Modeling transcranial stimulation using a realistic volume conductor model

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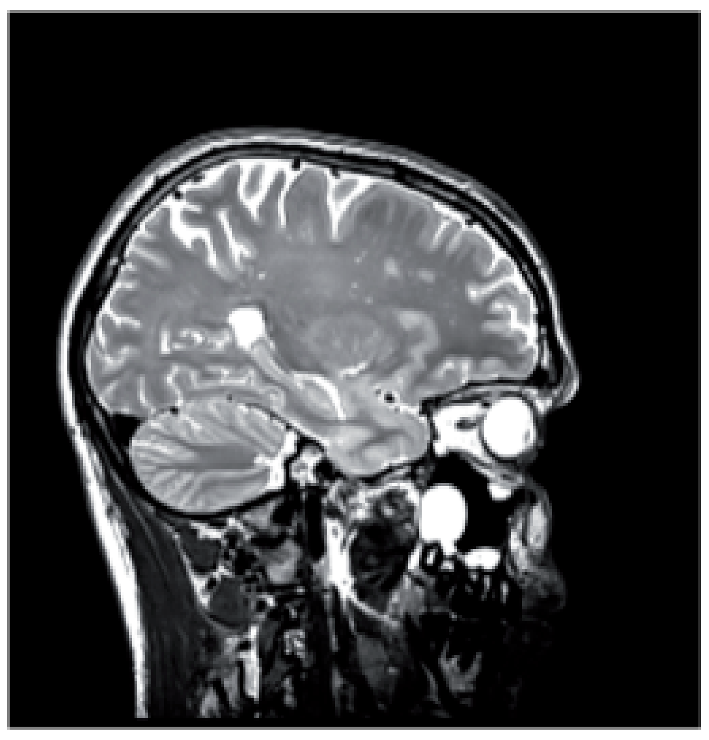
Introduction

Transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) are techniques that can induce changes in cortical excitability of stimulated brain area. These techniques are non-invasive and easy to apply. Over the last years transcranial stimulation has been used in a wide range of neurophysiological studies and also the first clinical applications have been described. Nevertheless, the underlying mechanisms of TMS and tDCS are still unclear. To optimize the effects a clear understanding of the underlying mechanisms is needed. Part of that concerns the estimation of the current flow induced in brain structures. In order to achieve this, a precise volume conductor simulation model of the current induced in the human head has been developed.

Volume Conductor Model

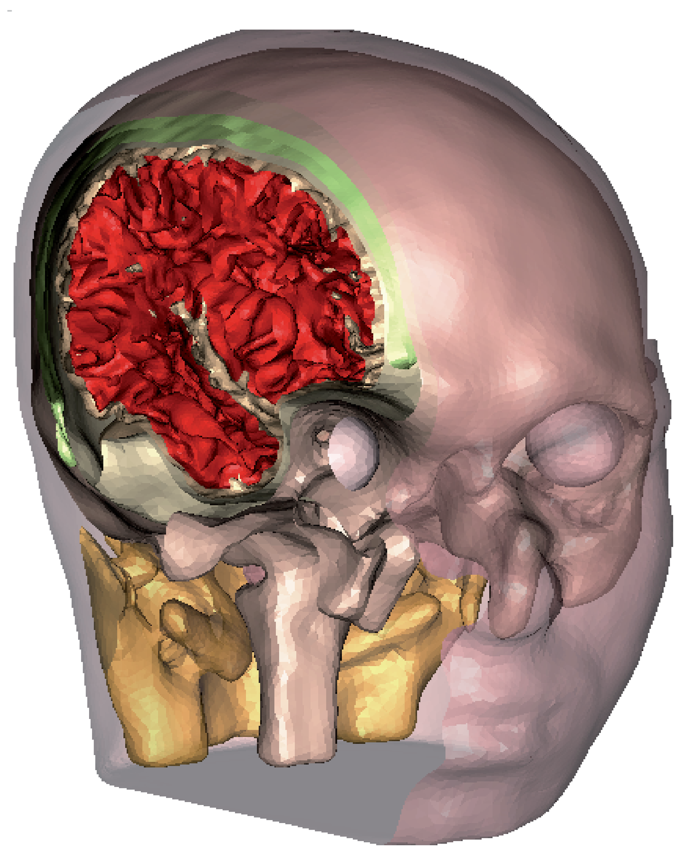
We created a tetrahedral model with more than 3 million elements based on magnetic resonance imaging (MRI) data. It includes 8 different tissue types: skin, skull compacta, skull spongiosa, cerebralspinal fluid, grey matter, white matter, neck muscle and eyes. The model also includes holes in the skull where the optic nerve enters the skull and at the foramen magnum. The model is inhomogeneous and allows implementation of anisotropy.

The construction process:

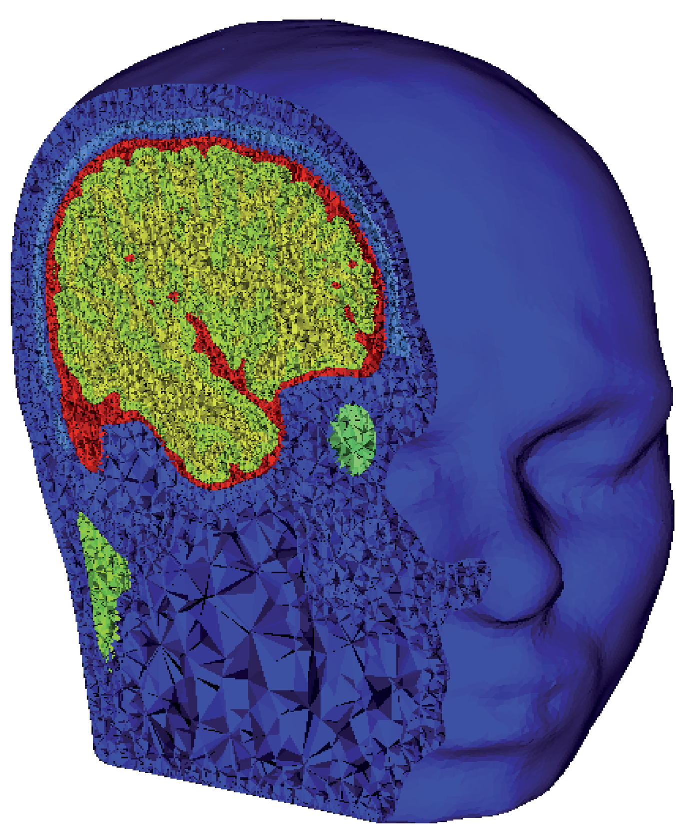


1.) T1 and T2 MRI dataset

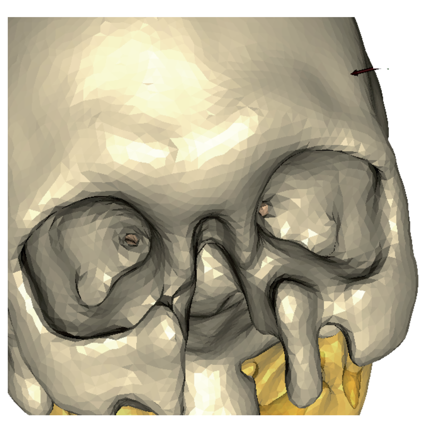
2.) Automatic segmentation followed by manual corrections



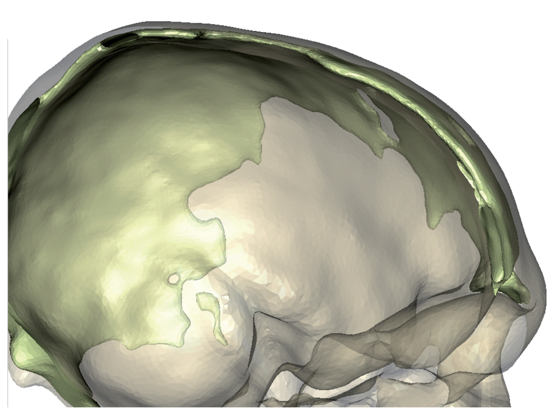
3.) Construction of triangular surfaces



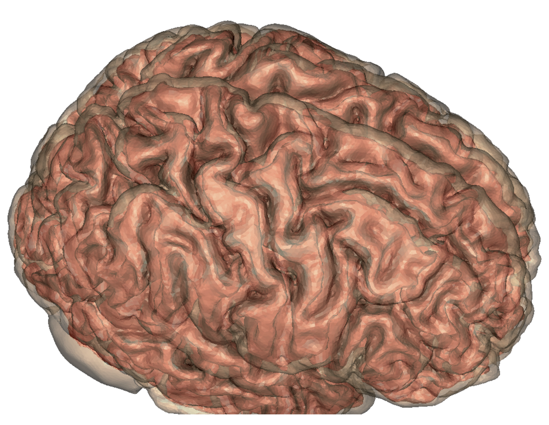
4.) Construction of tetrahedral mesh



Holes in the skull at the point where the optic nerve passes



Skull spongiosa surface inside skull compacta surface

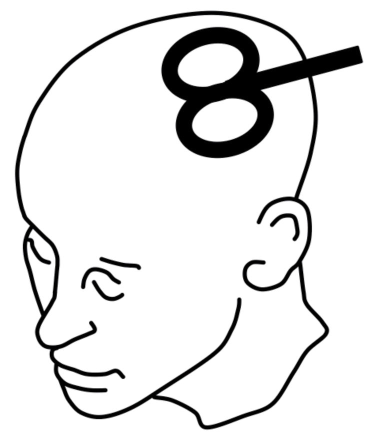


Highly accurate mesh of the grey and white matter

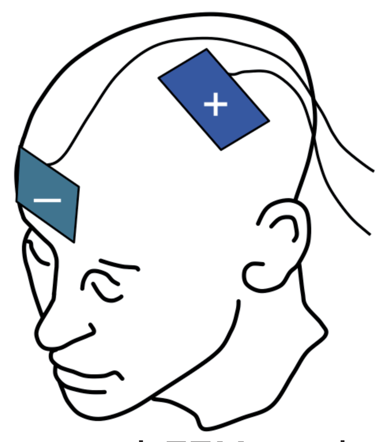
Transcranial Stimulation modeling

The goal of this study was to get an estimation of the current flow in the brain caused by TMS and tDCS with the finite element methode (FEM). The description of the problem for both techniques is similar.

In TMS the induced current flow is caused by a magnetic field, produced by a rapidly changing current in the stimulation coil. For simulating TMS, the forward biolectric problem can be described via Poisson's equation with Neumann boundary conditions on the surface.



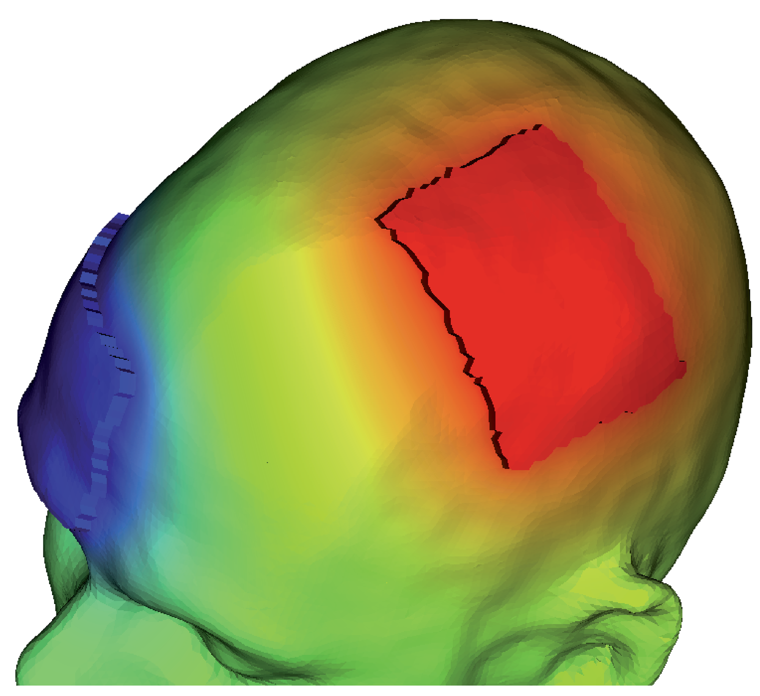
In tDCS the induced current flow is produced by a weak direct current (1-2 mA) sent through two electrode pads placed on the scalp.This forward bioelectric problem can be described by Laplace's equation with Dirichlet boundary conditions at the electrodes and Neumann boundary conditions on the remaining surface.



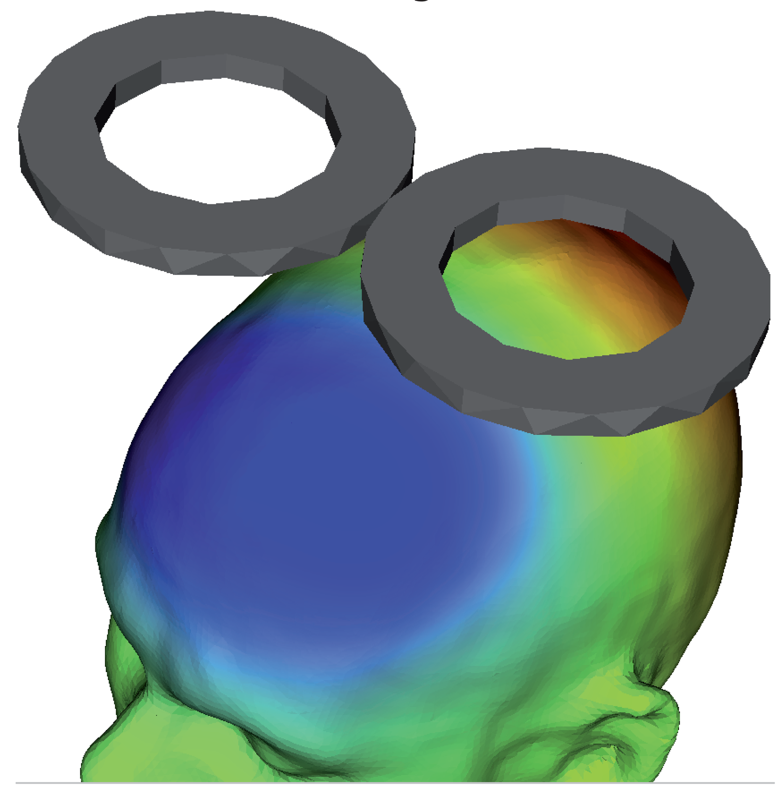
Both problems can be implemented and solved with several FEM packages. For this study the freely available SCIRun software was used. (http://software.sci.utah.edu)

Results

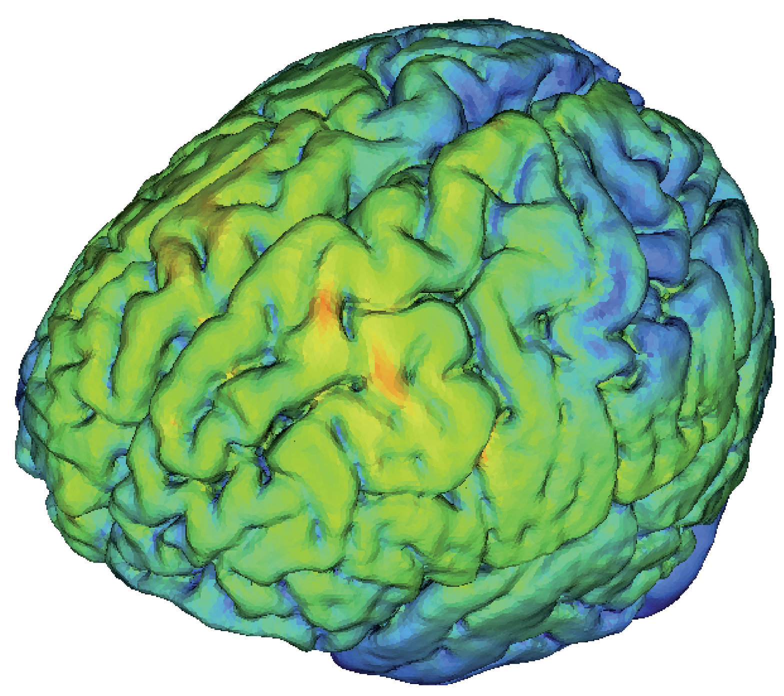
The preliminary results show that the induced current can be successfully calculated with the realistic volume conductor model using FEM.



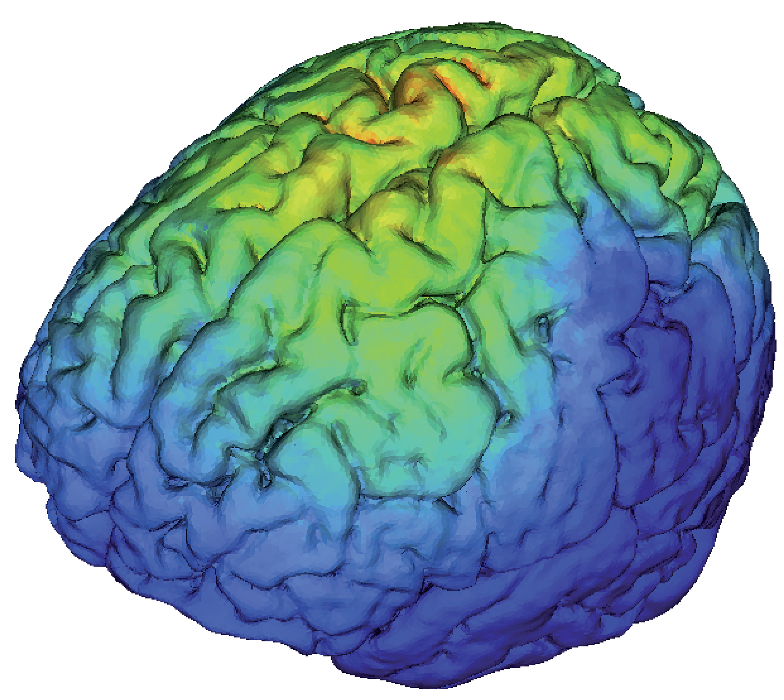
The potential φ on the scalp caused by the tDCS current (V/m)



The potential φ on the scalp caused by the TMS field (V/m)



The current density J induced by tDCS calculated on the brain surface (A/m²)



The current density J induced by TMS calculated on the brain surface (A/m²)

Discussion

The realistic volume conductor model can be successfully used to predict the induced current density for transcranial stimulation with FEM. Future plans are:

* Include diffusion tensor imaging (DTI) data for anisotropy in the brain.
* Find optimal coil/electrode configuration for maximal cortical current density in targeted area.
* Study the relative effects of several human head properties.
* Validation of model results with potential distribution measured on scalp (EEG).