

Magnetic Resonance Imaging (MRI) and Electromagnetic Fields (EMF)

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Introduction

The European Parliament and the Council of the European Union have published a draft directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from electromagnetic fields and waves.

These limitations for workers, especially those for static magnetic fields, given in the draft directive make the operation of MR scanners in the hospital environment virtually impossible, because the MR operators in the hospital would no longer be allowed to position the patient in the scanner in an effective way.

The draft directive also restricts or prohibits directly a number of specific MR applications for patient treatment such as interventional MR applications. With this application patients are treated directly inside the MR system under permanent control through MR imaging (for example tracking a biopsy needle or catheter). This is a situation where the medical staff is inside the examination room and can be exposed by the static magnetic-, the gradient- and radio-frequency-field (RF-field). The clinical benefit for the patient is estimated to be favourable compared to the potential adverse effects for the workers (for this application both the operators and medical doctors in the hospital). This new technique also might replace interventional procedures with conventional X-ray equipment which is beneficial for both patients and medical staff.

In addition the limitations given in the draft directive make the development, manufacturing and service of MR-scanners very cumbersome if not impossible.

In the following we would like to provide some basic information about MRI and the electro-magnetic fields associated with it. In the discussion, the practical situation in the hospitals for MR scanners and for exposure to static magnetic-, gradient- and RF-fields is described, the clinical benefits are illustrated briefly and the objections to the proposed European directive are discussed.

What is MRI?

The beginnings of MRI go back more than 25 years. This imaging technique is based on the fact that body tissues act differently in strong magnetic fields, because the water content of the individual tissues varies. The hydrogen nuclei within the water molecules align themselves in a specific direction in strong magnetic fields. When radio wave pulses of an appropriate frequency are directed perpendicular to the magnetic field at a tissue, the nuclei are deflected from their normal alignment. When the radio waves are switched off, the nuclei return to their original orientation and

emit weak electromagnetic waves during this short "relaxation time". These electromagnetic waves are acquired as signals, which are used by a computer to generate high-contrast images of the tissue. Stronger magnetic fields enable stronger signals to be received, resulting in clearer images and/or shorter total examination times.

MRI – Principle

Routine MRI is based on the magnetic characteristics of the ^1H hydrogen atom. The patient is placed in a strong magnetic field (e.g., 1 Tesla = 10,000 Gauss) that is externally shielded. *“To compare: the Earth’s magnetic field is 0.3 to 0.7 Gauss, a magnet on the refrigerator door has a strength of approx. 100 Gauss or 0.01 Tesla”*. High-frequency energy in the form of radio waves is applied to the patient. This energy is then emitted by the body in specific forms and at certain intervals. An antenna (coil) receives this energy, called the MR signal. For localisation of these MR signals low frequency magnetic pulses are applied to the patient by the gradient system. Using a mathematical transformation, the MR signals are converted into grey scale images. A patient study may take up typically 30 minutes per examination.

The Field Generating Components of the MR System and the Field Exposure to Patients and Personnel

Magnet

The largest component in an MR system is the magnet, which creates the external magnetic field (\mathbf{B}_0). Hydrogen nuclei in the body placed into the magnetic field align themselves, thereby enabling MR imaging. The system provides a measurement field of up to 50 cm diameter at the highest possible homogeneity, enabling e.g., the display of the entire spinal column. Active magnetic shielding keeps the stray field to a minimum. As a result, the exclusion zone (the 5 Gauss line) is usually limited to the examination room. MR scanners routinely apply static magnetic fields in the range from 0.2 T up to 3 T, whereby the whole body of the patient is exposed to this magnetic field. These types of scanners are commercially available world wide. For example fig. 1 shows a modern 3 T cylindrical magnet with a horizontal field direction, Fig. 2 shows a 1 T open system with a vertical field direction.

An MR operator gets exposed when for example positioning a patient in the magnet bore. Another more long term exposure is unavoidable for the medical staff when applying interventional MR techniques. The exposure values can be as high as those experienced by the patient.

The scientific literature is saying that no adverse effects from the exposure by static magnetic fields are observed up till now. Instantaneous health effects of exposure to higher magnetic field strengths (>1.5 T) are well known and reported in literature. These health effects (dizziness, nausea, metal taste) do not require treatment and no lasting effects nor cumulative (=dose) effects have been observed. The exposure values would exceed the limits given in the draft directive for 0 Hz in table 2.



Fig 1: 3 T MR system

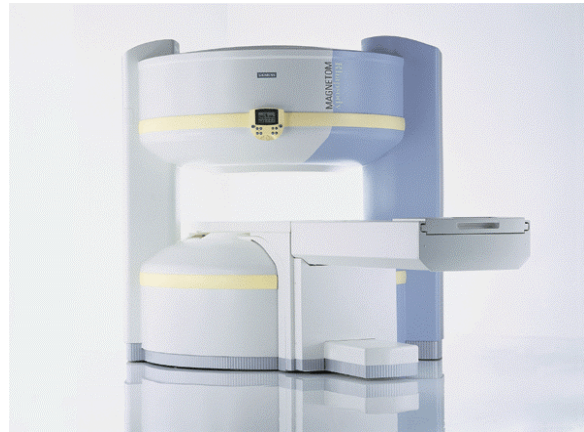


Fig 2: 1 T open MR system

Gradient System

The gradient system is the decisive component in determining measurement speed and spatial resolution. It localizes the body slice to be measured. It consists of the power amplifier and the gradient coil system.

The gradient system generates low frequency (up to 1 kHz) magnetic pulses with mostly trapezoidal wave forms. The amplitude and switching speed of the gradient pulses are limited such that the occurrence of peripheral nerve stimulation for the patient is limited. Outside the gradient coils the pulsed magnetic field rapidly drops to negligible values. So generally the MR personnel is not exposed from pulsed gradient fields even if a person is inside the examination room during the acquisition. However, during interventional MR at least a partial body exposition cannot be avoided. The exposure values would exceed the limits given in the draft directive in the frequency range close to 1kHz in table 2.

RF system

The RF-system can be separated in a transmit and receive path. The transmit path which consists of the RF power amplifier and a transmit antenna creates the pulses to deflect the hydrogen-nuclei from their alignment. The receive path consisting of different types of receive antennas detects the signals from the body tissue and prepares it for further processing to calculate the final MR image.

The RF power emitted by the transmit antenna causes slight heating in the patient body tissue. The power absorbed in the patient body is limited such that the body temperature does not increase by more than 1°C. Outside the RF transmit antenna the RF field is negligible. Similar to pulsed gradient fields under normal circumstances the MR personnel is not exposed by the RF-fields. In case of interventional MR the exposition would be limited to the extremities or body parts of the staff working close to the magnet bore (or between the magnet poles).

Discussion

MRI has moved to the forefront of medical imaging in recent years covering almost all areas ranging from neurological imaging, musculoskeletal imaging to cardiovascular and interventional. Complex, novel techniques like diffusion and perfusion imaging, functional imaging have even affected the approach to certain diseases and patients. The advances in hardware has had an impact in the still growing and maturing applications like parallel imaging techniques. These new advances might start a revolution in patient management and the role of MR in diagnosis of diseases. These statements only prove true if the application and further technological development of MR systems are not constricted by strict occupational exposure limits applicable to the medical personnel working at the MR system.

The clinical benefit of MR scanners for the patient can best be illustrated by reference to the enormous amount of literature on MR in the medical and scientific international journals (some URLs are listed at the end of this text). As an illustration two clinical images are given in Fig. 3.

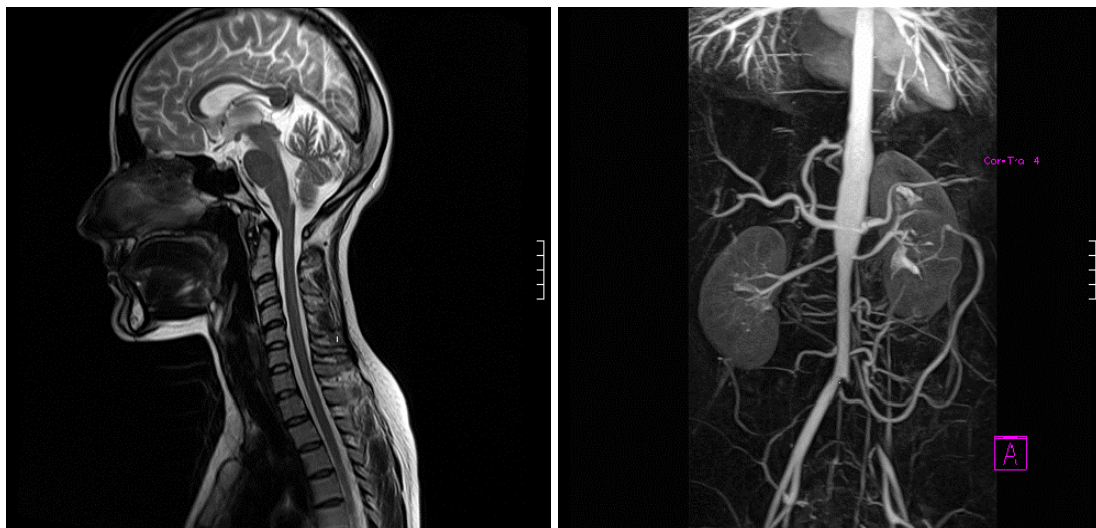


Fig 3: Two examples of MR images
a) sagittal head image,
b) abdominal angio image

The number of MR units installed world wide is estimated to be > 20.000 and since the introduction in 1983 more then 200.000.000 patients have been examined in the scanners. Up till now no adverse effects from the exposure of these patients nor from the exposure of the workers to the electromagnetic field created by MR systems is known.

The exposure of patients is not addressed in the European Directive proposal and therefore only mentioned in this memo for illustration. Actual limits for the parameters for patient scanning are given in the IEC 60601-2-33 particular standard for the safety of MR scanners. For information, the static magnetic field ceiling value

is 4 T for patients for whole body scanning, a number which is based on the clinical experience with 4 T MR scanners at a limited number of hospital sites since 1987.

At present the exposure to the static magnetic field of system engineers in the manufacturing area and service engineers in the hospital environment is minimised by introducing specific tools. For all normal engineering activities these tools can be applied. For abnormal situation, whereby troubleshooting is required, it may however be unavoidable that these engineers are exposed to higher values (then proposed in the draft directive).

The exposure time to the static magnetic field of the operators in the hospital is typically a few minutes per patient. In the worst case they are exposed to the maximum static magnetic field of the magnet, because they must position the patient on the patient support and therefore approach the magnet at a position where the static magnetic field is as high as the main magnetic field of the system. The operators in the hospital are typically not exposed to gradient- and RF-fields, because during the scanning of the patient, the operator is relative far away from the patient (at the operators console of the scanner).

The exposure of the medical staff during interventional MR however is much higher than the proposed limits in the draft directive. For both, the open MR systems and the cylindrical MR systems, the medical doctor can be present near the scanner during a longer time (up to one hour or even more) and is present in or close to the maximum static magnetic field with his hands and partially with his body. Since he is present near the patient during scanning, he is also exposed by gradient- and RF-fields. At parts of the body (extremities, head) they can reach values which can be maximally equal to those applied to the patient.

Conclusion

In view of the practical experience up to now, the large installed base for MR scanners at present, the importance of the diagnostic capabilities of these MR scanners for the health care and the weak scientific base for the proposed limiting values, it seems unrealistic and not in the interest of the patients to impose the requirements in the draft directive to medical equipment and MR scanners in particular.

There are already several national and international guidelines, recommendations and standards in place addressing the safety of medical personnel in the MR environment (for example: the recommendation of the “Strahlenschutzkommission” in Germany, the White Paper on MR safety of the American College of Radiology or the IEC 60601-2-33 particular standard for the safety of MR scanners). These papers also require permanent training of the personnel, special procedures to be defined and followed or the generation of emergency plans. That means, they are much more specific in addressing the potential hazards in the particular MR vicinity.

More detailed information about MRI can be found in the internet, for example:

special safety issues: <http://www.imrser.org/>

MR basics in general: <http://www.cis.rit.edu/htbooks/mri/>

product information and clinical examples:

<http://www.med.siemens.com/magnetom/default.asp>

<http://www.medical.philips.com/main/products/mri/>

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