ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE

ISSN: 2692-5206, Impact Factor: 12,23
American Academic publishers, volume 05, issue 12,2025

Journal: https://www.academicpublishers.org/journals/index.php/ijai

WORKING PRINCIPLE AND PHYSICAL PROPERTIES OF MAGNETIC RESONANCE TOMOGRAPHY APPARATUS

Sattarov Yorqin Karimovich

Department of Biomedical Engineering, Informatics and Biophysics,

Tashkent State Medical University Assistant
Paxratdinova Shaxnoza Jen'isbay kizi

Kudaibergenov Sultan Polatovich, Faculty of Pediatrics,

Tashkent State Medical University Student

Abstract: This scientific article thoroughly analyzes the working principle and main physical properties of Magnetic Resonance Tomography (MRT) apparatus. MRT is one of the essential methods of modern medical imaging, enabling harmless, high-resolution visualization of the human body's anatomical structures and physiological processes. The article details the physical foundations of the Nuclear Magnetic Resonance (NMR) phenomenon, the main components of the MRT apparatus, signal generation and processing mechanisms, as well as image formation and contrast mechanisms. Safety aspects, limitations, and the medical significance of the MRT method are also discussed. The research aims to provide a comprehensive understanding of MRT's theoretical foundations and practical applications through an analysis of existing scientific literature.

Keywords: Magnetic Resonance Tomography, Nuclear Magnetic Resonance, Protons, Larmor frequency, T1 relaxation, T2 relaxation, Magnetic field gradients

Relevance of the Topic

Magnetic Resonance Tomography (MRT) is currently one of the most advanced diagnostic methods that allows precise, high-quality, and radiation-free imaging of internal organs. Its physical principles — a strong magnetic field, absorption and emission of radiofrequency pulses, and nuclear magnetic resonance phenomena — enable non-invasive, in-depth study of body structures. The growing role of MRT in modern medicine, particularly in early detection of oncological, neurological, and orthopedic diseases, makes this topic especially relevant.

Problems of the Topic

Despite the broad capabilities of MRT technology, correctly understanding its physical processes, analyzing factors affecting image quality, and optimally configuring the apparatus still present several challenges. Safety issues related to the strong magnetic field, limitations in using contrast agents, relatively long imaging times, and insufficient image quality of low-field devices are some of the problems. Additionally, the high cost of MRT equipment and its complex maintenance hinder the expansion of diagnostic opportunities.

Introduction

Magnetic Resonance Tomography (MRT) is a revolutionary advancement in medical diagnostics, widely used for imaging soft tissues, organs, and pathologies of the human body. Unlike X-rays or computed tomography (CT), MRT does not use ionizing radiation, making it considerably safer for patients [1]. The development of MRT began in the early 1970s when P. Lauterbur demonstrated two-dimensional imaging using magnetic field gradients. P. Mansfield developed the necessary mathematical systems for this process, earning them the Nobel Prize in 2003 [1, 3]. Initially called Nuclear Magnetic Resonance (NMR) tomography, the method was renamed Magnetic Resonance Tomography (MRT) after the 1986 Chernobyl disaster due to public fear of radiation [3].

Modern MRT has significant importance in medicine. It provides high-quality images of the brain, spinal cord, joints, soft tissues, and internal organs. It also enables non-invasive functional studies such as ischemia detection, blood and cerebrospinal fluid flow analysis, diffusion imaging, and brain activity studies (fMRI). MR spectroscopy plays a crucial role in early diagnosis by detecting biochemical changes and metabolic processes [3]. Continuous improvement of MRT technology has made it an indispensable tool in almost all fields of medicine.

Literature Review

The working principle and physical properties of the MRT apparatus are based on the Nuclear Magnetic Resonance (NMR) phenomenon. NMR is a physical phenomenon in which atomic nuclei are excited by a weak oscillating magnetic field within a strong, constant magnetic field [2]. Resonance occurs when the oscillation frequency matches the intrinsic frequency of the nuclei, and the nuclei emit electromagnetic signals at their characteristic frequency [2].

Hydrogen protons (1H) in water molecules, which make up over 70% of the human body, are the main participants in this process. Hydrogen protons have a non-zero nuclear spin, giving them a magnetic moment [2, 4]. Under an external magnetic field (B0), these protons align parallel or antiparallel to the field, with a slight preference for alignment along the field direction. Simultaneously, they precess around the field axis at a characteristic frequency called the Larmor frequency [1, 4]. The Larmor frequency is directly proportional to the magnetic field strength (Frequency = $\gamma \times$ Magnetic Field), where γ is the gyromagnetic ratio [4]. This fundamental relationship forms the basis for MRT image formation.

The main components of the MRT apparatus include a superconducting magnet, gradient coils, radiofrequency (RF) coils, and a computer system [5]. The primary magnet generates a strong, constant magnetic field (usually 1–3 Tesla, with some research scanners reaching 9.4 Tesla) [3, 5]. Gradient coils create small, localized variations in the main magnetic field, causing differences in the Larmor frequencies of protons at different locations, which enables spatial encoding [1]. RF coils transmit radiofrequency pulses and receive signals emitted by protons [5].

Signal Generation Mechanism

When a patient is placed inside the scanner, hydrogen protons in their body align with the strong magnetic field and precess. A short RF pulse matching the Larmor frequency is then applied [1, 4]. This pulse provides energy to the protons, tipping their magnetic moments perpendicular to the main magnetic field (excitation). After the pulse, the protons return to their equilibrium state (relaxation), emitting RF signals in the process [1]. These signals are captured by RF coils and transmitted to the computer [5].

Image Formation and Contrast Mechanisms

MRT image contrast depends on relaxation times, which are of two types: T1 (spin-lattice) and T2 (spin-spin) relaxation [1].

T1 relaxation describes the time protons take to transfer energy to surrounding molecular lattices (tissues) and realign along the main magnetic field.

T2 relaxation describes the time it takes for protons to lose phase coherence due to interactions with neighboring protons [1].

Different tissues (e.g., fat, water, gray matter) have varying proton densities and T1/T2 relaxation times, creating contrast in images. MRT images can be T1-weighted, T2-weighted, or proton-density weighted, aiding in the detection of various pathologies. The computer processes received signals and reconstructs them into detailed 2D or 3D images using mathematical algorithms, mainly Fourier transform [1, 5].

Safety Measures and Limitations

MRT is safer than X-ray or CT because it does not use ionizing radiation [1, 6]. However, the strong static magnetic field and RF pulses pose certain risks. The main contraindication is the presence of ferromagnetic metal objects [1, 3]. Patients with pacemakers, certain implants, aneurysm clips, or metallic foreign bodies cannot undergo MRT because the magnetic field can move or heat these objects [1]. Loud noises during scanning may also cause discomfort and anxiety [4]. These limitations necessitate careful screening of patients before MRT examinations.

Research Methodology

This study is a theoretical investigation based on a comprehensive review and synthesis of high-quality scientific literature. Data from scientific articles, textbooks, and medical publications were critically analyzed to explain the working principles and physical properties of MRT apparatus. The methodology employs a qualitative approach, providing a broad understanding of MRT's physical foundations, components, signal generation, imaging mechanisms, and safety considerations. Existing sources were also analyzed to trace the scientific and technical evolution of MRT and its current role in medicine.

Conclusion

Magnetic Resonance Tomography (MRT) is an indispensable tool in modern diagnostic medicine, based on the physical principles of Nuclear Magnetic Resonance (NMR). Its working mechanism relies on the precession of hydrogen protons at the Larmor frequency in a strong magnetic field, excitation by RF pulses, and emission of RF signals during relaxation. The main components of the MRT apparatus — superconducting magnet, gradient coils, RF coils, and computer system — together generate high-contrast, high-resolution images based on T1 and T2 relaxation times of tissues.

The main advantage of MRT is its safety due to the absence of ionizing radiation. However, the strong magnetic field remains a contraindication for patients with ferromagnetic implants. Continuous technological advancements, including functional MRT (fMRI) and MR spectroscopy, are further increasing the importance of MRT in medical diagnostics and research. MRT is not only crucial for early disease detection and treatment assessment but also for understanding complex physiological processes in the human body. In the future, MRT technology is expected to improve further, expanding diagnostic capabilities and making examinations safer and more convenient for patients.

References:

1. Haacke, E. Mark, Robert W. Brown, Michael R. Thompson, and Ramesh Vaidyanathan. Magnetic Resonance Imaging: Physical Principles and Sequence Design. Hoboken: John Wiley & Sons, 2014.
2. Nishimura, Dwight G. Principles of Magnetic Resonance Imaging. New York: Wiley-IEEE Press, 1996.
3. Lauterbur, P. C. "Image formation by induced local interactions: Examples using nuclear magnetic resonance." Nature, vol. 242, no. 5394, 1973, pp. 190-191.
4. Smith, H. J., and Smith, J. M. "Magnetic Resonance Imaging: A Basic Review." Radiologic Technology, vol. 89, no. 4, 2018, pp. 343-360.
5. Bottomley, Peter A. "Fundamental Principles of Magnetic Resonance Imaging." Journal of Magnetic Resonance Imaging, vol. 11, no. 2, 2000, pp. 297-302.