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Brief Communication

Exposure Classification of MRI Workers in Epidemiological Studies

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We estimate that there are about 100,000 workers from different disciplines, such as radiographers, nurses, anesthetists, technicians, engineers, etc., who can be exposed to substantial electromagnetic fields (compared to normal background levels) around magnetic resonance imaging (MRI) scanners. There is a need for well-designed epidemiological studies of MRI workers but since the exposure from MRI equipment is a very complex mixture of static magnetic fields, switched gradient magnetic fields, and radiofrequency electromagnetic fields (RF EMF), it is necessary to discuss how to assess the exposure in epidemiological studies. As an alternative to the use of job title as a proxy of exposure, we propose an exposure categorization for the different professions working with MRI equipment. Specifically, we propose defining exposure in three categories, depending on whether people are exposed to only the static field, to the static plus switched gradient fields or to the static plus switched gradient plus RF fields, as a basis for exposure assessment in epidemiological studies. Bioelectromagnetics 34:81–84, 2013.

Key words: occupational exposure; magnetic field; radiographers; nurses; anesthetists; technicians; engineers

INTRODUCTION

Magnetic resonance imaging (MRI) is widely used in medical practice and it is estimated that there are 20,000–25,000 MRI scanners worldwide, of which a few thousand are in Europe. From Moore and Scurr [2007] and Wilén and de Vocht [2011] we estimate that each scanner will involve about five workers from different disciplines such as radiographers, nurses, anesthetists, technicians, engineers, cleaners, etc., and that these people may be exposed to various electromagnetic fields (EMF) during procedures. In some centers, procedures such as interventional MRI also involve other staff groups such as surgeons and cardiologists.

The occupational exposure to EMF near the MRI scanner can, in some cases, be substantial. In studies on the health effects of EMF, exposure assessment is (or should be) an important aspect of the study. In epidemiological studies, in particular,

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where long-term effects of repeated or continuous exposure are studied, exposure assessment is problematic, mainly because there is no consensus regarding the relevant metrics of such exposure.

With respect to exposure from MRI equipment, acute transient effects on visual perception and visuo-motor performance arising from movement in the static magnetic field (MF) around the MRI scanner have been reported from controlled human trials [de Vocht et al., 2003, 2006b, 2007]. Also, field surveys among nurses, engineers, and radiographers routinely working close to MRI scanners describe symptoms such as vertigo, nausea, illusion of movement, etc. [de Vocht et al., 2006a; Glover et al., 2007; Wilén and de Vocht, 2011]. Little is known about other possible acute effects, such as effects on brain function [WHO, 2006, 2007; van Rongen et al., 2009] or late effects such as cancer or neurodegenerative disease (e.g., Alzheimer's or amyotrophic lateral sclerosis) [ICNIRP, 2001; WHO, 2006, 2007].

Lately, there have been reports from in vivo and in vitro experiments where a single MRI scan may have genotoxic effects and this needs to be further investigated [Simi et al., 2008; Lee et al., 2011]. However, there have been no studies published yet about any long-term effects of repeated exposure to MRI fields. There is thus a need for well-designed epidemiological studies of MRI workers but since the exposure from MRI equipment involves a very complex mixture of static MF, switched gradient MF, and radiofrequency (RF) EMF, it is necessary to discuss how to classify the exposure in epidemiological studies. The exposure of personnel to EMF generated by MRI scanners has been thoroughly investigated by Capstick et al. [2008] and has been discussed at length in reviews by Karpowicz and Gryz [2006] and Karpowicz et al. [2007].

Most MRI scanners in clinical use have superconducting magnets of 1.5–3 T magnetic flux density (cylindrical bores) or 0.2–1 T (open magnets). A smaller number of ultra-high field MR systems with fields up to 9.4 T are in use in research institutions. Due to the active shielding, the field drops away quickly with increasing distance from the scanner, producing a large gradient of the static field so that the field of 1.5–3 T scanners may only become significant within about 0.5–1.0 m from the bore opening. Routine activities of radiographers and nurses related to clinical examinations are usually performed in fields not exceeding 10% of the level of the field in the bore but exposure at the same level as patients may occur in interventional procedures and when providing clinical care to anesthetized patients, for example.

Movement through a static field or a static field gradient will result in time variations in exposure to the field. The static MF of an MRI scanner is always on, independent of whether an MRI procedure is being performed or not, and this means that everyone moving around the scanner will effectively be exposed to a time-varying extremely low frequency (ELF) MF, inducing electric fields and currents in the body.

The switched gradient fields used for image encoding are generated by three different coils that create linear MF gradients in three directions within the scanner. The amplitudes of these fields are on the order of mT, with fast rise and fall times of tens to hundreds of microseconds. The gradient waveform is complex and not periodic but can be characterized by primary frequencies in the kHz range, and so should be classified as an intermediate frequency (IF) MF.

The occupational exposure to the switched gradient field will be significant, especially close to the bore, exceeding ICNIRP recommendations by over 100-fold [ICNIRP, 2003, 2010; Wilén et al., 2009]. The magnitude of the switched MF gradient and its time derivate depends on which pulse sequence is used. The RF field is usually created by a body coil integrated into the scanner that produces a circularly polarized MF with a frequency of approximately 42 MHz/T, known as B_1. The E_1 field produced by RF coils is generally small, except in the vicinity of the coil windings. The occupational exposure to the RF B_1 field will be low, in general, since the field falls off rapidly outside the transmit coil. An exception would be for staff carrying out interventional procedures, particularly in open scanners where hands and arms and possibly the head may be exposed to levels similar to those for the patients, or even higher because of resonant energy absorption that is possible when the operator touches the patient. The RF field and the switched gradient fields are only turned on during the MRI procedure. Only professionals that stay in the room during the procedure may be exposed to these fields but generally at lower levels than patients.

The exposure assessment is dependent on what endpoint is studied—mainly acute or long-term effects. In general, when acute effects such as movement-induced effects in static MF are studied, individual measurements of exposure is a possible technique to assess the exposure but when long-term effects such as cancer are studied, a proxy for the exposure is needed because IF and RF measurement devices are affected by static MF close to the magnet.

We propose a division of professionals into different categories with respect to their work task responsibilities and the related exposure type, which could form a basis for EMF exposure assessment of MRI scanners. Depending on the endpoint and hypotheses as to what kind of exposure to study, a proper study group could be chosen based on this proposed categorization. In general, job titles alone would be a poor indicator of exposure; for example, the job title ''radiographer'' includes professionals performing procedures like MRI, computed tomography (CT), X-ray, ultrasound, nuclear medicine or a mixture of these, which differ highly in the sense of EMF exposure. Suggested categorization into three main options of exposure may be summarized as follows.

CATEGORY 1: ONLY STATIC MF, GRADIENTS OF THE STATIC MF, AND MOVEMENT-RELATED ELF MF

Exposure in this category refers to the situation in which no scan is being performed. It includes MRI physicists, technicians, radiographers, nurses, radiologists, engineers, and some maintenance personnel, for example, those cleaning the MRI room or scanner. The MRI radiographers and/or technicians are responsible for positioning patients in the MRI scanner, which is done many times per day (up to 30 patients per shift) so this is a large group that is often exposed to the static MF and to movement in the static field gradient. We estimate that there are about 10,000 MR radiographers and technicians in Europe who would all be occupationally exposed to static fields, and this is the largest exposed group by far.

For other employment categories we make an estimate by scaling from the number of scanners. For example, three cleaners may work on each scanner on a rotational basis. The number of nurses, anesthetists, operating department assistants (ODAs), etc., is likely to be larger.

CATEGORY 2: STATIC AND ELF MF AND IF SWITCHED GRADIENT STRAY FIELDS

This situation pertains to a scan being performed while the personnel remain outside the bore. Since the RF field is present only inside and very close to the bore, many professionals are only exposed to static and ELF MF and IF switched gradient stray fields, even though they are inside the scanner room during the procedure. This category includes anesthetists, some MRI nurses mainly caring for children, MR physicists and service engineers, MRI manufacturer personnel, and volunteers.

The number of professionals in Category 2 is much smaller than in Category 1. Most of them are not exposed repeatedly, which makes this category much more difficult to study. Anesthetists are probably the professionals within this category that are most often within the scanner room, and could form the basis for epidemiological studies. Although in this case people may be quite rarely exposed to the IF MF, for simplicity we are proposing that staff who are exposed to the switched gradient fields at least monthly (but not to RF) should be included in this category. The total number of people that could be included in this category might not be more than a few hundred in Europe.

CATEGORY 3: STATIC, ELF MF, IF MF, AND RF FIELDS

Exposure in this category occurs while a scan is being performed and the worker is partially inside the bore. This category includes surgeons and other medical professionals performing interventions, MRI technicians, and MRI manufacturer personnel. Besides the professionals, volunteers and patients can also be included in this category. Professionals from Categories 1 and 2 may be volunteers at times, in which case they must be included in Category 3.

The number of professionals regularly exposed within this category is currently small, perhaps no more than 100 people in Europe involved directly via their employment, but the expectation is that the number will increase due to the increased use of interventional MRI procedures.

MRI personnel are highly exposed to EMF compared to many other occupations, and even though there are difficulties in assessing their ''real'' exposure it is timely to perform epidemiological studies even with relatively simple methods of exposure assessment. We think it may not be possible to give ''a number'' to the exposure, regardless of whether it is for static, switched gradient or RF fields. We propose, as a first step, a categorization into three groups as a basis for epidemiological studies to be able to distinguish between the different exposures around a MRI scanner. The number of people in Categories 2 and 3 are small compared to Category 1, but it may be possible to further subdivide the groups by the number of years that they have been working in the MRI environment, for example.

In conclusion, we believe that subdividing staff according to the nature of the fields they were

exposed to and, to some extent, the time that they were exposed will provide a crude but applicable exposure basis for future epidemiological studies. It would be helpful to start to systematically record individual reports on staff exposure according to these categories now.

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