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# Characterization of the MRI patient exposure environment and exposure assessment methods for magnetic fields in MRI scanners

**Jennifer Frankel**

## Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av teknologie doktorsexamen framläggs till offentligt försvar i sal Triple Helix, Samverkanshuset, Umeå Universitet fredagen den 21 maj, kl. 09:00.
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Fakultetsopponent: Professor Peter Lundberg,
Institutionen för hälsa, medicin och vård, Linköpings Universitet, Linköping, Sverige.

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## Author
Jennifer Frankel

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## Abstract
Magnetic resonance imaging (MRI) has become one of the most common imaging modalities available in modern medicine, and it is an indispensable diagnostic tool thanks to the unparalleled soft-tissue contrast and high image resolution. It is also a unique exposure environment consisting of a complex mix of magnetic fields. During an MRI scan, the patient is simultaneously exposed to a strong static magnetic field, a fast-switching gradient magnetic field, and a pulsed radiofrequency (RF) magnetic field. Transient acute effects, such as nerve excitation and tissue heating, are well known and limited by universal safety guidelines. Long-term health effects related to MRI exposure have, however, not been scientifically established, and no interaction mechanisms have been verified, despite a growing body of research on electromagnetic field exposure. Further epidemiological and experimental research on MRI exposure has been recommended but the lack of a common definition of dose or exposure metric makes evaluation of past research and the design of future experiments difficult.

The objectives of this thesis were to characterize the MRI patient exposure environment in terms of the magnetic fields involved, suggest relevant exposure metrics, and introduce exposure assessment methods suitable for epidemiological and experimental research on MRI and long-term health effects.

In Paper I, we discussed the MRI exposure environment and its complexity and gave an overview of the current scientific situation. In Paper II, we investigated the exposure variability between different MRI sequences and suggested patient-independent exposure metrics that describe different characteristics of the magnetic field exposure, including mean, peak, and threshold values. In Paper III, we presented three exposure assessment methods, specifically suited to the complex MRI exposure environment: a measurement-based method, a calculation-based method, and a proxy method.

Papers I and II showed that MRI exams are not homogenous in terms of exposure, and exposure variability exists between the individual sequences that comprise an exam. Differences in mean exposure between sequences were several-fold, peak exposure differences up to 30-fold, and differences in threshold exposure were in some cases more than 100-fold. Furthermore, within-sequence exposure variability, related to the parameter adjustments that can be made at the scanner console before the start of a scan, gave rise to 5-to-8-fold exposure increases. Paper III showed that magnetic field models could be used to approximate the exposure at arbitrary locations inside the scanner, with slight underestimation of gradient field metrics and large variability in some RF field metrics. With improvements in accuracy and efficiency, the method could become a useful exposure assessment tool for *in vitro* and *in vivo* research as well as clinical work on medical implant safety. Our search for suitable exposure metric proxies resulted in a limited selection with low correlation between proxies and their counterpart metrics, but, with further development, the proxy method has the potential to allow for much needed exposure classification relevant to large-scale epidemiological research.

The work in this thesis has contributed to increased awareness of the unique MRI exposure environment, the characteristics of the magnetic fields involved, and the inherent exposure variability in MRI exams. The metrics and methods presented are specifically suited to exposure assessment of the unique MRI environment, and may contribute to improved research quality by allowing for meaningful comparisons between study results and for experimental conditions to be easily replicated in future studies.

## Keywords
Electromagnetic fields, exposure assessment, magnetic resonance imaging, switched gradient fields, radiofrequency fields, exposure metrics

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