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Dosimetry of H-Coil in Deep Transcranial Magnetic Stimulation

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Abstract

This work aims at investigating the exposure experienced by the nursing staff executing deep transcranial magnetic stimulations (dTMS) using H-coil. The safety assessment was implemented by employing the H-coil and realistic human model. The distributions of magnetic flux density and induced electric fields in body tissues were obtained by impedance method. Results were compared with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Regarding occupational exposure, the nursing staff using H-coil can become exposed to magnetic field levels exceeding ICNIRP restrictions. We suggest the operator should stand at least 100 cm apart from the H-coil.

1 Introduction

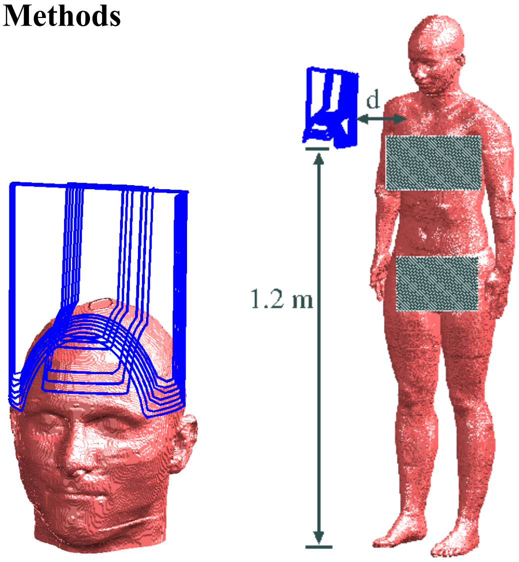
Transcranial magnetic stimulation (TMS) is a technique for noninvasive stimulation of the human brain. Magnetic fields are produced by passing a strong current through an electromagnetic coil placed upon the scalp that in turn induce electric field and eddy-currents in the underlying cortical tissue, thereby producing a localized axonal depolarization[1][2]. Stimulation of deeper brain structures by transcranial magnetic stimulation plays a role in the study of reward and motivation mechanisms, which will benefits for several diseases such as Parkinson, Addiction, and Epilepsy etc. that are related with the neuropsychiatric conditions in deep brain regions[3].

Standard TMS is applied with an electromagnetic coil called a round, or figure-of-eight coil which induces stimulation in cortical regions mainly just superficially under the windings of the coil. To stimulate deep brain tissues, the H-coil was developed for deep transcranial magnetic stimulation (dTMS) [4].

Exposure of the human body to time varying magnetic fields results in induction of internal body currents, may potentially cause health problems. The ICNIRP has set international guideline for limiting the human exposure to electromagnetic fields [5].

Although TMS is aimed at exposing patients, the nursing staff using these devices is easily exposed to magnetic pulses. Previous literatures have investigated the compliance of conventional round and figure-of-eight coils with the ICNIRP guidelines[6][7][8]. The purpose of the present study is to present dosimetry analysis for nursing staff exposed to magnetic pulses from H-coil in dTMS applications.

2 Methods



(a) (b)

Figure 1. H-coil with patient head (a), and H-coil with human body model (b).

The H-coil for patient treatment is shown in Figure 1(a). It is composed of a base portion running tangential to the scalp and return portions removed from the head. The coil with complicated winding patterns and larger dimensions is designed to generate the electric field in a specific brain region at a depth of 4~6 cm. The pulse current with amplitude of 5000 A and working frequency of 2.38 kHz was fed into the coil.

Exposure of H-coil for nursing staff is shown in Figure 1(b). The human model employed in this work was obtained from Virtual Family Project (VFP) [9]. This model was generated from MRI data of a 26-year-old female adult, comprising 77 separated tissues. The model is described using a uniform 3-D Cartesian grid and is composed of small cubic voxels. The size of each voxel is

1 mm x 1 mm x1 mm. There are 230 million voxels in the computational space.

The time variation of the applied magnetic field causes induced currents in the body through Faraday's induction mechanism. The magnetic flux density was calculated using Biot-Savart's Law, the induced current was calculated using the impedance method [10], and the induced electric fields were calculated using Ohm's Law. The electrical properties of body tissues were modeled using the 4-Cole-Cole method [11] and obtained by fitting to experimental measurements [12]. The tissue conductivities for part of the tissues are shown in Table I.

Table I. Tissue conductivities (σ) at f=2381 Hz.

Tissue	**σ (S/m)**	**Tissue**	**σ (S/m)**
Artery	7.00e-01	Hypothalam	5.26e-01
Blood.Vessel	3.10e-01	Mandible	2.03e-02
Cartilage	1.75e-01	Marrow-bone	2.44e-03
Cerebellum	1.24e-01	Muscle	3.31e-01
CSF	2.00e+00	Midbrain	4.65e-01
Eye-cornea	4.25e-01	Nerve	3.04e-02
Eye- humor	1.50e+00	Pineal-body	5.26e-01
FAT	2.32e-02	Pons	4.65e-01
Gray matter	1.04e-01	Skull	2.03e-02
Hippocampus	1.04e-01	Thalamus	1.04e-01
Hypophysis	5.26e-01	White Matter	6.44e-02

3 Results and discussions

For the working frequency of 2.38 kHz, the ICNIRP reference level (RL) is 126 uT for occupational exposure. The exposure level of the magnetic flux density (B-field) in human model was calculated by spatially averaging the magnetic flux density over the entire model (B_{avg}). The coil was placed at various distances facing the human model. The obtained results are shown in Table II. It was found that the B_{avg} exceed the ICNIRP RL at distance of 100 cm.

Table II. Calculated B-field and the ratio between the calculated value and the ICNIRP RL for occupational exposure.

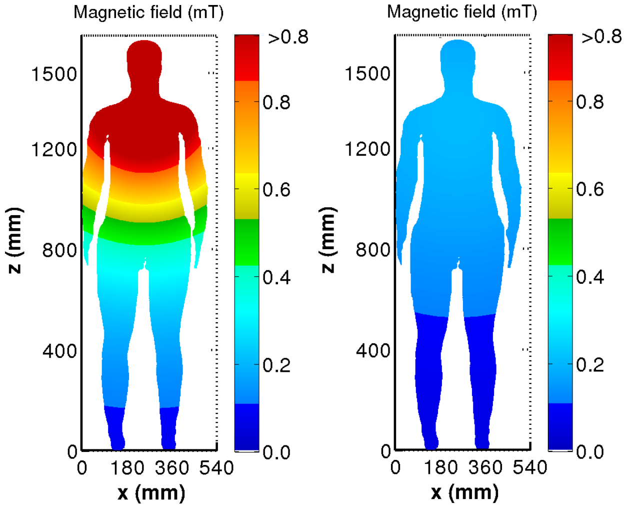
Distance (d) (cm)	B_{avg} (uT)	B_{RL} (uT)	Ratio B_{avg} / B_{RL}
50	646.4		5.13
100	160.5	126	1.27
150	65.1		0.52

In order to investigate the compliance of the H-coil with the ICNIRP basic restriction (BR), the induced electric field (E-field) in central nervous system (CNS) has been calculated. For the working frequency of 2.38 kHz, the BR limit is set at 0.8 V/m for occupational exposure. The maximum value of induced electric fields in CNS tissues were averaged over small contiguous tissue with volume of 2 mm x 2 mm x 2 mm (E_{avg}). The coil was placed at various distances facing the human model. The obtained results are shown in Table III. It was found that the E_{avg} is less than the ICNIRP BR at distance of 100 cm.

From Tables II and III, although the operator exposure exceeds the reference level at distance of 100 cm, the basic restriction is not exceeded, continuous exposure is allowed at the distance of 100 cm.

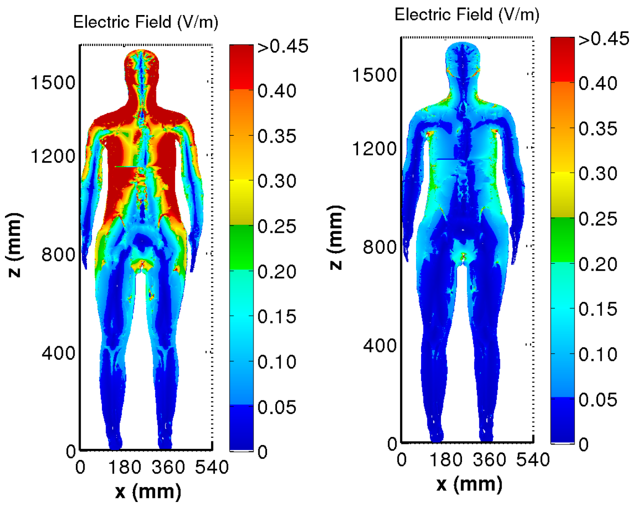
Table III. Calculated E-field in CNS and the ratio between the calculated value and the ICNIRP BR for occupational exposure.

Distance (d) (cm)	E_{avg} (V/m)	E_{BR} (V/m)	Ratio E_{avg} / E_{BR}
50	3.85		4.81
100	0.62	0.8	0.78
150	0.21		0.26



(a) (b)

Figure 2. Distribution of B-field (mT) in the coronal slice of y=119 mm for distance of 50cm (a) and 100cm (b).



(a) (b)

Figure 3. Distribution of E-field (V/m) in the coronal slice of y=119mm for distance of 50cm (a) and 100cm (b).

Dependence of the B-field distributions on the distance between the coil and the human model is shown in Figure 2. The slice is located in the coronal plane of y=190 mm. Dependence of the E-field distributions on the distance in the same slice is shown in Figure 3. As we expected, the stronger induced fields are presented in the tissues near H-coil at a distance of 50 cm, such as in the head, shoulders and chest etc. As the distance is increased to 100 cm, the induced fields in tissues decrease greatly.

The nursing staff working with patient treatments using H-coil can become exposed to magnetic field levels exceeding ICNIRP restrictions. According to the preliminary results in this study, the nursing staff should stand apart from the H-coil at least 100 cm.

Acknowledgements

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