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Magnetotherapy and peripheral magnetic stimulation: differences and application in pediatric practice

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ABSTRACT

BACKGROUND: Magnetic stimulation, a form of magnetotherapy using pulsed magnetic fields with high biological effect intensity, represents a promising therapeutic direction in pediatric practice.

AIM: To provide comprehensive insight into the therapeutic potential of magnetic stimulation and present a relevant clinical case.

MATERIALS AND METHODS: The study reviews materials on magnetic stimulation as a critical component of physical therapy and rehabilitation for pediatric patients.

RESULTS: Magnetic stimulation demonstrates pronounced neuromuscular stimulation effects, along with analgesic, trophic, and anti-edematous actions. Differentiating between various magnetotherapy modalities is crucial, with specific techniques tailored to clinical objectives. The main biophysical advantages of magnetic stimulation are noted. Unlike variable magnetotherapy, magnetic stimulation produces audible clicking sounds during the procedure (click = stimulus), perceived by the patient as distinct muscle contractions or comfortable vibrations, depending on the applied frequency. Frequency is a critical parameter that must be individualized. In physiotherapy, pulsed magnetic fields at frequencies up to 20 Hz elicit the most significant responses. Lower frequencies predominantly stimulate, while higher frequencies provide analgesic and microcirculatory effects.

CONCLUSION: Peripheral magnetic stimulation, due to its proven efficacy and excellent tolerance, is the physiotherapeutic method of choice in neuro- and orthopedic practice. It effectively addresses joint and spine diseases associated with inflammation or muscle spasm, nerve fiber injuries with pain syndrome, chronic pelvic pain, and urinary disorders. Its safety and effectiveness make peripheral magnetic stimulation a highly promising tool for pediatric practice, as demonstrated by the clinical case presented.

Keywords: magnetic stimulation; pulsed magnetic field; magnetotherapy; back pain; scoliosis; kyphosis; rehabilitation; physiotherapy.

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Магнитотерапия и периферическая магнитная стимуляция: отличия и особенности применения в детской практике

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АННОТАЦИЯ

Актуальность. Магнитная стимуляция является разновидностью магнитотерапии, при которой происходит воздействие импульсным магнитным полем, обладающим наибольшей интенсивностью биологического эффекта, перспективным направлением считается его применение в детской практике.

Цель исследования — предоставление необходимого объёма знаний о возможностях использования магнитной стимуляции в лечебной практике и описание клинического случая.

Материалы и методы. Обобщены материалы по методу магнитной стимуляции как одной из важных составляющих физической терапии и реабилитации пациентов.

Результаты. Магнитная стимуляция характеризуется выраженным нейромиостимулирующим эффектом, а также обезболивающим, трофическим и противоотёчным действиями. Следует дифференцировать разные модальности магнитотерапии и выбирать конкретную методику, исходя из клинической задачи. Отмечены основные биофизические преимущества метода магнитной стимуляции. В отличие от переменной магнитотерапии, магнитную стимуляцию во время процедуры пациент хорошо слышит в виде пощёлкиваний (щелчок = стимул) и ощущает как отчётливое сокращение мышцы или комфортную вибрацию в зависимости от частоты воздействия. Важным параметром, который нужно подбирать «под пациента» и при необходимости изменять, является частота. В физиотерапевтической практике считается, что особенно выражены ответные реакции при воздействии импульсным магнитным полем при частоте до 20 Гц, при этом более низкие частоты обладают в большей степени стимулирующим эффектом, в то время как более высокие частоты — обезболивающим и микроциркуляторным.

Заключение. Вследствие доказанной эффективности и хорошей переносимости периферическая магнитная стимуляция является физиотерапевтическим методом выбора в нейро- и ортопедической практике при заболеваниях суставов и позвоночника, связанных с воспалением и мышечным спазмом, поражениях нервных волокон с болевым синдромом, хронической тазовой боли и нарушениях мочеиспускания. Вследствие доказанной эффективности и хорошей переносимости метод периферической магнитной стимуляции имеет широкие перспективы применения в педиатрической практике, что можно проследить на примере представленного клинического случая.

Ключевые слова: магнитная стимуляция; импульсное магнитное поле; магнитотерапия; боль в спине; сколиоз; кифоз; реабилитация; физиотерапия.

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磁疗与周边磁刺激：在儿科实践中的区别及应用特点

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摘要

背景。磁刺激是磁疗的一种类型，其通过脉冲磁场产生最显著的生物效应，在儿科实践中的应用具有很大的前景。

研究目的。提供关于磁刺激疗法在临床实践中应用可能性的必要知识，并展示一个临床案例。

材料与方法。总结了磁刺激作为物理治疗和患者康复的重要组成部分的方法和资料。

结果。磁刺激具有显著的神经肌肉刺激作用，还具有镇痛、营养代谢改善和抗水肿等效果。应根据具体的临床需求区分磁疗的不同模式并选择适当的技术。研究表明，磁刺激的主要生物物理学优势之一是患者在治疗过程中能明显感受到其效果：与变频磁疗不同，患者可以听到清晰的“咔哒”声（刺激信号），并感受到肌肉明显的收缩或频率依赖的舒适振动。频率是一个需要根据患者需求进行个性化调整的重要参数。在物理治疗中认为，当脉冲磁场频率低于20 Hz时，反应尤其显著，其中低频主要具有刺激作用，而高频则具有镇痛和促进微循环的效果。

结论。由于已证明其有效性和良好的耐受性，周边磁刺激已成为治疗神经和骨科相关疾病（如关节和脊柱的炎症、肌肉痉挛）、神经纤维损伤伴随疼痛综合征、慢性骨盆痛和排尿障碍的首选物理治疗方法。由于其良好的效果和耐受性，周边磁刺激在儿科实践中具有广泛的应用前景，这一点可通过所提供的临床案例得以体现。

关键词：磁刺激；脉冲磁场；磁疗；背痛；脊柱侧弯；脊柱后凸；康复；物理治疗。

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BACKGROUND

Magnetotherapy and Magnetic Stimulation

Therapeutic effects of magnetic fields have been known to mankind since ancient times; the history of magnet use in medicine goes back centuries. The phenomena of magnetism, i.e. attraction and repulsion of poles, were actively used by healers in ancient times and the Middle Ages. In China, doctors applied magnetic stones to certain points on the patient's body; the Swiss alchemist and physician Paracelsus widely used magnets to treat inflammation, seizures, and bleeding. It can be assumed that he was the first one who began to use systematically different poles of a magnet as a cure; even now a wide range of magnetic products is offered throughout the world, including belts, insoles, and bracelets. Like in ancient times, such accessories are made of ferromagnets, i.e. objects that have their own magnetic field (magnetism). The efficacy of such products tends to a minimum as human tissues have a very low susceptibility to a static magnetic field. Thus, there is no scientific evidence to recommend its use for the treatment of any diseases.

A different effect is observed when a flow of current is passed through a ferromagnet with high magnetic permeability. In this case, a magnetic field is created with the lines of flux surrounding the trajectory of the moving charge [1]. Therefore, the magnetic field is a special matter that helps moving charges to connect and interact [2]. The magnetic flux direction depends on the current direction. When using direct current, a constant magnetic field (CMF, a field with constant direction, i.e. it does not change its magnitude or direction over time) is generated; when using alternating current, an alternating magnetic field (AMF, a field with variable direction, i.e. it changes its magnitude and direction over time) is generated and its frequency is determined by the frequency of the current supplying it. Pulsating magnetic field generated by passing a pulsating current changes its magnitude over time, but it has a constant direction. In clinical practice, all three types of magnetic fields (constant, alternating, and pulsating [either continuous or intermittent]) are used in therapy and prevention. In this case, an intermittent magnetic field is a concept identical to a pulsed magnetic field (PMF)—when a magnetic pulse (stimulus) with a certain peak power stimulates an object—while the PMF can have a different shape (sinusoidal, rectangular, exponential, etc.) [2].

In Russian physiotherapeutic practice, all types of magnetic fields are traditionally used. What are their differences? Any magnetic field causes physical and chemical molecular shifts in tissues, with a constant field inducing current in moving liquid media (e.g. blood flowing through blood vessels); whereas an alternating and pulsed fields primarily affect resting biological objects, leading to a change in the electrical charges in and around membranes [1, 3]. However, the intensity of biological effect increases from CMF to AMF and PMF. Alternating and pulsed magnetic fields usually promote more persistent and pronounced changes, stimulate, and enhance metabolism in tissues.

In general, magnetotherapy has a very impressive evidence base for use in a wide range of musculoskeletal and neurological diseases in both Russian and international practice. This is confirmed by the steadily growing interest of researchers and the increased number of publications in literature, which can be analyzed by the statistics in the international citation database PubMed: since 1966, when the first article was published, their number has increased by 2,000 times.

However, traditionally it has been the case that when referring a patient for magnetotherapy, the doctor means exposure to a low-frequency alternating magnetic field. Meanwhile, it is required to distinguish between the capabilities and indications for different methods. Alternating magnetotherapy has a gentle effect, a moderate analgesic effect, trophic and decongestion effects [4]. Low-frequency AMF is used for coronary heart disease, vascular diseases, inflammatory diseases of internal organs, bone fractures, skin diseases, and ENT organs [5, 6]. When exposed to an alternating magnetic field, most patients do not experience any sensations as the skin receptors are not irritated and the field does not generate much endogenous heat.

Among other magnetic field-based methods, pulsed magnetotherapy or magnetic stimulation (MS) has the most pronounced biological effects. Researchers' interest in the effects of MS has been actively developing since the mid-20th century. In 1965, at a medical electronics and biologic engineering conference in Tokyo, Bickford et al. presented their data on the stimulation of a peripheral nerve and subsequent muscle contraction in animals and humans using a high-frequency pulsed magnetic field, proving that the magnetic field primarily stimulates nervous tissues [7]. The experiment was subsequently reproduced many times using an electromyograph allowing to record muscle response to nerve stimulation and to identify the special mechanism of action of peripheral MS [8, 9].

The magnetic stimulus causes indirect secondary depolarization of the nerve membrane due to the resulting potential difference, activates the motor end plate, and promotes muscle contraction. In this case, nerve fibers (axons) are activated first and followed by cells (neurons). In the premises, MS stimulates nervous and muscle tissues, which is widely used in clinical practice for the rehabilitation in movement disorders associated with limb paresis, post-traumatic and post-operative decrease in functional muscle strength [9, 10]. The effect of MP on the neuromuscular system is manifested in increased muscular performance, including conditions of local and general fatigue. An intense pulsed magnetic field inducing eddy currents in tissues at a depth of 4–6 cm causes selective contraction of both skeletal and smooth muscles and internal organs.

In general, pulsed magnetotherapy is a non-pharmaceutical therapy most popular in neuro- and orthopedic rehabilitation. The reason is definitely the pronounced analgesic

effect associated with a dual mechanism of action [11]. First, MS has a vasoactive and anti-inflammatory effect due to the improved rheological blood properties and microcirculation and the inhibition of pro-inflammatory enzymes and peptides, mostly manifested at exposure of less than 0.8 T. Second, magnetic pulses suppress the sensory pain signal traveling to the posterior horns of the spinal cord via Aδ- and C-fibers, preventing the central sensitization and activating the pain gate control system. Thus, the analgesic effect is presented in various pain syndromes associated with inflammation (spondyloarthritis, articular syndrome, myositis, acute and chronic back pain, and cervicocranialgia) and damage to nerve fibers with a neuropathic component (painful polyneuropathy, plexopathy, tunnel syndromes, complex regional pain syndrome, and chronic pelvic pain) [10–14].

It is interesting that even in cases of central pain syndrome (fibromyalgia, central post-stroke pain, and phantom limb pain), peripheral MS has a therapeutic effect. Some studies of cortical structure response to peripheral stimulation showed that MS promotes the enhanced neuroplasticity, cerebral blood flow, increased intracortical integration, and improved excitability in the cerebral cortex [10, 15, 16].

Today, the efficacy of magnetic stimulation has been studied and demonstrated in multiple clinical studies, including those of a very high methodological quality, i.e. randomized, double-blinded, and placebo-controlled studies. In particular, it has been shown that the efficacy (pain relief) of pulsed magnetotherapy is comparable with transcutaneous electrical stimulation (TES) after a course of treatment, but significantly surpasses TES and placebo in the long term (at 1 and 3 months) in patients with acute and chronic back pain localized in the cervical and lumbosacral spine [17]. MS is distinguished by its trace effect; after a single exposure, the body or individual system reactions persist for 1–6 days and for 30–45 days after a course of treatment. Thus, noticeable physiological and therapeutic effects of the magnetic field are observed after multiple exposure, but the resulting effect lasts for several months, thus distinguishing this method from electrotherapy.

The studies of peripheral magnetic stimulation in chronic pelvic pain (CPP) syndrome are promising. Kim et al. highlight a significant reduction of prostatic CPP with perineal MS in patients with a history of three months of ineffective pharmacotherapy [18]. Patients with painful bladder syndrome and pudendal neuralgia showed similar outcomes when exposed to pulsed magnetotherapy in the region of sacral nerve roots [19, 20]. It is noteworthy that MS works both for CPP and urination disorders, including overactive bladder syndrome, where the most effective frequency is 5 Hz [21]. Clinical practice and research significantly expand the therapeutic niches of magnetic stimulation in urology and gynecology, expanding the scope of management options for complex cases resistant to basic pharmacotherapy [22–25].

One can say that magnetic stimulation with its diverse effect on the body can replace some other physical therapies. It is important to consider the technical aspects. The peripheral MS device must have a high output power (3–4 T) to ensure peak stimulus intensity, which, however, should be flexibly and manually adjusted for personalized selection of parameters. It should be noted that, unlike alternating magnetotherapy, the patient hears MS exposure well as a clicking sound (a click means a stimulus) and feels it as a distinct muscle contraction or a comfortable vibration depending on the frequency. Thus, frequency is the second important parameter that should be individually selected for the patient and adjusted, if necessary. In physiotherapeutic practice, it is believed that responses are particularly pronounced at the pulsed magnetic field frequency of up to 20 Hz, with lower frequencies having a greater stimulating effect; whereas higher frequencies have an analgesic and microcirculatory effect. Due to the wide range of indications for MS and its proven efficacy, it is convenient both to create personalized stimulation programs and use default protocols of the device based on data from published studies to improve the operator's work and therapeutic effect.

In addition, the magnetic stimulation method has the following main biophysical benefits [23]:

MS freely penetrates all tissues without pulse attenuation and significant loss of electric field strength induced by the magnetic inductor, comfortably stimulating the region surrounded by bone tissue and deep structures (spinal cord roots, brachial plexus, sciatic and femoral nerves, etc.) without pain, unlike, for example, electrical stimulation;

MS does not require special preparation of the skin or full physical contact with it, i.e. the effect is achieved even at a distance of several tens of millimeters of the stimulated surface from the inductor, which is extremely important if the integrity of the skin is violated;

During the MS session, there is no need to remove clothing thus ensuring comfort and compliance when stimulating the genital area (e.g. the pelvic floor and perineum).

Magnetotherapy is one of the most gentle and comfortable stimulation methods; it is easily tolerated, does not promote any unpleasant subjective sensations and general reactions, and combines well with some other physical factors. All of these things allow for the wide use of magnetotherapy in patients of various ages, from children (from 1.5 years) to the elderly population with a wide range of indications, including severe comorbidities as MS has a few contraindications, including metal implants made of ferromagnets or electronic devices used to control the physiological functions of the body in close proximity to the inductor.

As the MS has a proven efficacy and good tolerability, the peripheral magnetic stimulation has broad prospects for use in pediatric practice, which can be illustrated by the following clinical report.

CLINICAL REPORT

Patient V., 14 years of age. The patient reported a several-year history of back pain, which had recently been getting

worse (the average pain level is 50–60 mm with occasional worsening to 80 mm on the Visual Analog Scale [VAS]). The patient had nagging and squeezing pain localized paravertebrally along the spine in the thoracic and lumbar regions. The pain significantly limited the patient's daily activity and intensified in a sitting position and when walking a distance of more than 800–1,000 m.

The examination revealed a severe postural abnormality, thoracic and lumbar kyphoscoliosis (see Fig. 1). Palpation reveals tension and pain in the paravertebral muscles, more pronounced on the left side.

The family history is significant due to the mother's dysplastic scoliosis; she had a transpedicular spine fixation system installed at the age of 17.

A general spine X-ray shows a deformation of the thoracic and lumbar spine (S-shaped kyphoscoliosis with torsion of the vertebrae).

Diagnosis: Postural abnormality. Grade 3 dysplastic kyphoscoliosis of the thoracic and lumbar spine. Vertebrogenic pain syndrome. Myotonic syndrome.

The patient had several courses of rehabilitation, including therapeutic exercises, physiotherapy (alternating magnetotherapy, low-intensity laser therapy). He noted that the pain interfered with physical exercise and physiotherapy reduced the pain. However, the effect was unstable, regressing at 1–2 weeks post-rehabilitation. The patient was referred to the National Medical Research Center for Traumatology and Orthopedics, where a reconstructive and stabilizing operation was recommended.

Given the severe pain syndrome, impaired support ability, and reactive muscle spasm, during the preoperative preparation (the operation was scheduled in 3–4 months), the patient was prescribed peripheral paravertebral magnetic stimulation on both sides of the thoracic and lumbar spine (10 Hz, 5 s pulse, 3 s pause; total session duration: 20 min; 4 points of action) in a course of 10 sessions every other day.

During the follow-up period, the patient noted that the pain reduced at the 3rd session, the average VAS score was 20-30 mm after the course of treatment with the highest severity of no more than 40 mm, and long pain-free intervals. The patient reported that after the course of treatment he could sit for a long time ("I was able to sit through a movie with friends for 2 hours for the first time ever"). When assessed at 1 and 2 months after the peripheral MS course, a trace effect and a long-term effect were maintained, the VAS score for pain was 30–40 mm.

Fig. 1. The patient's appearance from behind during examination.

CONCLUSION

Magnetic stimulation (MS) is a type of magnetotherapy involving exposure to a pulsed magnetic field with the highest biological effect. MS stimulates nervous and muscle tissues and has analgesic, trophic, and decongestion effects. It is required to differentiate between various magnetotherapy modes and select a specific technique based on the clinical case. MS is the physiotherapeutic method of choice in neuro- and orthopedic practice for diseases of the joints and spine associated with inflammation and muscle spasm, damage to nerve fibers with pain syndrome, chronic pelvic pain, and urination disorders. As the MS has a proven efficacy and good tolerability, the peripheral MS has broad prospects for use in pediatric practice, which can be illustrated by the presented clinical report.

ADDITIONAL INFORMATION

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. M.Yu. Gerasimenko — article supervision and editing; I.V. Borodulina — collection and processing of material, writing the text; O.V. Kotova — collection and processing of material, editing the text of the article; S.V. Pavlova — collection of material; A.A. Ipatov — collection of material.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Источник финансирования. Исследование проведено на личные средства авторского коллектива.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с проведённым исследованием и публикацией настоящей статьи.

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