Focused Transcranial Magnetic Stimulation

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Abstract: Transcranial Magnetic Stimulation is a non-invasive technique used to regulate the synaptic activity of neurons, improving the functionality of several regions and bringing effective treatment to neurological and psychiatric disorders[1], [2]. These conditions can be treated by applying external time-varying magnetic fields to superficial regions of the brain, but most of them originate in deeper areas [3]–[5]. The stimulation of small areas in animals like rodents is not easy, since most of the studies in TMS use commercial equipment for human, with power and coil geometries not designed for small animals. This work presents the design and evaluation of a customized conical coil with a MnZn ferrite core [6], [7] to increase the focality in areas as small as 2mm of radius using finite element analysis with ANSYS Maxwell software. Three scenarios of tip sharpening are evaluated at the average lambda-bregma distance in adult mice, through a novel definition of focality that shows the effectiveness of the coil to perform in vivo experimentation on rodents.

METHODS: Using ANSYS Maxwell software, finite element simulations were conducted for a conical coil. A cylindrical MnZn Ferrite core with tip-sharpening variation is used to generate three cases of study: 180°, 120° and 60° of opening angle in the tip. The geometry of the coil is a truncated cone of 174.4mm height, with 20mm and 60mm of diameter in the circumferences of the bottom and the top. The material used were standard copper for windings and air of standard properties for the surroundings -both selected from the ANSYS-MAXWELL Data Base- along with MnZn Ferrite for the core, with initial relative magnetic permeability of 2200 at 1mT. A 1000A dc current was used to study the geometric distribution of the flux density (B). Frequency effects/losses are ignored due to the quasi-invariant complex permeability for the MnZn ferrite in the TMS

| Actual Layer in the Rat Head | Layer in the Simplified Head Model | Thickness (μm) | Electrical Conductivity (σ) [S/m] | Relative Electric Permittivity ($\varepsilon_r$) | Relative Magnetic Permeability ($\mu_r$) |
|---|---|---|---|---|---|
| Scalp | Scalp | 500 | 0.17 | 12000 | ≈ 1 |
| Periosteum | | 100 | Approximated to the same as the scalp | | |
| Skull | Skull | 1000 | 0.01 | 800 | ≈ 1 |
| Dura mater | | 300 | Approximated to the same as the skull | | |
| Aracnoid | Cerebrospinal Fluid (CSF) | 75 | 1.654 | 6000 | ≈ 1 |
| Subaracnoid S. | | 750 | Approximated to the same as the CSF | | |
| Pia Matter | Brain cortex | 25 | Approximated to the same as the GM | | |
| Gray Matter (GM) | | -- | 0.276 | 12000 | ≈ 1 |

Table 1: Properties of brain regions used in the calculation of induced stimulation electric fields

range (up to 3KHz). A definition for the focality is proposed, based on B and the proximity between the stimulated and the targeted areas.

RESULTS: The results show focalities for the threshold of 30% bigger than those for the 70% due to the difference of area under the curve and the bigger proximity for the first case between the radius of the targeted area and the stimulated area which results in higher weights assigned by the erfc. The coil of 120° in the tip resulted the more suitable to stimulate an area of 20mm of radius at the specified distance without overstimulate the outer region beyond the 30% of B.

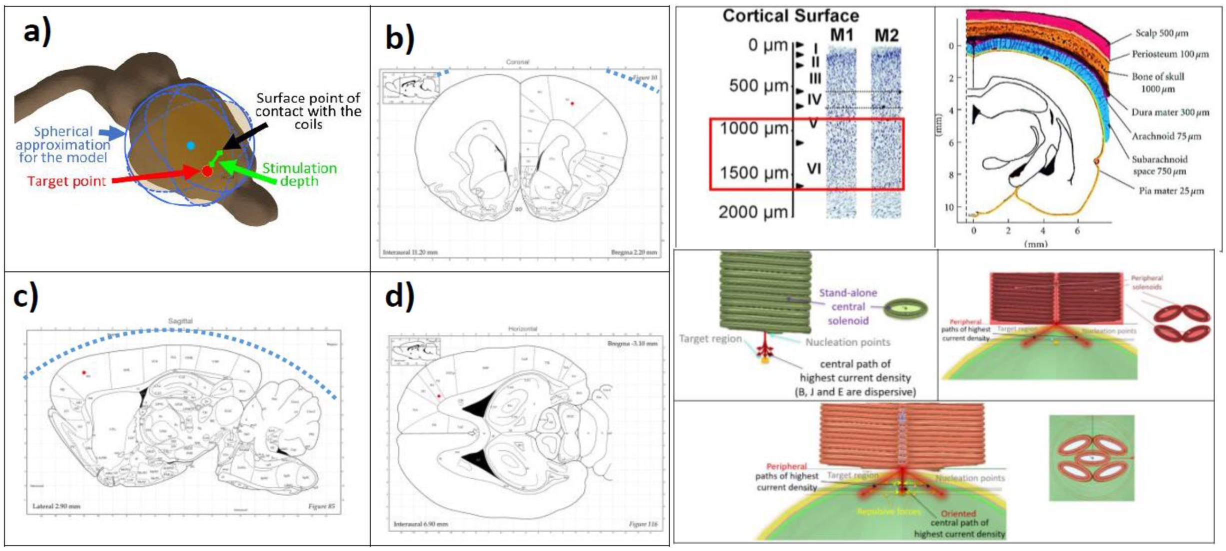


**Fig1. a) 3D model of the rat brain surface. Target coordinates in the Rat Brain Atlas. b) Coronal plane c) Sagittal plane. d) Hor. plane. Stand-alone central solenoid. b) Right top: Depth by layer in the rat brain cortex. Thickness by layer in the rat head. Right bottom: Stand-alone central solenoid, Quadruple arrangement of peripheral solenoids and oriented control of J and E with the quintuple arrangement of elliptical solenoids.**

DISCUSSION & CONCLUSION: The work demonstrated that sharpened cores increase the flux density in the neighborhood of the tip, useful if the target is close enough. Different core materials can increase the saturation point, but this does not increase the flux density significantly outside the tip (1 or 2 mm). However, the effect in the energy distribution -and thus in the focality- would still be notable. The attenuation also affects the focality increasing the dispersion of the flux lines in successive planes from the tip.

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