Numerical Estimate of the Induced Electric Field along Neuronal Fibers: Influence of TMS Coil Orientation

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The navigated Transcranial Magnetic Stimulation (nTMS) has recently proved to be a valid and promising tool both for the therapeutic treatment of a wide range of neurological and psychiatric disorders [1], both for pre-surgical planning in patients with brain tumor lesions [2]. In both cases, it is of crucial importance the knowledge of the electric field (E) distribution induced in the brain regions of interest by the a coil placed near the scalp is required. Generally, stimulation is considered effective if the intensity of E exceeds a certain threshold, of the order of 80-100 V/m. Recent studies have shown that the effectiveness of a TMS application significantly depends on the coupling of the E field in the direction of the neuronal fibers [3] as well as on the local intensity. Aim of this work is to provide a tool, based on the rigorous calculation of the E field along the neuronal fibers, that provides the best coil positioning to induce the stimulation of the region of interest.

The induced E field is calculated, by means of a custom code implementing the admittance method [4], inside the entire volume a realistic brain model taken from Duke of the virtual population (v.1.0, Zurich Med Tech AG, Zurich, Switzerland, [5]), including gray matter (GM) ($\varepsilon=6.7\times10^4$, $\sigma=0.1$ S/m), white matter (WM) ($\varepsilon=3.01\times10^4$, $\sigma=0.065$ S/m) and cerebrospinal fluid (CSF) ($\varepsilon=109$, $\sigma=2$ S/m) [5]. The TMS coil is the MAG-9925-00 (Magstim), placed in correspondence of the primary motor cortex (M1), at a distance of 5 mm from the scalp and rotated along the vertical axis through the center of the coil of 24 counterclockwise angles, from 0° to 360° in steps of 15°, with respect to the sagittal plane. The current flowing through the coil is a 3 kHz sinusoid with amplitude equal to 2 kA. In the post-processing step, the E-field component parallel to the fibers is extracted to give technical indications to the operator on the stimulation parameters able to induce effective stimulation of the region of interest.

Results show that both the E maximum and its position in the brain cortex are strongly affected by the coil rotation angle, with a shift of the maximum position of ± 1 cm. Thus, the maximum E field is not necessarily coincident with the region under the coil focus but depends on cortical circumvolutions and coil orientation. The E-field component along the axon of a pyramidal fiber placed in the post-central gyrus varies between 44 V/m and 114 V/m, with the maximum value corresponding to a rotation angle of 45°. Specifically, the induced E-field along the fiber overcomes the motor stimulation threshold of 100 V/m only if the coil is oriented between 15° and 60°. Results of this study confirm the importance of an accurate E field calculation, for the identification of optimum coil position and orientation. Future developments include a more realistic evaluation of fiber directions taken from DTI images to be inserted in the brain model and the introduction of anisotropic properties of white matter in the E field calculation.

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