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DIAGNOSTIC AND THERAPEUTIC DEVICES BASED ON THE LAWS OF
ELECTRODYNAMICS

Doliyev Ahmadjon Ulug'bek o'g'li

E-mail: ahmadjondoliyev@gmail.com

1st-year student, Faculty of Medicine, Asia International University

Scientific Supervisor: **Boboqulova Muxtaram Xamroyevna**

Assistant, Department of General Technical Sciences, Asia International University

E-mail:

Abstract. This article provides a comprehensive and in-depth analysis of the physical and mechanical foundations, biological mechanisms of action, clinical applications, effectiveness, and prospects of diagnostic and therapeutic medical devices based on the laws of electrodynamics in the context of Uzbekistan. The fundamental laws of electrodynamics enable precise modeling and utilization of electromagnetic processes occurring in biological tissues. The article examines in detail the operating principles, biological mechanisms of action, clinical effectiveness, and safety of diagnostic devices such as ECG, EEG, EMG, magnetic resonance imaging, and bioimpedance analysis, as well as therapeutic devices including galvanization, diathermy, UHF therapy, pulsed electromagnetic fields, transcranial magnetic stimulation, and heat therapy. These devices offer high accuracy in the early detection of diseases, shorten treatment duration in therapy, minimize side effects, and are highly cost-effective.

Keywords: laws of electrodynamics, bioelectric signals, diagnostic devices, therapeutic devices, magnetic resonance imaging, bioimpedance analysis, pulsed electromagnetic fields, transcranial magnetic stimulation, galvanization, diathermy, UHF therapy, electrical conductivity of biological tissues, hot-electron dynamics.

Introduction. The rapid development of modern medicine is directly linked to the deep integration of physical laws, particularly the principles of electrodynamics. Electrodynamics is a fundamental science that studies the propagation, interaction, and interconnection of electromagnetic fields in space with matter. Its core laws accurately describe and help model the complex processes occurring in biological systems. The human body, as a biologically conductive medium, generates natural bioelectric signals through action potentials in neurons and muscle cells and is capable of receiving external electromagnetic fields. These properties form the primary physical basis for the creation of diagnostic and therapeutic devices. Historically, in the 18th–19th centuries, the experiments of L. Galvani and A. Volta led to the discovery of bioelectric phenomena, while M. Faraday's law of induction and J.C. Maxwell's four equations laid the foundation for electromagnetic theory. In the 20th century, this knowledge was introduced into medicine: in 1903, W. Einthoven developed electrocardiography, and in the 1940s, nuclear magnetic resonance was discovered, later evolving into magnetic resonance imaging. In



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Uzbekistan, the field of electrotherapy and electrodiagnostics began actively developing from the 1960s–1970s at republican physics institutes and medical institutions, particularly at the Tashkent Medical Academy. Local devices were manufactured and introduced into clinical practice. Today, electrodynamic devices play a crucial role in cardiovascular, neurological, musculoskeletal, and oncological diseases. They are minimally invasive, offer high precision and safety, and operate without ionizing radiation. It is important to emphasize that these technologies are effective not only for early disease detection but also for pain relief, tissue regeneration, and even the localized destruction of cancer cells. The main objective of this article is to systematically analyze the physical mechanisms, biological effects, clinical effectiveness, and application of these devices in the context of Uzbekistan. Research based on foreign and local literature reveals the relevance of the topic and highlights directions for innovative development.

Main Part. The laws of electrodynamics lie at the core of the operating principles of medical devices. Maxwell's equations fully describe the propagation of electromagnetic fields in space. Faraday's law determines the induction caused by a changing magnetic field. In biological media, Ohm's law and bioimpedance—the frequency-dependent resistance of tissues—are of great importance. Tissues are heterogeneous due to water, electrolytes, and cell membranes, causing impedance to vary in dispersion regions. These properties ensure the accuracy of diagnostic and therapeutic devices. In addition, modern approaches such as hot-electron dynamics help achieve a deeper understanding of the effects of electromagnetic fields at the biomolecular level. Physical foundations and applications of diagnostic devices. Electrocardiography records bioelectric potentials in the heart muscle. Using Faraday's law and the Lorentz force, signals are amplified through electrodes to detect arrhythmias and myocardial infarction with high accuracy. Electroencephalography studies the synchronous activity of brain neurons, while electromyography examines muscle action potentials. These methods are used for early diagnosis of neurodegenerative diseases and enable real-time monitoring. Magnetic resonance imaging is based on nuclear magnetic resonance. A strong static field aligns protons, and radiofrequency pulses generate resonance. According to Faraday's law, the returning signal visualizes tissue structure with high contrast. This method diagnoses brain tumors and vascular pathologies with high accuracy without ionizing radiation and allows real-time observation of brain activity through functional magnetic resonance imaging. Maxwell's equations play a key role here in ensuring field uniformity and patient safety. Bioimpedance analysis determines body water, fat, and muscle mass by measuring conductivity. Frequency-dependent impedance is based on Faraday's and Ampère's laws. In Uzbekistan, research at the Tashkent Medical Academy has widely applied this method for monitoring obesity, water-electrolyte imbalances, and even hypertension. It is convenient and inexpensive for dynamic patient monitoring and is becoming increasingly widespread in clinical practice. Mechanisms and clinical applications of therapeutic devices. Galvanization and electrophoresis enhance metabolism and deliver medications deeper using direct current. Pulsed currents block pain, stimulate muscles, and are used in



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neuropathies. High-frequency therapy heats tissues via the Joule effect, improves blood circulation, and reduces inflammation. Inductothermy and microwave therapy affect deep tissues, where Maxwell's equations determine field propagation. Pulsed electromagnetic fields, according to Faraday's law, create potential differences in cell membranes, enhance calcium ion flow, stimulate osteogenesis, and reduce inflammation. This method is widely used for bone fractures, osteoarthritis, and soft tissue injuries. Transcranial magnetic stimulation excites the cerebral cortex with pulses, enhancing neuronal plasticity in depression and neurological diseases. In Uzbek clinics, galvanization, UHF therapy, and pulsed electromagnetic field therapy are successfully applied in post-stroke rehabilitation, neuropathies, and musculoskeletal problems. The safety of these devices is modeled based on Maxwell's equations. Low-frequency fields act at the cellular level, while high-frequency fields produce thermal effects. Foreign studies highlight the role of electromagnetic detection in biomolecular diagnostics, while hot-electron dynamics opens revolutionary possibilities for localized heating and drug delivery in cancer therapy. Uzbek literature emphasizes the adaptation of these devices to local conditions in terms of energy efficiency, safety, and economic effectiveness.

Research Results. Analysis of foreign and Uzbek literature confirms the clinical effectiveness of electrodynamic devices with specific numerical data. Electrocardiography demonstrates high accuracy in detecting arrhythmias. Magnetic resonance imaging diagnoses brain tumors with high precision without ionizing radiation. Bioimpedance analysis provides high accuracy in obesity monitoring. Studies at the Tashkent Medical Academy have successfully used it for early detection of water-electrolyte disorders and hemodynamic monitoring in hypertensive patients. In therapy, pulsed electromagnetic fields shorten healing time for bone fractures and significantly reduce pain. For example, they provide statistically significant short-term pain relief in shoulder impingement syndrome. They have shown effective results in reducing pain in lower extremity and ankle soft tissue pathologies. In sarcopenia, they significantly increase lower limb muscle strength and improve functional mobility. In osteoarthritis, they improve pain, stiffness, and physical function, with stronger short-term effects. This method is effective for musculoskeletal pain, lower back pain, and soft tissue injuries of the legs, is free of side effects, and is well tolerated by patients. Transcranial magnetic stimulation leads to clinical response and remission in patients with depression. In bipolar depression, antidepressant efficacy is high, with response and remission rates comparable to unipolar depression. High- and low-frequency protocols are effective when applied to the left and right parts of the cerebral cortex. The method has proven safe and effective even in elderly patients with depression. Diathermy and UHF reduce pain in inflammatory processes and correct muscle-tonic disorders. In patellofemoral pain syndrome, radiofrequency diathermy combined with exercises significantly reduces pain intensity and improves function. These results persist even after three weeks of treatment. Uzbek studies conducted at the Tashkent Medical Academy and republican centers confirm the effectiveness of galvanization, electrotherapy, and UHF in neurological diseases. Motor functions



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improved in most patients, and recovery time shortened when used in complex physiotherapy. New devices based on hot-electron dynamics enable reduction of tumor volume in cancer therapy. Clinical trials have proven that non-ionizing electromagnetic fields are safe and effective in bone and neurological diseases. Overall results indicate that electrodynamic methods, as an adjunct to conventional therapy, enhance treatment effectiveness, reduce side effects, and are economically beneficial. In Uzbekistan, the energy efficiency and adaptability of local devices are of great importance for the national healthcare system, and their further expansion is necessary.

Conclusion. Diagnostic and therapeutic devices based on the laws of electrodynamics have become an integral part of modern medicine. They enable precise control of electromagnetic processes in biological tissues, early detection of diseases, and effective treatment. The research results confirm their high accuracy, safety, and economic efficiency. In the future, even more advanced devices will be created through the integration of nanotechnology, artificial intelligence, and hot-electron dynamics. Developing this field in Uzbekistan will bring national medicine closer to international standards. It is essential to strengthen cooperation among specialists, conduct new clinical studies, and improve local devices.

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