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TRANSCRANIAL MAGNETIC STIMULATION – A 3-D ANATOMICAL SIMULATION

BY

CĂTĂLIN CURTA[*] and RADU CIUPA

Technical University of Cluj-Napoca

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Abstract. Transcranial magnetic stimulation (TMS) allows direct initiation of cortical activity, adding a new dimension to studies of the human brain. In TMS, cortical cells are stimulated noninvasive by strong magnetic field pulses that induce a flow of current in the tissue leading to membrane depolarization and thereby to neural excitation.

Recent developments have allowed the introduction of TMS in psychiatry for the treatment of drug resistant depressions. The treatment implies repetitive TMS applied to the brain, with protocols lasting for tens of minutes, in which thousands of impulses are applied by the stimulator.

The area stimulated in the treatment of depression is the prefrontal dorsolateral cortex. Since the aim of the treatment is the increase of the metabolism of the neurons in that girus, we designed a simulation to allow us to see the effects of the variable magnetic field on a realistic brain model. The coil was positioned on top of the left prefrontal dorsolateral cortex in order to evaluate the effects on the specific location.

Key words: transcranial magnetic stimulation; coil position; bioelectro-magnetism.

1. Introduction

Transcranial Magnetic Stimulation (TMS) allows direct initiation of cortical activity, adding a new dimension to studies of the human brain. In

[*] Corresponding author: *e-mail*: Catalin.Curta@et.utcluj.ro

TMS, the cortical cells are stimulated non-invasively by strong magnetic field pulses that induce a flow of current in the tissue leading to membrane depolarization and thereby to neural excitation.

TMS is used in neurology to determine different conditions by evaluating the cortical-motor threshold or to assess the continuity of nervous pathways.

In recent years TMS has proven its capabilities in treating psychiatric conditions like depression or schizophrenia. There is also a lot of research under development for the treatment of other psychiatric conditions (Pascual-Leone *et al.*, 1996; Fitzgerald & Daskalakis, 2003).

Because psychiatric treatments imply stimulation (or inhibition) of certain cortex gyrus, we designed a simulation to see the effects of a circular stimulation coil on a realistic model of the cortex.

1.1. TMS – Basic Principles

The neurons are stimulated by applying a rapidly changing magnetic field. In TMS the excitation is obtained through a pulse current that drives a coil situated in the vicinity of the head. The source of the activation of neurons is the electric field, **E**, induced in the tissue by the varying magnetic field, **B,** (Faraday's Law) (Ilmoniemi *et al.*, 1999) (Fig. 1)

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}. \qquad (1)$$

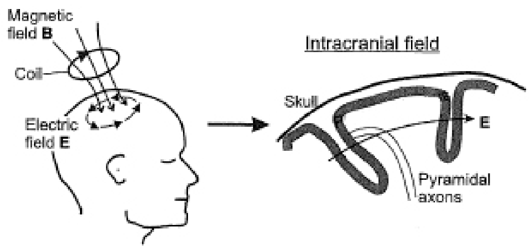


Fig. 1 – TMS mechanism – macroscopic view (Ilmoniemi *et al.*, 1999).

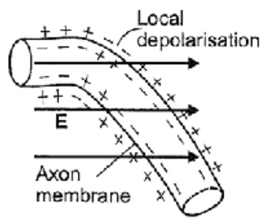


Fig. 2 – TMS mechanism – cellular level (Ilmoniemi *et al.*, 1999).

At cellular level the electric field, **E**, affects the transmembrane potential which may lead to local membrane depolarization and firing of the neuron (Ruohonen, 1998) (Fig. 2).

In this paper, the authors use a 3-D brain model in order to determine the electric field distribution supposed to be induced by TMS using a circular coil.

2. Simulation Setup

Because the surface of the cortex is highly irregular, we wanted to view the effects of stimulation on a realistic brain model. To reach our goal we designed a 70 mm copper circular coil placed in the vicinity of the brain. The brain is represented by an anatomically correct right side cortex.

The coil is excited by a 1 kA current with a frequency of 5 kHz, which corresponds to duration of 200 µs for each pulse, similar to the generally accepted time frames for TMS (Wassermann *et al.*, 2008).

The cortex was modeled as a 3-D solid object composed of 268 faces (Fig. 3). Conductivity of the brain was set according to recent research regarding brain conductivity. For body temperature and frequencies between 10 Hz…10 kHz the conductivity was set to 1.79 S/m (Baumann *et al*., 1997).

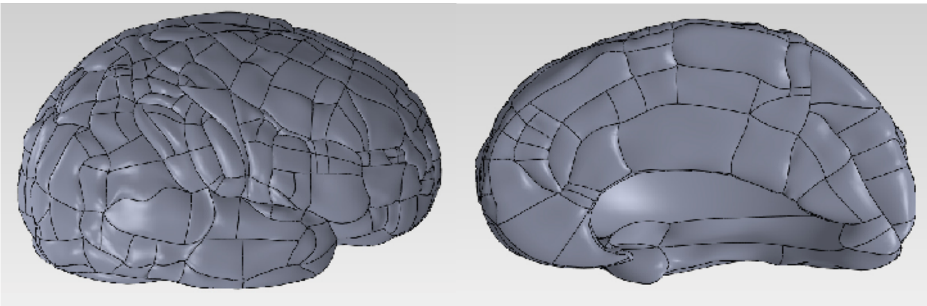


Fig. 3 – Cortex views.

The exterior diameter of the coil is 70 mm, and the interior ones 40 mm. The coil and cortex objects were included in a sphere containing air. To mimic realistic stimulation conditions, the coil was positioned parallel to the scalp, rather than to the surface of the cortex (Fig. 4).

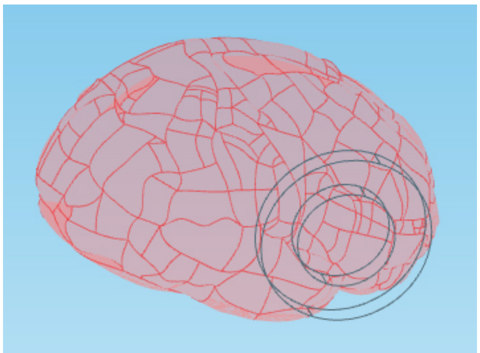


Fig. 4 – Overview for the position of the coil relative to the brain.

3. Results and Discussions

The solution was obtained for 950,792 degrees of freedom. The overview of the results is in concordance with our expectations – the biggest values for induced electric field are located under the coil. But the distribution is not uniform. Although one could expect bigger values for the electric field in the gyri, since they are closer to the coil, we find higher intensities along the lines between them (Fig. 5).

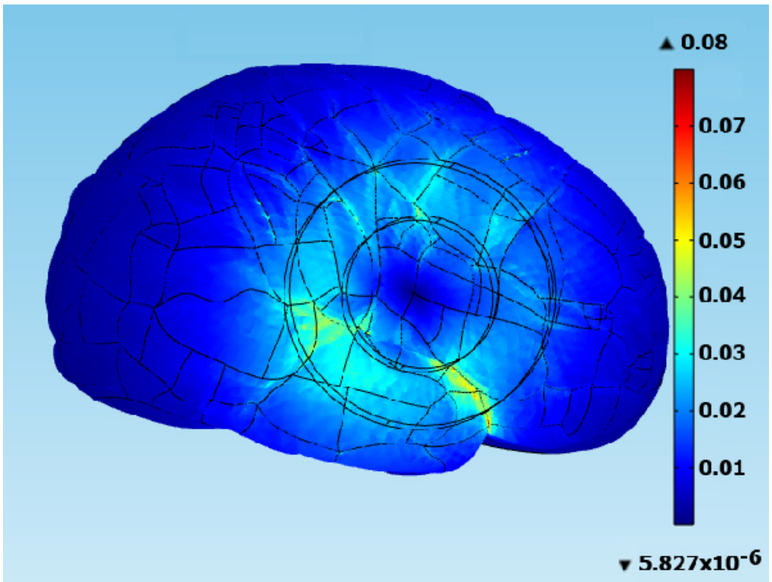
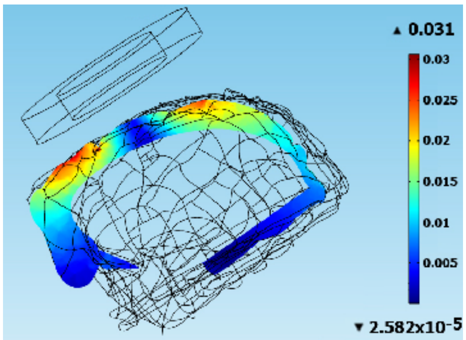


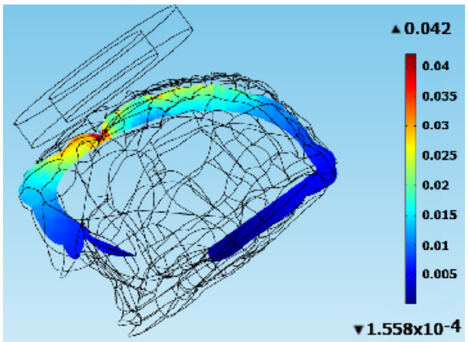
Fig. 5 – Overview of induced electric field, [V/m].

If we look at different slices through the cortex, we realize that the biggest values for the electric field are not necessarily in the closest vicinity of the coil, but rather in the tight sulci (depressions or fissures in the surface of the brain). This means that stimulation can occur at rather smaller power levels between gyri (Fig. 6).

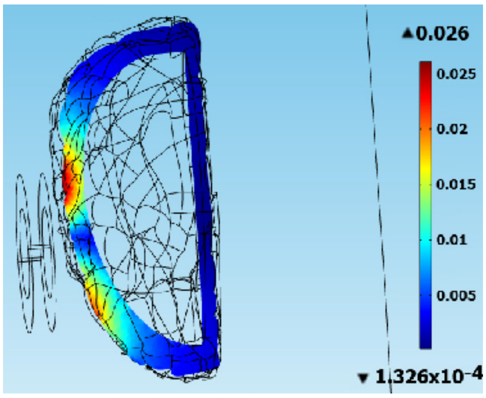
Analysing the obtained results we see that the electric field intensity is 25%…30% higher in the sulci then in the gyri (Figs. 6 *a*…*d*). Also, the highest values of the electric field are in one sulcus, despite the fact that this sulcus is not the closest to the coil (Figs. 6 *e*…*f*). The maximum value in that sulcus is double the value in the gyri under the coil (compare Figs. 6 *a*…*f* and *c*…*e*).



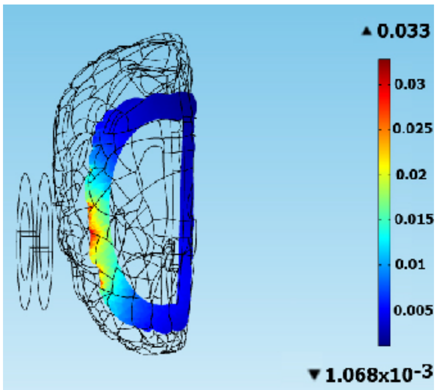
a – vertical slice, 0 mm



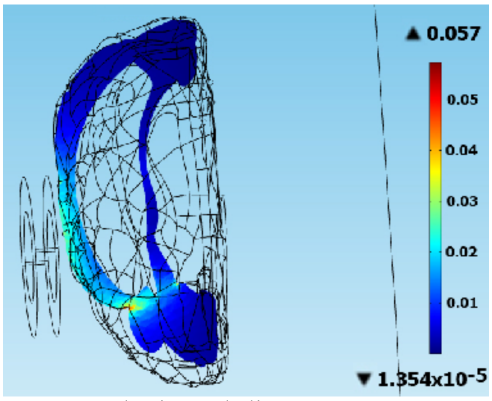
b – vertical slice, 20 mm



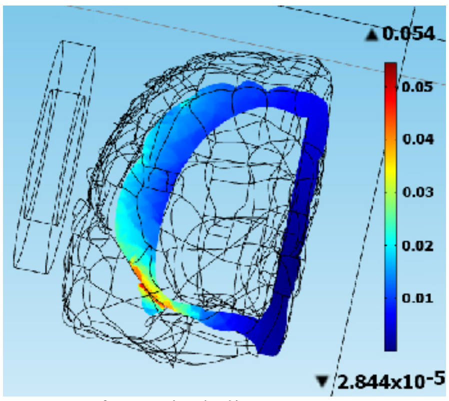
c – horizontal slice, 0 mm



d – horizontal slice, 23 mm



e – horizontal slice, –36 mm



f – vertical slice, –21 mm

Fig. 6 – Slices for induced electric field, [V/m]; distances are taken relative to the center of the coil; *a*…*b* and *c*…*d* – comparative slices, *e*…*f* – slices showing area with maximum value for the electric field.

4. Conclusions

The obtained results show that the shape of the targeted area of the cortex greatly influences the distribution of the induced electric field during TMS. This effect has a big impact on the locus of stimulation, and should be taken into consideration by physicians when applying TMS.

More studies are needed to confirm our findings, including more complete models that contain the scalp, skull, cerebro-spinal fluid and the cortex.

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STIMULARE MAGNETICĂ TRANSCRANIANĂ – O SIMULARE 3-D ANATOMICĂ

(Rezumat)

Stimularea magnetică transcraniană (SMT) permite inițierea directă sau manipularea activității corticale, aducând o nouă dimensiune studiilor asupra creierului uman. Prin SMT celulele corticale sunt stimulate neinvaziv prin pulsuri ale unui câmp magnetic puternic care induce un curent în țesut ducând la depolarizarea membranei şi deci la excitarea neurală.

Cercetările recente au permis introducerea SMT în psihiatrie pentru tratamentul depresiilor rezistente la medicație. Tratamentul presupune SMT repetitiv, cu protocoale care durează zeci de minute şi în care mii de impulsuri sunt aplicate cu ajutorul stimulatorului.

Aria stimulată în tratamentul depresiilor este cortexul prefrontal dorsolateral. Deoarece scopul tratamentului este creşterea metabolismului neuronilor din acel gyrus, am realizat o simulare care să ne permită să estimăm efectele câmpului magnetic variabil în timp asupra unui model realist de creier. Bobina a fost poziționată în dreptul cortexului prefrontal dorsolateral drept pentru a evalua efectele câmpului magnetic asupra zonei respective.