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THE HISTORY OF THE CREATION OF MAGNETIC RESONANCE IMAGING AND THE ORDER OF GROWTH OF THE USEFUL WORK COEFFICIENT

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ABSTRACT

In this article, before studying magnetic resonance tomography, the motivations that led to its invention were first of all discussed, and scientists who were able to obtain a sufficient useful work coefficient are discussed. Simultaneously, the study of its working mechanism was also considered relevant.

АННОТАЦИЯ

В этой статье, прежде чем заняться магнитно-резонансной томографией, в первую очередь обсуждаются мотивы, приведшие к ее изобретению, и обсуждаются ученые, которым удалось получить достаточный коэффициент полезной работы. Одновременно с этим было признано актуальным изучение механизма его работы.

ANNOTATSIYA

Ushbu maqolada magnit-rezonans tomografiyani o'rganishdan oldin, birinchi navbatda, bu ixtiroga sabab bo’lgan olimlar haqida so’z borgan va bu davr mobaynida foydali ish koeffitsientini yetarli darajada ortib borish suratlari miqyosida tushuntirilgan. Shu bilan birga, uning ishlash mexanizmini o'rganish ham dolzarb deb topildi.

Key words

magnetic resonance phenomena, radio frequency, magnetic field, transmitter, frequency, interference, diffraction, polarization, dispersion, reflaction and retraction, wave and particle property, photon, velosity, energy, light pressure, photoelectric effect, momentum, wavelength.

Ключевые слова

явления магнитного резонанса, радиочастота, магнитное поле, передатчик, частота, интерференция, дифракция, поляризация, дисперсия, отражение и втягивание, свойства волны и частицы, фотон, скорость, энергия, световое давление, фотоэффект, импульс, длина волны.

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magnit-rezonans hodisalari, radiochastota, magnit maydon, uzatuvchi, chastota, interferensiya, difraksiya, qutblanish, dispersiya, refleksiya va chekinish, toʻlqin va zarracha xossalari, foton, tezlik, energiya, yorugʻlik bosimi, fotoeffekt, impuls, toʻlqin uzunligi.

INTRODUCTION

MRIs use powerful magnets that create a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is passed through the patient, the protons are excited and thrown out of balance, compressing against the gravitational force of the magnetic field. When the radiofrequency field is turned off, MRI sensors can detect the energy released when protons align with the magnetic field. The time required for protons to align with the magnetic field, as well as the amount of energy released, varies depending on the environment and the chemical nature of the molecules. Based on these magnetic properties, doctors can distinguish between different types of tissue.

LITERATURE ANALYSIS AND METHODOLOGY

Magnetic Resonance Imaging, or **MRI**, is a method of imaging the interior of structures noninvasively. An MRI device consists of a magnet, magnetic gradient coils, an RF (radio frequency) transmitter and receiver, and a computer that controls the acquisition of signals and computes the MR images. The full name, **N**uclear **M**agnetic **R**esonance **I**maging, usually shortened to MRI, describes the technique. If an atomic **N**ucleus is exposed to a static **M**agnetic field, it **R**esonates when a varying electromagnetic field is applied at the proper frequency. An Image is computed from the resonance signals of which the frequency and phase (timing) contain space information. MRI is important because it is noninvasive, safe, and yields information that cannot be obtained with any other techniques. Its most common use by far is in diagnostic medicine but MRI has other applications, particularly in the oil and food industries.

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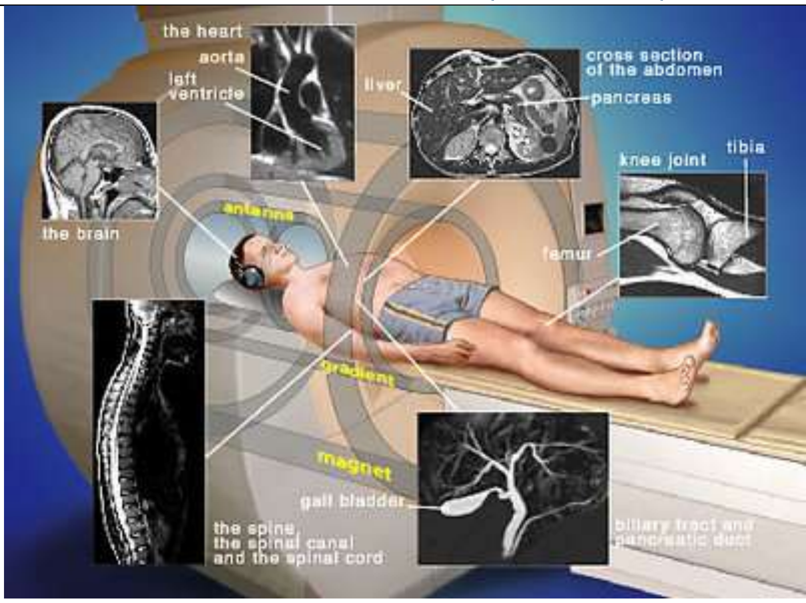

Figure 1. Diagram of an MRI system.

The nuclei of many kinds of atoms, commonly hydrogen, are tiny magnets. In the earth's magnetic field they line up to some extent just as you walk around. When you walk past a piece of iron they'll flop around in different directions. Think of us as having microscopic compass needles precessing (spinning on their axes like gyroscopes) in an orderly direction. To make an MR image, this tendency of the nuclei to line up in the direction of a magnetic field can be manipulated and measured. Since the nuclei from different regions of the body can be made to precess at different frequencies (their magneto-resonance frequencies), the electromagnetic energy at these frequencies yields signals that are location dependent. Computer images can be calculated, enhanced, and displayed. MRI is safe because only a very tiny amount of energy is absorbed or emitted, corresponding to the amount of energy in radio waves, to which we are constantly exposed. MRI does not affect any chemical processes. It doesn't change molecules at all. The atomic nuclei within the molecules just report what is happening.

In the presence of a static magnetic field (B), the atomic nuclei possess energy which differs depending on their orientation (ΔE). ΔE determines the strength of the signal and is related to the resonance frequencies (ν), by Planck's constant (h).

$$\Delta E = h\nu \qquad (1)$$

The size of ΔE and ν depend on the size of the static magnetic field, ($B0$), and the magnetogyric ratio, (γ), a characteristic of each kind of atomic nucleus, as shown in equation 2. This is the Larmor (Joseph Larmor) relationship. The Larmor equation (2) is fundamental to all of nuclear magnetic resonance (NMR) and its subfield, MRI.

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$\nu=(\gamma 2\pi)B$ (2)

Together these two equations determine that

$\Delta E=h\nu=h\gamma 2\pi B$ (3)

I.I.Rabi (Nobel Prize in Physics, 1944) demonstrated the phenomenon of nuclear magnetic resonance in 1937, and Felix Bloch and Edwards Mills Purcell, working independently and within one month of each other (December 1945 and January 1946), demonstrated the use of radio waves to detect nuclear magnetic resonance signals, for which they jointly received the Nobel Prize for Physics in 1952. With their discovery, nuclear magnetic spectroscopy was born, without which chemistry would not be modern chemistry and without which MRI could never have been invented.

In the static magnetic field, B, the nuclei are primed for a response to a transient magnetic field $B1$ at their resonance frequency, ν, which changes their energy status. When the transient field is switched off, the nuclei emit radio waves as they return to their steady state condition. These reradiated signals yield NMR spectra or MR images. Many different atomic nuclei (those that possess a net nuclear spin) are susceptible to NMR, and a few produce signals that are strong enough for diagnostic MRI. The nucleus of the hydrogen atom (a single proton) has the largest magnetogyric ratio and, according to equation 3, has the highest energy and therefore the largest signal at any given field strength. Hydrogen is abundant as an element of water. The human body is about two thirds water, so the combination of natural abundance and signal strength determines that imaging with the hydrogen nucleus gives the highest possible resolution. Nearly all clinical MRI is proton or hydrogen MRI. Other nuclei such as ^{23}Na and ^{31}P are also used, although until now primarily in research.

For MRI, as opposed to NMR, spatial gradients of magnetic field (G) are also needed. G makes the field experienced by each nucleus dependent upon its location within an object. For example Gx is a linear gradient along the x-axis and produces an extra field, GxX at the point of X. Together Gx, Gy, and Gz determine a unique point (X,Y,Z) in three-dimensional space. Equations 2 and 3 are modified to:

$\nu=\gamma 2\pi(B0+G)$ (4)

$E=h2\pi\gamma(B0+G)$ (5)

where for two-dimensional imaging G is usually Gx and Gy, with Gz added for three-dimensional imaging.

Since the atomic nuclei in different physical positions experience different values of $(B0+G)$ the problem of making an image is now transformed into a problem of interpreting the spectral frequencies.

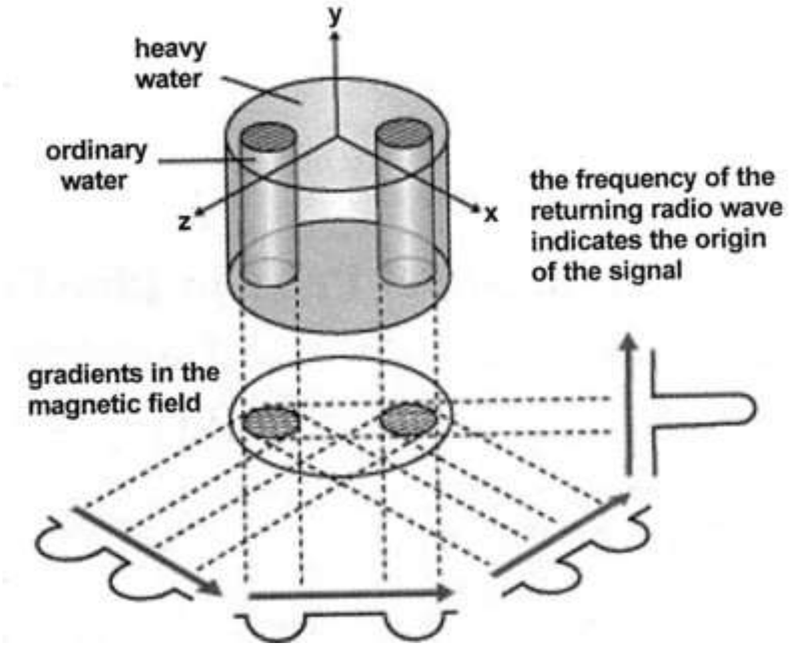

Figure 2: Simple model of MR imaging

Figure 2 models the first MRI study ever done, and serves to illustrate the basic principle. Two capillaries of water are within a cylindrical test tube in the sample holder of an NMR spectrometer. This is not one of the large imaging systems of today, but a machine that will fit nothing larger than 5 mm in diameter. Magnetic field gradients are applied at 45^0 intervals in the XZ-plane. As shown by the arrows, which represent changing magnetic field or signal frequency along each projection, humps of NMR signal appear at spectral frequencies corresponding to the positions of the water protons in the tubes. The physical positions of the nuclei are now encoded as spectral frequency. These are one-dimensional projections, from which a two-dimensional image can be made. Paul Lauterbur and Peter Mensfield shared the Nobel Prize in Physiology or Medicine in 2003 for Lauterbur's discovery of MRI in 1972, and its enhancements by Mansfield. Since that time many complex techniques of encoding position and computing images have been developed to improve quality, speed, resolution and contrast in MRI.

MRI is fundamentally different from all other imaging techniques. Image formation usually requires that the imaged object interact with a radiation field characterized by a wavelength comparable to or smaller than the smallest features to be distinguished, so that the region of interaction may be restricted and a resolved image generated. Light microscopy, electron microscopy, infrared and ultraviolet imaging and your own eyes all work in this way. The wavelengths of magnetic resonance signals approach a kilometer, and the frequencies are in megahertz. By the well-known half wavelength rule, imaging the human body by magnetic resonance is absurd.

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RESULT AND DISCUSSION

Paul Lauterbur, originally called his technique *Magnetic Resonance Zeugmatography* (Greek for 'that which joins') to emphasize that he had found an entirely new way of making images, unknown to physics at the time. It is because of the novel method of coupling the two fields that imaging with the long wavelength and low energy magnetic resonance signals is possible. In principle zeugmatographic techniques can be used with any energy couplings, but it is only recently that they have been used in fields other than MRI or its companion technique, *Electron Spin Resonance Imaging*.

Most magnets are configured as shown in Figure 1, but other configurations, such as *open MRI*, which allow room for MRI guided surgical procedures and may lessen claustrophobia as well as *stand up MRI* are also being tried.

All other things being equal, the resolution of an MR image depends upon the strength of the magnetic field; the higher the field strength, the bigger the signal (Equation 3) and the more imaging resolution obtained. The first MRI systems used permanent magnets that could achieve field strengths up to about half a Tesla (5×10^{-5} Tesla being the strength of the magnetic field of the earth). While MRI can be done with permanent iron-core magnets or with ordinary electromagnets or even, under very special circumstances[5] at the earth's magnetic field , the images obtained are not useful for medical diagnostic purposes. Clinical MRI systems use superconducting electromagnets that achieve field strengths of up to 10 Tesla, typically 1.5 to 3 or 4 Tesla. The use of superconducting magnets may have been the single most significant contribution to making medical MRI possible.

Gradients

Three electromagnets, (back-to-front, side-to-side, and head to toe of the patient) generate known variations of the constant magnetic field (*Gx*,*Gy* and *Gz*), so that according to equation 4 the signals are spatially encoded. The gradients can be mixed freely, so MRI allows completely flexible orientation of images. These *gradient coils* are powered by amplifiers that permit rapid and precise adjustments to their field strength and direction. The power and precision of these adjustments determine the resolution and quality of the image obtained. Stronger gradients allow for higher resolution or faster imaging; gradients systems capable of faster switching can also permit faster imaging. Safety concerns determine the upper limit for strength and speed.

RF system

The varying electromagnetic field (B_1) is introduced into the magnet using an RF transmission system that consists of an RF synthesizer, a power amplifier, and a

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transmitting coil. Although the transmitting coil can also be used to receive the MR signals, better quality images are obtained using a separate receiving coil that fits closely to the part of the body being imaged. These are built for specific imaging purposes, e.g. head coils, spinal coils, body coils, knee coils; each of the images in Figure 1 would be obtained with a separate, specific coil. The more sophisticated receiving coils use multi-element phased arrays that are capable of acquiring multiple channels of data in parallel. *Parallel imaging* uses unique signal acquisition schemes to replace some of the spatial coding provided by the magnetic gradients with the spatial sensitivity of the different coil elements, and yields large improvements in imaging time or resolution.

Image acquisition and computation

For the original MR images, Lauterbur attached a resistor to a wire and another wire to a capacitor, with a vacuum tube in between. Numbers were read and penciled onto a grid, thus creating the image. The first computer used to generate MR images had 14K of memory. It is no small coincidence that progress in MRI has closely tracked progress in computer technology. Image computation algorithms vary widely, and signal acquisition methods evolve for use with specific image processing methods. *K-space*, well known in other types of imaging, quickly became a useful concept in MRI. K-space is a temporary virtual space enclosing the phase and frequency of imaging data, and it functions to simplify their conceptualization. K-space is covariant with actual physical space, so that k and physical spaces are interconvertable with each other. The observed signals can be described in a much simpler way in k-space than in physical space and this simplicity has aided development of many alternative methods of sampling imaging data.

One of the most important attributes of MRI, which distinguishes if from all other human imaging techniques, is the high quality of contrast, especially among soft tissues. In a typical MR image the contrast is provided by the concentration, or density, of the observed nucleus, and the exponential relaxation times of the signals following the transient *B*1 pulse. Different tissues may have different amounts of water and water proton relaxation times, and these may be changed by disease as, for example, shown by Raymond Damadian in the case of some cancers.

Physiological MR imaging

The magnetic resonance behavior of the atomic nucleus is determined by the surrounding magnetic field it experiences, and thus by a large number of different parameters, including blood flow, chemistry, chemical exchange, diffusion and other physiological phenomena. An image that contains information about these parameters provides information on how tissues and organs function, both normally and in disease. Specific MRI techniques have been developed and

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continue to be developed that highlight changes in these phenomena and emphasis different physiological states or differential diagnosis of disease.

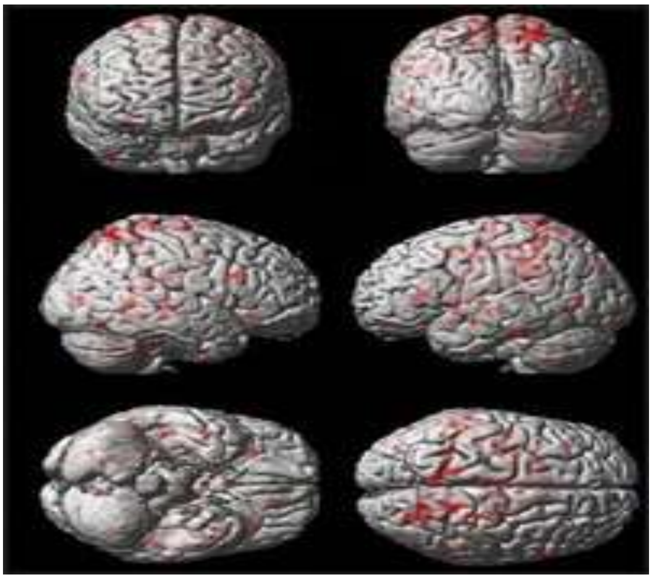

Figure 3. Functional image of a finger moving task

Magnetic resonance angiography

Magnetic resonance angiography is used to generate pictures of arteries in order to evaluate them for potential ruptures or for abnormal narrowing. MR angiographpy was first introduced in the late 1980s, and a number of different specific methods are now used.

Diffusion imaging records the rate and direction of water (or sometimes of metabolites) diffusion within body organs. The technique is useful in observation of strokes, in which the water of edema diffuses particularly freely. A variant, 'diffusion tensor imaging' or 'diffusion tractology' provides spectacular images of tracts of muscle or nerve fiber bundles, because water diffusion is much faster along the length of the fibers than across them. These images are clinically useful in showing interuption of normal fiber anatomy by tumors or trauma.

CONCLUSION

Spectroscopic imaging was first described[9] by Paul Lauterbur in 1975. The technique combines the effect of molecular structure on the magnetic field experienced by an atomic nucleus, *the Chemical Shift*, with the effects the magnetic field gradients used in MRI. Chemical shifts show different chemical entities in a spectrum and are thus the basis of NMR in chemistry. Chemical shifts are combined with MRI to make physical maps of molecules that are important to cellular function.

This *Spectroscopic MRI* or *Chemical Shift MRI* has enormous potential because it allows direct observation of the chemical basis of disease. Spectroscopic MRI is difficult because of formidable sensitivity problems, and has not yet lived up to its

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promise. Metabolically important chemicals are best observed using insensitive atomic nuclei that are present in concentrations only one thousandth or less that of body water. The sensitivity may be improved by the use of 'a priori' techniques (for example, use of a high resolution proton image to constrain the computation of the spectroscopic image); these techniques appears promising.

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