ПРИКАЗИ
ОБЗОРЫ
REVIEWS

APPLICATION OF NUCLEAR MAGNETIC RESONANCE IN MEDICINE AND ITS INFLUENCE ON THE QUALITY OF LIFE AND WORK ENVIRONMENT

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Abstract:

This work describes the application of nuclear magnetic resonance (NMR) in medicine and its influence on the work and life environment. Nuclear magnetic resonance, a powerful research tool, is based on the physical principle that cores of certain atoms (in this case hydrogen) can absorb or emit radiofrequency waves when placed in a magnetic field. This method is used for making high quality section pictures of the inside of the human body; in addition, it shows high sensitivity in revealing cancer, its position and its relation to the surrounding tissue. It is characterised by the use of non-ionizing radiation and a strong magnetic field, and, as explored by now, it does not have harmful effects on the human body.Therefore, it is completely noninvasive, comfortable and safe for patients as well for medical workers.

Key words: *nuclear magnetic resonance, NMR, cancer, non-ionizing radiation.*

Introduction

The phenomenon of nuclear magnetic resonance (NMR) was discovered in 1946 by two independent research groups from Stanford and Harward who detected the NMR signal in condensed matter (Bloch, 1946, pp.127), (Purcell, 1946, pp.37-38). For that discovery, the leading researchers, F. Bloch and E.M. Purcell, were awarded the Nobel prize for physics in 1952. Soon after that, it became a powerful research tool in different areas, from physics and chemistry, to biochemistry. It has also been sucessfully applied in medical visualization for obtaining high quality section pictures of the inside of the human body. In this fileld, it reached its peak in 2003, when the Nobel prize for medicine was awarded to P. Lauterbur and P. Mansfield for a discovery regarding soft tissue images taken by NMR.

In this paper, we will review the principle of NMR, its application in medicine, and its influence on the work and life environment.

The principle of NMR

Nuclear magnetic resonance is based on the phenomenon occurring when the cores of certain atoms, placed in a magnetic field, absorb or emit radiofrequency waves of characteristic frequency. The element of choice for this case is hydrogen, precisely the proton (Ivanović, 1971, pp.253-257). In an external magnetic field, the proton spin precesses around the direction of the magnetic field at a certain angle. Therefore, the precession frequency is equal to the resonant frequency (Georgijević, 2005, pp.753-756).

Visualization by magnetic resonance is a contemporary, almost completely noninvasive technique for screening the interior of the human body. The apparatus consists of a strong magnet which produces a static magnetic field with the induction B_0. Three additional magnets, known as gradient magnets, can adjust the value of the resulting magnetic field (in which the patient is placed) in space and time. The radiofrequency coil allows the emission of a short RF pulse towards the patient and the capture of the signal which comes from him. After the emission of the RF signal, which is of the same frequency as the one with which the protons precess around the direction of the magnetic field, the protons from the lower energy state jump to the higher one followed by the relaxation process of returning of the proton into the lower energy state with the emission of electromagnetic waves of the same frequency. Protons outside these directions will not be activated because they have different frequency from that of RF signals. By the same loop with which the RF pulse has been emitted, the emitted waves are captured and recorded by

the acquisition system. After that, some other direction is activated and the process is repeated in a number of directions. The image of the layer is then reconstructed by the same algorithms as in the case of emission tomography.

Figure 1 – NMR examination at the VMA Clinic (http://images2.kurir.rs/slika-724x489/vma-magnetna-rezonanca-pacijenti-klinicki-centar-srbije-milorad-rabrenovic-1328585176-34906.jpg)
Рис. 1 – Обследование методом ЯМР в Военно-медицинской академии (http://images2.kurir.rs/slika-724x489/vma-magnetna-rezonanca-pacijenti-klinicki-centar-srbije-milorad-rabrenovic-1328585176-34906.jpg)
Slika 1 – Pregled NMR-om na Klinici VMA (http://images2.kurir.rs/slika-724x489/vma-magnetna-rezonanca-pacijenti-klinicki-centar-srbije-milorad-rabrenovic-1328585176-34906.jpg)

The command console consists of monitors and an instrument board (Figure 1). It serves for the selection of the necessary parameters, the analysis of the obtained image and the selection of the data stored and documented. A computer is a separate unit. The obtained data can be saved on a magnetic tape or a laser disc thus being available for later interpretations and analyses. The immediate documentation of the results is performed by a multisport camera (x-ray tape) or by a polaroid camera.

Application of NMR in medicine

Application of NMR in oncology

Nuclear manetic resonance represents one of the most modern visual modalities. Its basic technical possibilities - multiplanarity, high space and tissue resolution in the combination with biological non-

invasiveness - place it in the group of the most sensitive and specific radiology methods for the most parts of the human body (Baltić, 2002).

One of its most important applications is in the early detection of breast cancer which is the leading cause of cancer death in the female population, where each ninth gets sick (Dähnert, 1996, pp.398-41). The procedure of breast screening involves the use of a special surface dressing where the patient is in the prone position. The technique of the inspection is somewhat different than for the other regions of the human body. Namely, the application of the contrast is necessary for a dynamic study where the contrast dynamics is monitored in the same, repeated time intervals. Such technique is necessary since both types of lesions, benign and malignant ones, give postcontrast signal intensity amplification. However, unlike benign, malignant lesions have characteristic signal intensity growth (Figure 2).

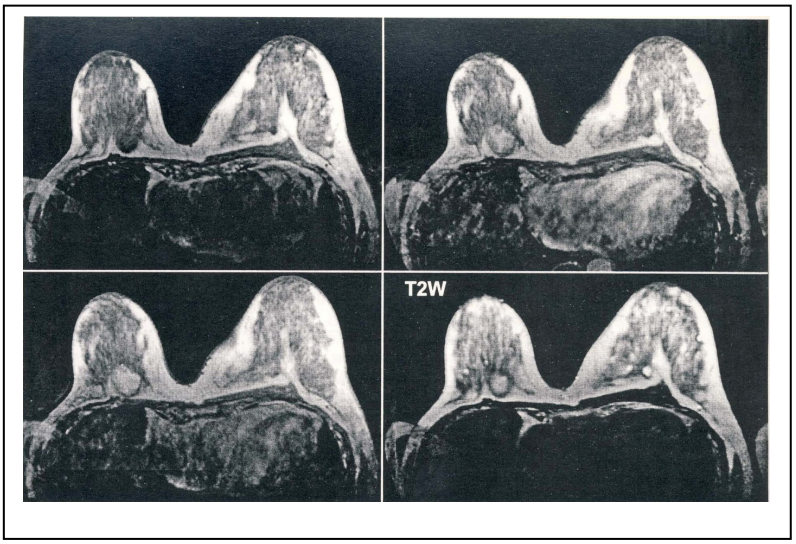

Figure 2 - Breast cancer in an NMR image.(clearly defined oval change in the right breast with typical centrifugal amplification) (Baltić, 2002)
Рис. 2 – Рак молочной железы на снимке ЯМР (на правой груди отчетливо видна овальная опухоль с типичными бугристыми уплотнениями) (Baltić, 2002)
Slika 2 – Tumor dojke na NMR snimku (jasno definisana ovalna promena u desnoj dojci sa tipičnim centrifugalnim pojačanjem) (Baltić, 2002)

The application of the NMR imaging in the diagnostics of diseases of the female genitourinary system started in the middle of the 1980s. Although the visualisation of the female genital organs can be performed by a number of radiological techniques (such as ultrasound and computer tomography), radiological diagnostics of pathological

processes in the female genital system is a very complicated problem (Rubin, 1993, pp.369-372). The advantage of NMR in comparison to other techniques is especially considerable in the diagnostics of two groups of diseases: congenital anomalies of the female reproductive system and malignant gynaecological tumours such as ovarian tumours which have high specific mortality. The major task of NMR here is the detection of the changes in the projection of the ovarian vein: physiologic cysts, primary cistoadenomas, dermoid cysts, and ovarian carcinomas. Cervical cancer is one of the leading causes of death in the female population, being in the second place of mortality just after breast cancer. Here, the role of NMR is not in the detection, but in the evaluation of the local spread of the disease.

Pancreatic cancer accounts for approximately 20% of new registered carcinomas in the world and can be surgically treated in 10-15% of cases (Kern, 1998, pp.74-78). For pancreatic cancer diagnosis, the first step is CT-imaging with the contrast and then NMR screening. In some cases, when pancreatic tumours are small and cannot be detected by CT or NMR, additional examination is performed by endoscopic ultrasound, or intraoperative ultrasound can be used for small endocrine tumours (Figure 3).

Figure 3 – Cancer of the pancreas head (Baltić, 2002)
Рис. 3 – Рак головки поджелудочной железы (Baltić, 2002)
Slika 3 – Karcinom glave pankreasa (Baltić, 2002)

Application of NMR in other areas of medicine

Soon after its introduction into clinical practice, NMR became a very important technique (Lazić, 1997, pp.360-367). It is particularly useful in the examination of the central nervous system for diagnostics and characterization of numerous lesions. Brain contusions and intracerebral hematomas are very well defined during NMR examination, which is especially important if they are located in the brain stem or back fossa, i.e. in the areas which give less diagnostic information during the standard CT-examination. Diseases from the group of dementia, which affect about 5-15% of the population over 65, with Alzheimer's disease being the most frequent, are characterized in the NMR imaging by the damage of the gray matter, deposits of iron and dilatation of the temporal horn. NMR also provides reliable evidence of changes caused by Multiple Sclerosis. The major manifestation of the disease are zones of demyelination called plaques (Figure 4).

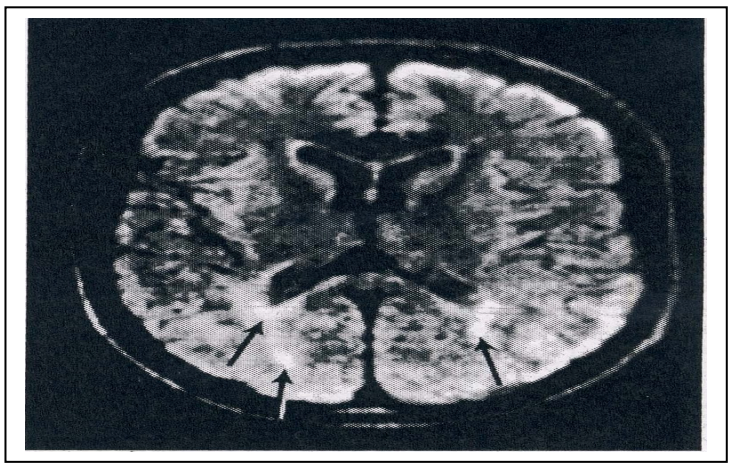

Figure 4 – NMR image of a pacient with Multiple Sclerosis (Lazić, Šobić, 1997)
Рис. 4 – Изображение ЯМР пациента, страдающего рассеянным склерозом (Lazić, Šobić, 1997)
Slika 4 –NMR snimak bolesnika sa multiplom sklerozom (Lazić, Šobić, 1997)

In the field of the diagnostics of the diseases of the torax and the cardiovascular system, the advantages of NMR are a high-resolution, wide-angle image, a possibility to choose a section plane, a high soft tissue contrast and the contrast between the blood flow in the blood vessels and the surrounding tissues. The usefulness of NMR has been verified in the examination of heart tumours, cardiomyopathy, congenital heart diseases and the diseases of the aorta and the pericardium. The ECG monitoring enables constant image quality during the whole cardiac cycle.

The application for the diagnostics of lung diseases is still limited.

Influence of nmr on the work and life environment

A formal procedure, nowadays known as environmental impact assessment, was established in the developed countries by the end of the 1960s, as a result of the increased awareness about the protection of the environment. The Law on the Environment Protection (Službeni glasnik RS, Nos 135/2004a, 36/2009a, 72/2009, and 43/2011), in our country for the first time established the obligation to analyze the impact of civil engineering structures and activities on the environment. This system of assessment was changed by passing the Law on Environmental Impact Assessment (Službeni glasnik RS, No 135/2004b and No 36/2009b), as well as by passing a number of bylaws; therefore, it has been completely adjusted to the environmental impact assessment process in the EU countries.

Strong magnetic fields and RF pulses are used in the NMR technique, so it is necessary to comply with the Act on Preventive Measures for Safe and Healthy Work during Exposure to Electromagnetic Fields (Službeni glasnik RS, No 101/2005). This Act prescribes the requirements about preventive measures employers are to meet in order to decrease or remove risks of damaging health during exposure to electromagnetic fields of frequencies from 0 Hz to 300 GHz. It also provides limit values and action values. According to this Act, employers are required to ensure that employees are in no case exposed to electromagnetic fields beyond the limit values defined by this Act.

The specific energy absorption rate (SAR), for the whole body or for particular parts - the energy absorption rate for the mass unit expressed in W/kg – is of particular importance. The specific energy absorption rate (SAR) for the whole body is a known measure for linking unfavorable thermal effects and exposure to radiofrequency waves (RF). Besides the SAR averaged for the whole body, local values of the SAR are necessary for the evaluation and limitation of the over-exposure of body parts during specific conditions of exposure. This refers particularly to the protection from acute exposure of the central nervous system, the head tissues and the torso. This Act prescribes the following limit values of the SAR for the 20-100MHz RF wave range:

- Averaged SAR for the whole body: 0.4 W/kg
- Localized SAR (head and torso): 10 W/kg
- Localized SAR (extremities): 20 W/kg.

In the case of using NMR for clinical purposes, a magnetic field with induction between 0.1 and 4.0 T is used, i.e. a magnetic field of high intensity (in order to improve the signal-to-noise ratio). For the sake of comparison, the Earth's magnetic field has induction of 50μT, which means that the 1.5 T magnetic field is 30,000 times stronger than the magnetic field of the Earth. There is a question about the

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impact of such a magnetic field on the human body. Investigations so far did not show any negative effect on the body, except a few cases of dizziness due to weaker electric current induction in some brain neuron structures. In the case of a new generation of superconducting magnets, which nowadays are in expansion, very homogeneous magnetic fields may be created due to the loss of electrical resistance. The disadvantage is very strong noise during the examination which also needs to be taken into account. Magnets themselves need to be separated from their environment, since strong magnetic fields may have negative effect on sensitive electronic equipment as well on patients with pacemakers and other prosthetic devices. The device also has to be separated from a wide range of radio-waves in order to avoid disturbance in radiofrequency waves. Therefore, the whole system is set in the Faraday cage.

When it comes to the influence of this method on the environment, nowadays when ecological awareness is increasing, it is necessary to be aware of its possible negative effects. Radiofrequency waves used in NMR devices belong to the group of non-ionizing radiations. Non-ionizing radiations are electromagnetic radiations with energy lower than 12.4 eV. This radiation does not have necessary energy to cause ionization in living creatures. Natural sources of non-ionizing radiation are rare and weak. They are: Sun, distant pulsars, other sources from the space and the Earth (lighting). Epidemiological studies and experimental research have shown that electromagnetic radiation, non-ionizing radiation as well, presents a constant threat to our health even when it is within the allowed limits (SCENIHR, 2007). The primary and the simplest negative effect of the electromagnetic field is heating. Exposure to radio-frequency radiation higher than mW/cm^2 can cause serious damage to the human tissue due the over-heating. Long exposure can cause a whole number of negative symptoms such as increased anxiety, nervousness, insomnia, headache, exhaustion and chronic fatigue, tendency to depression, problems with memory and concentration, loss of vitality, weight and activity, etc. On the other hand, some studies have shown that magnetic fields of the intensity used in NMR examination can cause visual sensations such as flickering or can stimulate nerves and muscles.

Conclusion

Magnetic resonance (MR) represents a technique used in medicine for obtaining high quality section images of the human body interior. Nuclear magnetic resonance (NMR) is a spectroscopic technique used for a long time for gathering information on the fine structure of the matter. This method is based on the behavior of the proton spin in the magnetic

field. The spin and the magnetic moment attributed to it are the fundamental characteristics of the particles such as protons and neutrons.

Magnetic resonance provides visualisation of the organs inside the human body such as the head, the neck, the thorax, the abdomen, the pelvis, muscles and joints.

The advantage of this method in comparison to other diagnostic methods is a possibility of changing the image contrast of different tissues in order to emphasize the most important elements as well as obtaining cross-sections in different planes during the same examination without changing the position of the patient. Also, this method shows high sensitivity in revealing tumours, their position and relation to the surrounding tissue. In accordance with research and taking into account that it is performed without using ionizing radiation, NMR shows no harmful effects on the human body.

This method is completely nonpainful, non-invasive, comfortable and safe both for the patient and the medical staff taking part in the examination.

When it comes to the effects of this method on the quality of the environment, longer exposure to the sources of non-ionizing radiation, where NMR devices belong, can cause damage to the tissue due to overheating and lead to a number of psychological symptoms. Also, magnetic field intensity values used during NMR examinations can cause visual sensations like blinking or they can stimulate nerves and muscles.

The effect on the global environment is negligible since the applied magnetic fields are of very low strength compared to the Earth's magnetic field and the diagnostic system itself is usually well insulated from the surrounding area.

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ПРИМЕНЕНИЕ ЯДЕРНО-МАГНИТНОГО РЕЗОНАНСА В МЕДИЦИНЕ И ЕГО ВЛИЯНИЕ НА РАБОЧУЮ И ОКРУЖАЮЩУЮ СРЕДУ

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ОБЛАСТЬ: ядерные технологии
ВИД СТАТЬИ: обзор
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной работе описано применение в медицине ядерно-магнитного резонанса (ЯМР), являющегося мощным исследовательским средством в различных сферах, а также описано его влияние на рабочую и окружающую среду. Ядерно-магнитный резонанс основан на физическом явлении поглощения веществом электромагнитного излучения, атомных ядер, находящихся в постоянном магнитном поле.

Данный метод используется для получения высококачественных изображений органов человеческого тела, а также для диагностики онкологических заболеваний и выявления опухолей. ЯМР отличается нейонизирующим излучением и сильным магнитным полем, не представляющих опасности для организма. Следовательно, применение ЯМР безболезненно, безвредно, удобно и безопасно, как для пациентов, так и для медсотрудников, проводящих процедуру.

Ключевые слова: *ядерно-магнитный резонанс, ЯМР, опухоль, нейонизирующее излучение.*

PRIMENA NUKLEARNE MAGNETNE REZONANCE U MEDICINI I NJEN UTICAJ NA KVALITET RADNE I ŽIVOTNE SREDINE

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OBLAST: nuklearne tehnologije
VRSTA ČLANKA: prikaz
JEZIK ČLANKA: engleski

Sažetak:

U ovom radu opisana je primena nuklearne magnetne rezonance (NMR) u medicini, kao moćnog istraživačkog sredstva u različitim oblastima, i njen uticaj na radnu i životnu sredinu. Nuklearna magnetna rezonanca zasniva se na fizičkom fenomenu da jezgra određenih atoma (u ovom slučaju vodonika), postavljena u magnetno polje, mogu apsorbovati i emitovati radiofrekventne talase. Ova metoda koristi se za dobijanje visokokvalitetnih slika preseka unutrašnjosti tela, a pokazuje i visoku osetljivost u otkrivanju tumora, njihovog smeštaja i odnosa prema okolini. Odlikuje se korišćenjem nejonizujućeg zračenja i jakog magnetnog polja, a prema dosadašnjim istraživanjima nema štetno dejstvo na organizam. Potpuno je bezbolna, neinvazivna, konforna i bezopasna, kako za pacijenta, tako i za zdravstveno osoblje koje učestvuje u pregledu.

Ključne reči: *nuklearna magnetna rezonanca, tumor, nejonizujuće zračenje.*

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