STUDY OF ENVIRONMENTAL EFFECTS OF THE MAGNETIC RESONANCE IMAGING

BY:

Eng. Sherine Ibrahim Hassan Farrag
B.Sc. Biomedical Engineering
(Cairo University 1994)

A thesis submitted in partial fulfillment
of
The requirements for the Master Degree
in
Environmental Science
Engineering Department

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CONTENTS

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ABSTRACT

The wide spread use of recent technology especially in the medical diagnostic field mandate the evaluation of their environmental effects specially the recent equipment utilizing ultrasounds or magnetic fields. Magnetic Resonance Imaging (MRI) is one of these equipment which needs environmental impacts evaluation as it gives accurate results in diagnosis and treatment because it depends on three variables compared with a single variable used in almost all other imaging techniques.

The phenomenon was discovered since 40 years. The technique has been introduced in the field of medicine since 14 years and the first MRI equipment has been introduced in Egypt since 6 years.

The objectives of this study is to Plot the magnetic field distribution in different MRI sites in Egypt, calculate the SAR limits values for the exposed workers in each site, and evaluate various ways of shielding and safety parameters for MRI patients and workers at those sites.

In this research, the basic principles, techniques, and the various effects of Magnetic Resonance Imaging (MRI) on biological systems of the human being are presented. The static magnetic field, alternating magnetic field and high frequency field are also described on the basis of current literature.

The basic information for the safe operation during diagnosis using Magnetic Resonance system and the limits for exposure to magnetic fields are presented. The time dependent changes of electromagnetic fields in patients and the occupational hazards for workers as suggested by health authorities are addressed.

The investigations of the power deposition factor (specific absorption rate) (SAR) values at eleven sites in EGYPT, with emphasis on its effect on the workers in MRI labs are stressed. The magnetic field distribution of each site is measured and drawn.

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It was found that the power deposition values (SAR) at the investigated positions are much higher than the permissible limits. Environmental regulations concerning those sites and future similar ones should be addressed by the environmental health authorities in Egypt.

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Introduction

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INTRODUCTION

Magnetic resonance imaging (MRI) is founded on the principle of nuclear magnetic resonance (NMR). NMR has been an important branch of physics and chemistry since the 1940s when it was discovered independently by Bloch and Purcell.

Initially it is a tool used by chemists to better understand the properties of materials, NMR came to be thought of as having applications for biological systems as early as 1971. Over the time since then, techniques have evolved to the point at which NMR has become indispensable in the diagnosis of disease.

This thesis covers the fundamental principles of MRI with a focus on the properties of atomic nuclei that allow magnetic resonance; magnetic moments and proton precession in a magnetic field. The properties of magnets that allow a large object to be imaged, as well as the types of magnets that are typically used in commercial MRI systems are examined.

Property of spin relaxation that allow the discrimination between protons that live in various environments is also covered, and the radio frequency pulses that produce the information used to create MRI images are also discussed.

Studies of the physiological and health effects of human subjects exposure to the NMR experimental conditions started in earnest in the late 1970s. At that time, most of the magnets had field strength's of 0.15T with low RF absorbed power of less than 0.1 W/Kg and switched fields of less than 3 T/s. During the last few years, comprehensive reviews of the literature appeared in 1987 and 1989. However, the field strengths have now increased to 1.5 T and greater. The basic interaction mechanisms of static magnetic fields are the electrodynamic interactions with moving electrolytes, magnetomechanical effects (translation and orientation), and on electron spin states of chemical reaction intermediates. Electrodynamic effects are induced due to the flow of an electrolyte solution through a static magnetic field which result in the retardation of axial flow and an increase in intra-aortic pressure. Magnetomechanical field affects

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molecular and cellular substances such as DNA, retinal rods, and sickle cells. Flow potentials can be induced in volume conductors in motion, such as flowing blood. Fields of more than 0.1T can affect the T-wave in the electrocardiogram (ECG) of animals. Interactions at the atomic and nuclear levels may affect transfer reactions such as growth, reproduction, prenatal and postnatal development, or behavioral and physiological parameters. RF pulse sequences being used for many useful imaging techniques have been found to deliver sufficient power to cause measurable body temperature distribution changes, and rapidly switched gradients of about 40 T/s used for fast imaging can induce momentary E-fields near the thresholds of neuromuscular stimulation. Thus, whereas the major problem of potential injury from projectiles of ferromagnetic objects attracted by the field and field gradient has remained an important health hazard, the potentials of physiological effects of MRI have precipitated a reevaluation of the safety of present day and near future NMR imaging and spectroscopic methods. In this discussion, an overview of the human health effects will be presented.

Magnetic field measurements were conducted at eleven sites in Egypt of a variant MR imager (Philips- General electric - Siemens - Toshiba - Hitachi) with variable intensities (0.2 - 0.5 - 1 - 1.5 Tesla). The value of the magnetic flux density (B) was measured using a gaussmeter for the eleven sites, and the magnetic field distribution was then plotted.

Two SAR values were calculated, one for bones and the other for fatty tissues due to the great difference in their electric conductivity.

It was found that the power deposition values (SAR) at the relevant positions are much higher than the permissible limits.

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Chapter 1

Interaction of three types of magnetic fields generated by MRI and the human body

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CHAPTER ONE

INTERACTION OF THREE TYPES OF MAGNETIC FIELDS GENERATED BY MRI AND THE HUMAN BODY

1.1) Static Magnetic Fields.

In 1987, most MR devices used static magnetic fields with flux densities of 0.5 to 1.5 Tesla (T). Some small bore spectroscopy systems employed fields up to 10 T and large bore imaging systems using 4 T fields were under development. The patient is exposed to the main field and levels up to 900 mT are expected, at the mouth of the bore and up to 250 mT in the imaging room and adjoining areas.

There are three classes of magnetic field interactions: a) electrodynamic and magnetohydrodynamic effects, b) magnetomechanical effects, and c) interactions at the atomic and nuclear levels.

Interaction of magnetic fields with ionic currents through the Lorentz force law may influence the propagation of action potentials along peripheral nerve fibers and loops in the central nervous system.

Perturbations in the EEG patterns were observed by Beischer and Knepton 1966 in squired monkeys and by Kholodov 1969 in rabbits exposed to fields ranging from 0.1 to 9.1T. The changes were induced upon the application of the field and disappeared after removal of the field. In humans, changes in amplitude and latency periods of evoked acoustic potentials were seen during exposure to 0.35T fields. These changes disappeared over 20 to 30 minutes following termination of exposure. Following exposures to 2T fields, the pattern of evoked acoustic potentials reverted to preexposure levels during three hours.

Electrodynamic interactions also result in flow potentials during the flow of an electrolyte solution through a static magnetic field. The magnitude of the induced potential is linearly related to the magnetic flux density and diameter of the vessel and also depends upon the flow velocity and the orientation of the flow relative to the field. From this, it

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can be predicted that the largest potentials will be associated with blood flow into the aorta because of its diameter and the velocity of blood flow. The induced potentials can be calculated and studied experimentally using ECG surface electrodes. The magnetically induced flow potentials by moving conductor such as flowing blood, beating heart, or respiring lungs appear in the ECG superimposed on the T wave. Their occurrence and their dependence upon exposure parameters were studied in rats, rabbits, and baboons. Biological effects can be expected when the induced flow potentials reach values at which interference with the cell membranes of heart muscle fibers and the impulse conduction system occur.

The maximum aortic flow potential for an adult (diameter of 2.5 cm, peak flow of 6.3 cm/s) is 16 mV per Tesla. Using a different model, Kinouchi et al. 1987 calculated the induced current density at 1 T as 0.05 A/m^2 on the vascular wall and as 0.02 A/m^2 in the vicinity of the sinoatrial node, compared to the 50% response level for ventricular fibrillation of about 1.7 A/m^2. Such calculations were the basis for the limitation of the static magnetic flux density to 2.5 T in the British (NRPB) MR safety recommendations.

Electrodynamic interactions with the flow of electrolyte solution lead to magnetohydrodynamic effects, resulting in the retardation of axial flow and an increase in intra-aortic pressure.

Magnetomechanical effects include magneto-orientation and magnetomechanical translation. Diamagnetic and paramagnetic molecules are subject to a torque force, which leads to an orientation in the field that minimizes their free energy. Several biological macromolecular structures have diamagnetic anisotropies and are subject to orientation in magnetic fields. One example of such a structure in mammals is the array of photopigments in retinal rod disk membranes.

Spatial gradients of static magnetic fields exert forces on paramagnetic and ferromagnetic structures that lead to a translation motion. This effect is of limited significance in mammalian systems, which contain little magnetic material. Magnetomechanical effects are, however, important if metallic inclusions or implants are present. Displacement or reorientation of such objects in the presence of magnetic fields may lead to injury.

Interactions at the atomic and nuclear levels may affect charge transfer reactions, such as growth, reproduction, prenatal and postnatal development, or behavioral and physiological parameters. (Athey 1992)

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