotherapy in the vast majority of cases.

The staff may not stay within the danger zone.

In the area of protective zones, only the employees who meet fixed requirements, in whose case medical examination found no contraindicatives to occupational exposure to magnetic field, are allowed to stay [11, 12].

Of course, the restrictions provided in this paragraph, regulated by the law, concern people who are exposed to magnetic field for extended periods during their whole life. This is related mostly to their profession.

The maximum values included in the regulations do not apply to single diagnostic tests or therapies applied repeatedly – such as magnetotherapy, where a patient or a substantial part of his body is in the danger zone – in this case, however, the impact is justified and allowed consciously.

The provisions shall also be supplemented by recommendations and the risks associated with the influence of magnetic field on cardiac pacemakers. In 2005, in Poland there were over 300 thousand people with implanted cardiac pacemakers [13] and a systematic increase of this number is noted. In case of magnetic field with a frequency of 50 Hz, the maximum level of magnetic field strength is 80 A/m according to [14], and these magnetic field levels are included in the intermediate zone of safety. Setting the boundaries of each zone, even the intermediate zone should include a warning sign for people with cardiac pacemakers.

Safety zones around the applicators

Figure 2 shows the spatial distribution of the three zones identified within the protective zone. For the numerical model solenoid applicator of 750 mm diameter with a predetermined maximum value of the magnetic field strength (in the main axis of the applicator) of 16 kA/m (20 mT). To illustrate the decay of the magnetic field with increasing distance from the applicator, the distribution of the field is presented on the surface of a model of a lying patient.

The danger zone (the surface marked red colour) covers only the lower limbs. Most of the patient's body is located within the threat zone (yellow). The intermediate zone (green) reaches up to 2 meters away from the applicator.

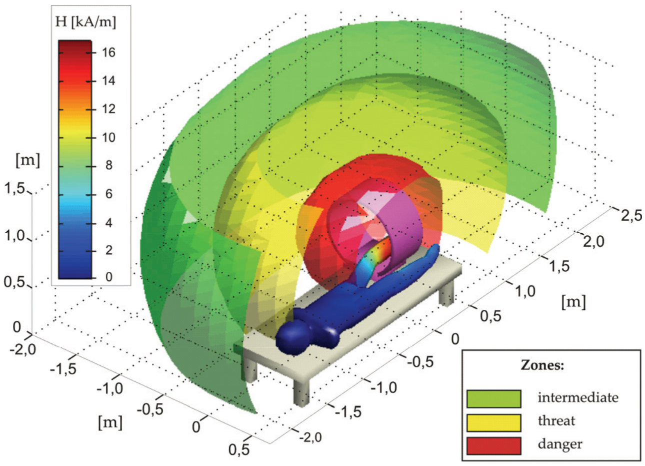

Fig.2. Distribution of the protective zones and magnetic field strength derived from the solenoid applicator of 750 mm diameter

This simulation shows that the applicator should be placed in the cabinet in such a place, that the protective zone does not reach beyond the walls of the room – especially those walls behind which there is a waiting room or a hallway, where there is a large group of accidental people – including those with the cardiac pacemakers.

Figure 3 shows the distribution of zones surrounding a portable applicator. For the sake of comparison of simulation results, it was assumed that the strength of the field induced by the portable applicator is 16 kA/m (20 mT). The results of the comparison are more favourable for portable coil, the range of the danger zone is about twice smaller than the solenoid applicator. This is important from the point of view of the body parts that do not require treatment, especially when not only the limbs are treated.

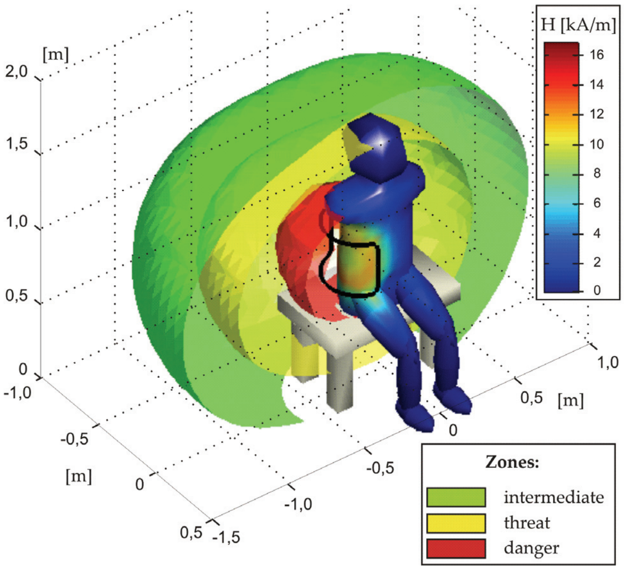

Fig.3. Distribution of safety zones and the magnetic field strength induced by the portable applicator

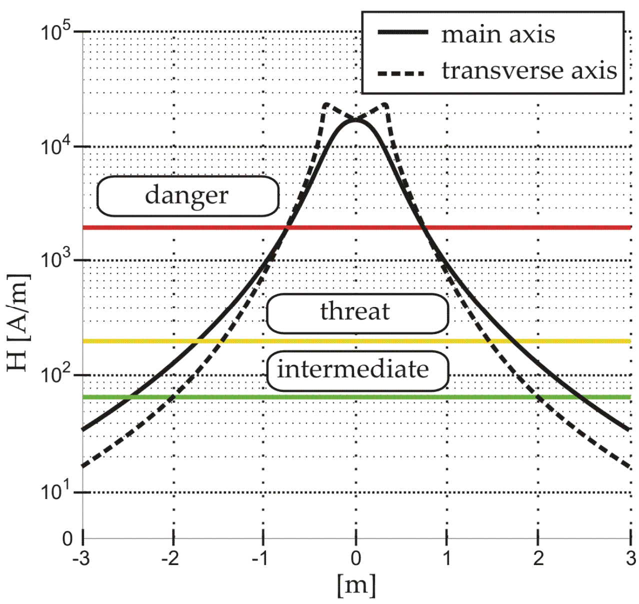

Fig.4. The distribution of the magnetic field strength along the axis of the ring solenoid applicator of 750 mm diameter

The magnetic field disappears with the distance from the applicator in the assumed direction of analysis. Figure 4 presents the field distribution along the two axes of the applicator: the main (cylindrical symmetry axis) and the transverse around the applicator with a diameter of 750 mm. Difference in decay rate and the limit of coverage of the protective zone is small – on the order of several centimeters – thus it is a negligible distance. It follows that the attempt to change the spatial extent of safety zones by appropriate rotation of the applicator are futile.

The effect of magnetic field strength (adopted as a maximum in the principal axis) applied during treatment on the extent of the intermediate zone is shown in figure 5.

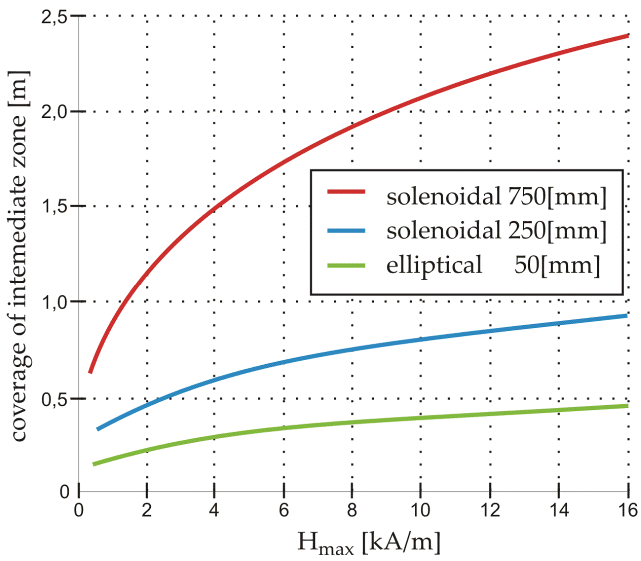

Fig.5. Intermediate zone coverage in the function adopted for the treatment of magnetic field

In the case of the solenoid applicator of 750 mm diameter, the range varies from 0.5 m to nearly 2.5 m at the applied field strength of 80 A/m (0,1 mT) to 16,000 A/m (20 mT). For the applicators with smaller diameters (250 mm solenoid and elliptical 50 mm) the coverage of the zone is definitely shorter.

Table 2
Coverage of safety zones during transcranial magnetic stimulation

Field strength [kA/m]	Danger [m]	Threat [m]	Intermediate [m]
800 (1 [T])	0.51	1.11	1.61
1200 (1,5 [T])	0.59	1.27	1.84
2000 (2,5 [T])	0.69	1.51	2.19
2400 (3 [T])	0.78	1.75	2.58

As mentioned earlier, the magnetic field strength used in psychiatry is very high in comparison with the standard magnetotherapy (up to 100 times higher). However, the extent of each zone does not exceed the areas known to standard magnetotherapy up to such an extent – this is a consequence of the strong field decay with the distance from the source and the smaller size of the applicator (the simulations assumed the diameter of 50 mm).

Table 2 lists the ranges of each zone, depending on the strength of field used. In the therapy with a field value of 1200 kA/m (1.5 T), the danger zone does not even reach the distance of 1 m from the applicator, and at the highest field values used in medicine (2400 kA/m) the distance is 0.78 m. The limit of the intermediate zone (protective) but does not exceed 3 m.

Conclusions

The results give a picture of the spatial distribution of magnetic field used for magnetic therapy. In case of standard applicators used e.g. for orthopedic injuries, the distance between individual borders of zones are small and highlight the threat zone and associated with the calculation of the dose limit of the magnetic field seems to be pointless.

The authors suggest in this situation to limit the lower intermediate zone (due to cardiac pacemakers), which is also a border of protective zone, regarded as an area within which both employees and third parties should not be present during the operation. Thus, for each applicator there should be a determined minimum distance that should be kept by the staff during operation.

In case of magnetic field therapy used in psychiatry, in spite of significant differences in the values of the applied magnetic field (higher in psychiatry), the protective zone is stretched by about 1 m more than in the case of a solenoid applicator of 750 mm diameter. Thus, in terms of the range of safety zones, the type and dimensions of the applicator are the most important issues, and the value of magnetic field assumed in therapy is not so crucial. Thus, according to the authors, magnetic field even of values used in psychiatry does not need screening, and a room in which treatments are carried out need not have dimensions of sports halls so that the protection zone did not reach outside them.

In case of patients, the portion of the body lying within the danger zone, depends mainly on the part of the body which is subjected to treatment, and the type of applicator and the field value is of little importance.

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