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THE INFLUENCE OF LOW-FREQUENCY MAGNETIC FIELDS OF DIFFERENT PARAMETERS ON THE SECRETION OF CORTISOL IN MEN

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Abstract
Objectives: The aim of this paper is to test the influence of long-term application of the low-frequency magnetic fields in magnetotherapy and magnetostimulation on cortisol secretion in men. **Materials and Methods:** Patients were divided into three groups: 16 men underwent magnetotherapy and 20 men (divided into two groups) underwent magnetostimulation. Magnetotherapy – 2 mT induction, 40 Hz, bipolar square wave, was applied for 20 min to lumbar area. Magnetostimulation (Viofor Jaroszyk, Paluszak, Sieroń (JPS) system, M2P2 program) was applied to 10 patients for 12 min each day. The third group (10 patients) underwent magnetostimulation (Viofor JPS system, M3P3) for 12 min each day using a different machine. All groups had 15 rounds of applications at approximately 10:00 a.m. with intermissions on the weekends. Blood serum was taken four times in a 24-hour period, before applications, the day after applications and a month later. Chemiluminescence micromethod was used to indicate hormone concentrations. Data were statistically analyzed with the analysis of variance (ANOVA) method. **Results:** The statistically significant gains in the circadian cortisol profile at 4:00 p.m., before and after application, were observed as a decrease in concentration during magnetotherapy. In magnetostimulation, with the M2P2 program, a significant increase in the cortisol concentration was observed in circadian profile at 12:00 p.m. one month after the last application. After magnetostimulation with the M3P3 program, a significant increase in concentration at 6:00 a.m. and a decrease in concentration at 12:00 p.m. were observed one month later. Statistically significant difference was demonstrated in the participants after the application of magnetotherapy and magnetostimulation with M3P3 program compared to the men submitted to magnetostimulation, with M2P2 program, at 4:00 p.m. after 15 applications. **Conclusions:** Biological hysteresis one month after magnetostimulation suggests long-term influence on the hypothalamo-hypophysial axis. The circadian curves of cortisol secretion a day after magnetotherapy and magnetostimulation with M3P3 program compared to magnetostimulation with M2P2 progam differs nearly by 100%, which proves that they show varied influence on cortisol secretion in men. All changes in hormone concentration did not exceed the physiological standards of cortisol secretion, which suggests a regulating influence of magnetic fields on cortisol concentration rather than a strong stressogenic impact of magnetostimulation.

Key words:
Magnetic fields, Cortisol secretion, Stressogenic effect

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Without stress, there would be no life,
Hans Selye

INTRODUCTION

In adults, adrenal glands weigh 8–10 grams in total. They are situated retroperitoneally, medially and superior to the kidneys. Mature cortex of the glands consists of three layers: the outermost layer, zona glomerulosa, which secretes aldosterone, zona fasciculata located in the central part of the adrenal glands which produce cortisol, and the zona reticularis, which is responsible for the production of androgens,. The functions of the layers are regulated mainly by adrenocorticotropic hormone (ACTH). In blood, it combines with transcortin, a transporting protein (corticosteroid-binding globulin – CBG) and, to a lesser degree, with albumins.

Only 10% of cortisol is left unbound; the so-called free cortisol, which easily permeates into the designated cells [1–3].

The main function of cortisol is its influence on the genetic apparatus of cells. The hormone-receptor complex enters the nucleus of a cell, where it affects the production of biologically active proteins, most frequently enzymes. A reaction of this type requires a certain period of time. The influence of cortisol on lysosomal membranes reveals itself more quickly, even in seconds. Medicine benefits from this phenomenon in the treatment of serious allergic reactions, anaphylaxis or cerebral oedema. ACTH feedback inhibition is yet another example of cortisol functions [1,3,4,].

Cortisol does not only play the key role in sustaining homeostasis in human organism but it is also a wide-range medicine. It exerts, among other things, immunosuppressive, anti-inflammatory, and anti-allergic actions. In the liver, cortisol stimulates glycogenolysis and glyconeogenesis through catabolism – it enhances the degradation of proteins in distal tissue. Moreover, glyconeogenesis is increased thanks to lipolysis directly stimulated by cortisol and indirectly stimulated by other hormones such as somatotropin. Glucocorticosteroids inhibit secretion of TSH and reduce conversion of T4 to T3 [1,2].

In men, they inhibit secretion of gonadotropins and in women they abolish the response of luteinizing hormones (LH) to gonadotropin releasing hormone (GnRH), which results in the inhibition of estrogens and progesterone production, leading to ovulation arrest and the absence of menstruation [1,2].

Cortisol enhances the retention of sodium and water, raising blood pressure. Cortisol also shows a positive influence on contractility and systolic blood volume of the heart muscle as well as regulating the expression of adrenergic receptors in the circulatory system. It influences mood, cognitive functions, appetite, libido and sleep [1,3].

The concentration of cortisol in blood is 5–25 μg/dl. Higher values appear in the morning, which is in accordance with the circadian profile of cortisol secretion. In basic conditions, the secretion of cortisol amounts to 10–30 mg in 24 hours. Secretion of cortisol in stressful situations can rise ten times the normal amount [2,3]. Since it is secreted in situations when the organism experiences stress, changes in cortisol concentration may indicate the stressogenic influence of long-term magnetic fields action as in physiotherapy.

The influence of magnetic fields on living matter can be explained through resonance mechanisms. They are responsible for: the transport of ions through cell membranes, producing actions on membrane receptors, calcium ($Ca2+$) binding to calmoduline (which regulates enzyme activity) as well as changes in the level of dielectrophoresis and dielectrical permeability. The influence of magnetic fields on ions that are loosely bound to molecules can be explained through precession of ionic orbits [5,6].

The potential mechanisms of magnetic field actions on adrenal system result from their influence on the ATP-activated receptor [5], as well as from their influence on the serotonin and melatonin concentrations [6–8]. They influence the activity of the enzymes, induction of eddy currents and ferromagnetic mechanism [9].

The aim of this paper is to test the influence of low-frequency magnetic fields applied on a long-term basis (as in physiotherapy) in magnetotherapy and magnetostimulation on cortisol secretion in men.

MATERIALS AND METHODS

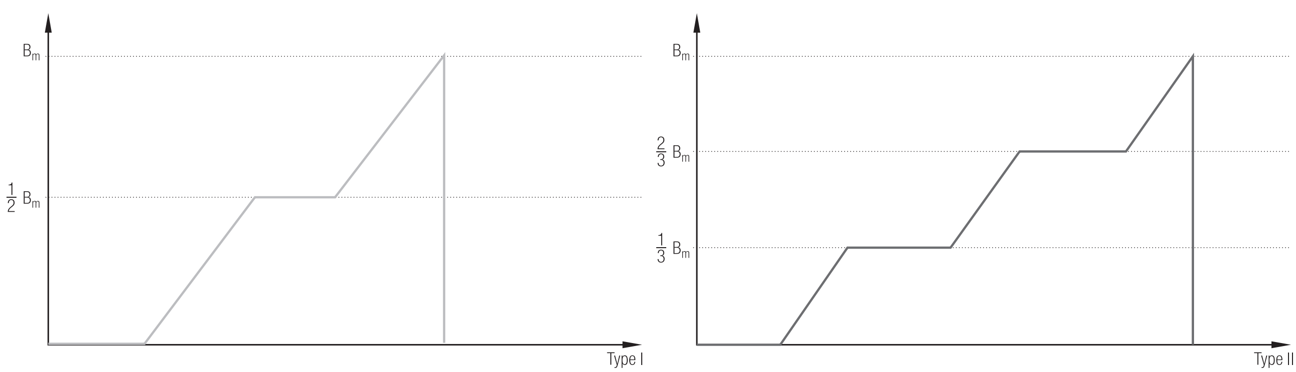
Patients were divided into three groups: 16 men underwent magnetotherapy and 20 men in two groups of 10 underwent magnetostimulation. The patients were treated at the Rehabilitation Ward of the Regional Hospital in Sieradz. The study was granted ethical approval by the Medicine Ethical Committee of Medical University of Łódź: number RNN/254/05/KB dated the July 26, 2005.

Magnetic field 2,9 mT induction, 40 Hz frequency, bipolar square wave, (Magnetronic MF-10 apparatus, coil-shaped applicator) form of magnetotherapy was applied for 20 min to the lumbar area in patients suffering from chronic lower back pain. The average age of the patients was 48 (range: 28–58). Magnetostimulation (Viofor JPS system, M2P2 program with a mattress as the applicator) was applied to 10 patients, treated for chronic lower back pain, for 12 min each day. The average age of patients in the second group was 44 (range: 34–52). The third group of 10 patients underwent magnetostimulation (Viofor JPS system, M3P3 program with a mattress as the applicator) for 12 min each day as well. The average age in the third group was 45 (range: 33–54). All the groups were subjected to 15 applications at approximately 10:00 a.m., one application a day with intermissions on the weekends.

Component parts of magnetostimulation include:

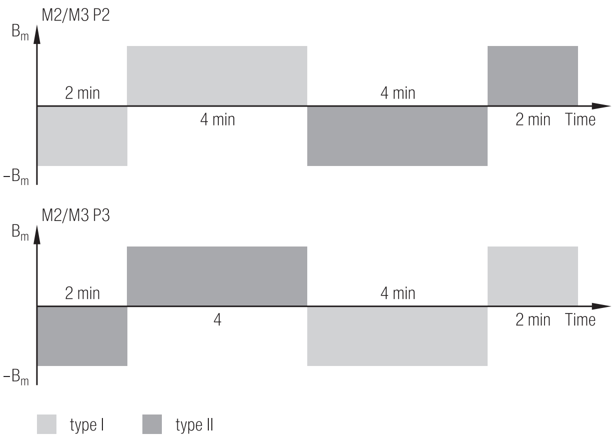
- M2 application mode – application with increasing intensity; the degree of field intensity increases every 10 or 12 seconds from 0.5 to the selected intensity, cyclically during the time of application; recommended in persons of lowered health conditions (for prophylaxis);
- M3 application mode – application with an increasing-decreasing intensity; the degree of field intensity increases in 2 min from 0.5 to the selected value, during the next 8 min remains at the selected level, during the last 2 min decreases to a level of 0 (applying mainly in therapy);
- P2 program – JPS system with two impulse types;
- P3 program – JPS system with two impulse types of different order and impulse structure as compared with P2.

The shape of individual impulses resembles a complex saw-like shape (expotential). In the rising section they show part of linearly rising induction of variable tilt intersected with constant induction (impulses types I and II) (Figure 1–3).



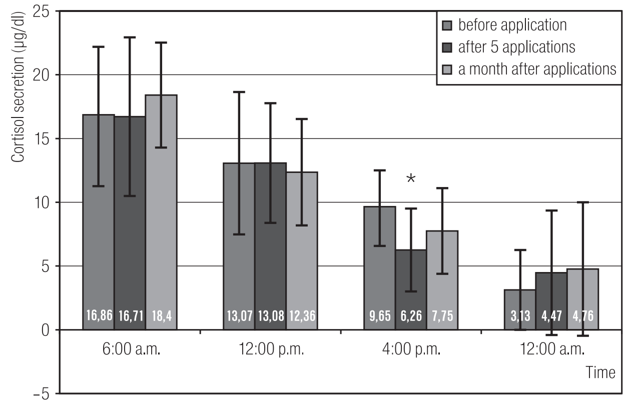
B_m – intensity of magnetic field.

Fig. 1. Basic impulse shapes of type I and II



B_m – intensity of magnetic field.

Fig. 2. Schematic structure of the signals for application method M2 and M3 and programs P2 and P3 without taking into account changes in the intensity



* Statistically significant gain ($p < 0.05$) compared to the result before magnetotherapy application.

Fig. 4. Circadian rhythm of cortisol secretion in patients before the application of magnetic field, a day after 15 applications and a month after magnetotherapy

Blood serum was taken four times in a 24 hour period – at 6:00 a.m., 12:00 p.m., 4:00 p.m. and 12:00 a.m. The chemiluminescence micromethod was used to indicate concentration of the hormone (reagents provided by DPC Poland, Ltd.). Circadian profile of cortisol (in μg/dl) was marked before the application of magnetic field, a day after all of the 15 applications and a month after all applications.

The data was statistically analyzed by the use of the analysis of variance (ANOVA) method. In statistics, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes T-test to more than two groups.

Assumed significance level was $p < 0.05$. Microsoft Office Excel software was used to carry out the statistical analysis. Tests used to compare groups, on Figures 4–6, are for

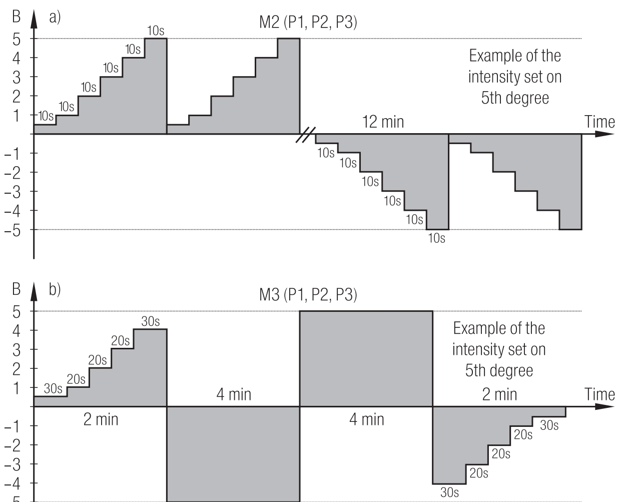
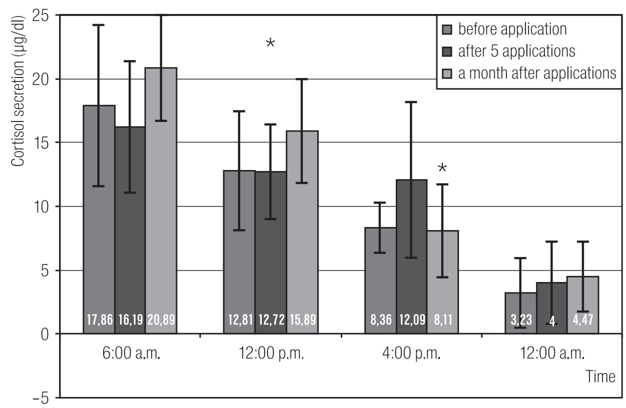
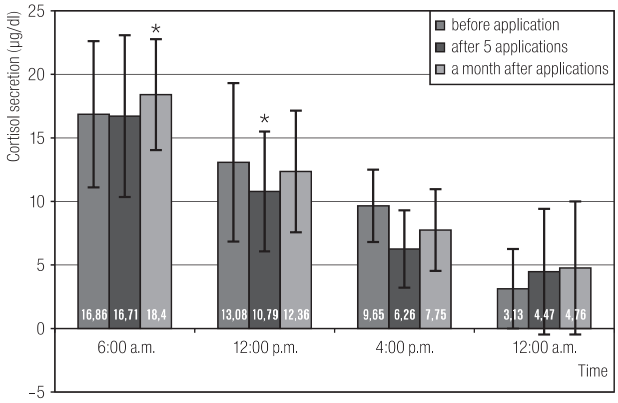


Fig. 3. Scheme changes in the amplitude of the method of application: a) M2, b) M3



* $p < 0.05$ compared to the result after 15 applications of M2P2 magnetostimulation.

Fig. 5. Circadian rhythm of cortisol secretion in patients before the application of magnetic field, a day after 15 applications, a month after magnetostimulation (M2P2 program)



* $p < 0.05$ compared to the result before application of M3P3 magnetostimulation.

Fig. 6. Circadian rhythm of cortisol secretion in patients before the application of magnetic field, a day after 15 applications and a month after magnetostimulation (M3P3 program)

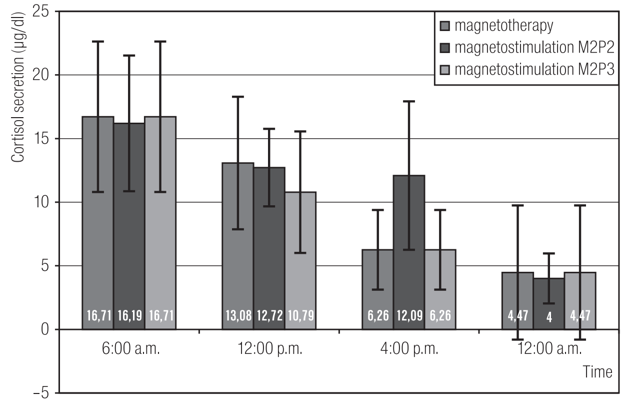
dependent observations. Comparison of treatment groups (magnetotherapy, M2P2, M3P3) the day before the start of treatment was not included due to lack of significance at any time.

RESULTS

A significant decrease in cortisol concentration was observed after magnetotherapy in the circadian rhythm at 4:00 p.m. after 15 applications when compared to the concentration before applications (Figure 4).

As a result of magnetostimulation in the M2P2 program, a statistically significant increase of cortisol concentration was observed in the circadian rhythm at 12:00 p.m. as well as statistically significant decrease of cortisol concentration at 4:00 p.m. was observed a month after the last application of the field when compared to the concentration observed after 15 applications (Figure 5).

After magnetostimulation in the M3P3 program, a statistically significant decrease in cortisol concentration was observed at 12:00 p.m. after 15 applications and an increase of cortisol concentration in circadian cycle was observed



* $p < 0.05$ compared to the result of M212,P2 magnetostimulation.

Fig. 7. Comparison of circadian profiles of cortisol secretion a day after 15 applications of magnetotherapy and magnetostimulation (M2P2 and M3P3 programs)

at 06:00 a.m. a month after the end of applications when compared to the concentration before application (Figure 6).

The research showed a significant difference between the circadian rhythm of cortisol secretion after 15 applications in patients after magnetotherapy and magnetostimulation in the M2P2 program as well as between the M2P2 and the M3P3 programs at 4:00 p.m. (Figure 7).

No significant differences between the effects of the programs were observed after a month after the end of all procedures (Figure 8).

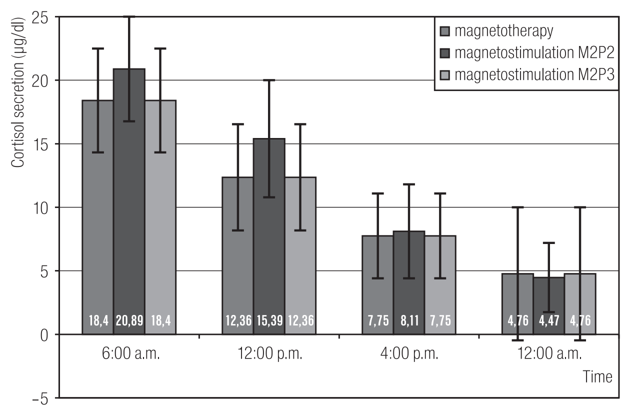


Fig. 8. Comparison of circadian profiles of cortisol secretion a month after magnetotherapy and magnetostimulation (M2P2 and M3P3 programs)

DISCUSSION

In the works cited in the references, a majority of the reports on experimental research on animals refers to a long-term exposure. Clinical test on humans usually describe immediate reactions after a short exposure because of the natural character of cortisol secretion connected with the rapid action of the stimulus and imminent reaction of the organism to a stressor [1–3].

There are few reports on the long-term effects of magnetic fields on cortisol secretion in humans. Such reports seem important for the secretion of cortisol, especially in routinely used physiotherapy.

In laboratory animals, an acute reaction to the physical stimulus showed a significant increase of cortisol concentration [10]. Udincew et al. [11] observed an increase of 11-OKS to 94% in serum and by 40% in the hormones excreting organs.

In contrast, Harakawa et al. [12] and Hedges-Dawson et al. [13] noted a decrease of the cortisol hormone; however, this decrease occurred some days after (long-term application in rats), which the authors explained as exhaustion of the pituitary-adrenal system due to the long-term exposure [14,15].

Bonhomme-Faivre et al. [16] describe decreased changes in the white cells system (neutropenia) in mice exposed to a magnetic field of 5μT induction resulting in a decrease of cortisol concentration on the 190th day of research. Reiter [17] quotes the experiment by Free et al. where the long-term exposure caused a decrease in corticosterone in rats.

De Bruyn et al. observed an increase of cortisol or corticosterone concentrations after exposure up to 18 months [18], whereas Hedges-Dawson et al. [19] and Mostafa et al. [20] observed an increase after several weeks. Zekka et al. [21] report an increase of adrenal hormones in the central nervous system of the rats which were exposed to 100 μT magnetic field for 5 days, 8 hours a day, accompanied by an increase in endorphins. The parameters returned to normal after 360 days. Burchard et al. [22] did not observe any changes in concentration of cortisol after a long-term exposure in cows, nor did Thompson et al. [23] in sheep. The long-term exposure to magnetic field in chicken embryos and young chickens resulted in high mortality of embryos (68%) and significantly low concentration of cortisol in hatchlings [24]. It seems that very long-term exposure of low frequency magnetic fields causes a decrease of concentration of cortisol.

Changes in the circadian concentrations of cortisol in rats were also observed during a magnetic storm [7,25], which was probably connected with the changes of melatonin concentration.

Zyss et al. describe weak influence of 50 Hz magnetotherapy in humans (increase in cortisol concentration) after the application of this physical stimulus in an acute reaction – up to an hour. The results were not statistically significant [26,27]. Ponomariewa et al. reported observing similar significant reactions in her studies [28].

Akerstedt et al. [29] and Schiffmaman et al. [30] observed a lack of acute reaction in their studies, by, whereas Evers et al. [31] observed a decrease in acute reactions.

Selmanoui et al. [32] suggests that the 50 Hz, 10 μT induction magnetic field applied for 24 hours in humans does not work as a stressor.

Long-term magnetotherapy influences the circadian profile of cortisol secretion; a decrease of cortisol concentration after 3 weeks of applications at 4:00 p.m. was observed [33]. Mann et al. [34] reports that in humans exposed to high frequency magnetic field, 900 Hz, pulsating at 217 Hz (the frequency of the field similar to magnetostimulation), there appears to be a slight increase in the concentration of cortisol during acute exposure, which is sustained for about an hour after the application.

In a 24-hour long-term exposure, the statistically significant changes in cortisol secretion were not noted [34], just as in Kurokawa et al. [35] and Randon et al. [36].

Long-term M2P2 magnetostimulation influences the circadian profile of cortisol secretion by significantly increasing the concentration of cortisol a month after the applications [33], which does not confirm Pecyna's [37] reports on relaxing characteristics of this program.

Miecznik et al. [38] compared magnetotherapy and M1P1 magnetostimulation used in hypertensive people and in the control group of non-hypertensive people. After each magnetostimulation, a drop in blood pressure was shown. In case of magnetotherapy, a significant drop in blood pressure appears in people without hypertension. The authors explain the effects of magnetostimulation as a stabilization of cortisol distribution. Magnetotherapy causes a decrease of melatonin secretion during the nocturnal peak, which may influence the adrenal system [6].

Magnetic storms did not cause changes in cortisol concentration during circadian observation [39]. In long-term observation, as in case of astronauts, rapid changes of magnetic field caused by magnetic storms resulted in an increase of cortisol secretion [40].

It is difficult to put forward a clear interpretation of the data presented in the research due to the problems with reference to the quoted examples because there are different conditions of magnetic field exposure in the cited articles. Neither is it possible to transpose the conclusions from tests on animals to humans.

What can be said is that the reaction to the stimulus depends on the duration of the exposure, field parameters (frequency, induction, polarization and shape of impulse) [6], subjects of research and also on whether the exposure was continuous or intermittent in character.

It is possible that the different reactions of organisms to magnetic field depend on the time of application within the circadian time during intermittent exposure. Sieroń [10] says that the relation of induction to frequency, not just the frequency, is a significant biological factor of magnetic field actions.

Marino et al. [41] put forward a hypothesis of non-linear effects, instead of dose dependent effects, of magnetic fields in endocrinal and immune systems. In their work, the statistical analysis shows that changes in corticosterone concentrations and immune system are non-linearly related to the application of magnetic fields and do not reveal a conventional dose-effect.

Wilson et al. [42] and Pridmore [43] confirmed the results of Marino's statistical analyses. Wilson and Pridmore observed that the reaction to magnetic field only occurs at definite parameters of magnetic fields in sensitive persons. The inconsistent effect of magnetic fields on individual persons can be explained by a resonance phenomenon connected with non-linear action of these fields in low-frequency spectrum for different threshold values of individuals. This phenomenon is called "a biological widow effect" or Adey's window [by 42]. In the light of the above, it would be difficult to find certain rules, which would govern the influence of magnetic fields on living organisms in terms of cortisol secretion.

Magnetotherapy affects circadian profile of cortisol secretion in the way that it increases its concentration at 12:00 p.m. one month after 15 applications. During magnetostimulation with M2P2, the statistically significant difference between cortisol concentrations was observed in the circadian profile at 12:00 p.m. one month after the last application of magnetic field (increasing concentration). Magnetostimulation with M3P3 also affects the circadian profile of cortisol secretion by decreasing its concentration at 12:00 p.m. after the end of application and by increasing it at 6:00 a.m. one month after all procedures. The effect that occurs as the biological hysteresis phenomenon one month after magnetostimulation suggests long-term influence on the hypothalamo-hypophysial axis.

The statistically significant difference between the circadian secretion rhythms of cortisol was demonstrated after the end of application in men subjected to magnetotherapy and the men subjected to M2P2 magnetostimulation at 4:00 p.m. A significant difference between the circadian secretion rhythms of cortisol was observed between M2P2 magnetostimulation and M3P3 magnetostimulation, so it is possible to conclude that the two programs of stimulation show different effects as shown in the results.

The magnetic fields used in physical therapy cause significant changes in the circadian rhythm of cortisol secretion; however, as the results show, their actions differ in case of magnetotherapy and both magnetostimulation programs. Therefore, it is possible to consider the magnetic fields used in physical therapy as a regulating factor or a very weak stressogenic factor (as a result of reaction on the physical stimuli according to the Hans Selye theory of stress because there "would be no life without stress" [44]).

CONCLUSIONS

Magnetotherapy affects the circadian profile of cortisol secretion in such a way that it decreases its concentration at 4:00 p.m. one month after 15 applications. M2P2 magnetostimulation significantly affects cortisol concentrations by increasing its concentration in the circadian profile at 12.00 p.m. one month and decreasing cortisol concentration at 4:00 p.m. after the last application of magnetic field.

M3P3 magnetostimulation also affects the circadian profile of cortisol secretion by decreasing its concentration at 12:00 p.m. after the end of applications and by increasing its concentration at 6:00 a.m. one month after all procedures.

The effect that occurs as the biological hysteresis phenomenon one month after magnetostimulation may suggest a long-term influence on the hypothalamo-hypophysial axis. The circadian curves of cortisol secretion compared the day after the end of magnetotherapy and M3P3 magnetostimulation significantly differ from the M2P2 program – nearly by 100%, which proves that this type of magnetotherapy and magnetostimulation shows varied influence on cortisol secretion in men.

It is possible that both programs of magnetostimulation affect the secretion in different ways.

All the changes in the concentration of hormones did not exceed the physiological standards of cortisol secretion and did not achieve the level as in great stress, which suggests a regulating influence of magnetic fields on cortisol concentration rather than a strong stressogenic impact of magnetotherapy and magnetostimulation.

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