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Deep and Localized Transcranial Magnetic Stimulation in Rat Using Conventional Round Coil

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Abstract

Transcranial magnetic stimulation (TMS) shows significant values in both brain research and therapeutic applications in the treatment of various psychiatric and neurological disorders. Animal studies of TMS plays an important role in understanding of the cellular and molecular mechanisms underlying TMS induced effects in the brain. This work investigated TMS in rat brain by employing conventional round coil with varied coil positions. Three dimensional distributions of induced electric field in realistic rat model were calculated by 3-D impedance method. Simulations results indicated that the conventional round coil can be applied to rat TMS with improved focality while also keeping high stimulation intensities in deep brain regions.

1 Introduction

Transcranial magnetic stimulation (TMS) uses rapidly changing magnetic fields to induce electric field in the brain, leading to excitation of neurons [1,2]. Although TMS has achieved success in the treatment of various psychiatric and neurological disorders, no nclear-cut conclusions have been reached on the underlying cellular and molecular mechanisms as well as the therapeutic mechanism in used in clinical practice. Animal models are helpful in elucidating some mechanisms of TMS as we are allowed to carry out invasive studies of molecular and genetic changes which are ethically not possible to be done on human beings [3, 4].

A limitation of current rat TMS studies are the use of existing human stimulator coils which are larger than the rat brain, resulting in high intensity but non-focal stimulation [5]. In order to delivers more focal stimulation in rat, smaller coils were developed at the expense of stimulation intensity. Although computational research on comparing TMS coils used for rats was reported, little is published on the use of conventional human round TMS coils on rats for realization of both the stimulation focality as well as penetration depth.

2 Methods

The realistic rat model was obtained from Brooks Air Force Laboratory (BAFL), USA. There are 36 different tissues in rat model which is composed of more than 1.6 million cubic voxels with resolution of 0.5 mm x 1 mm x 0.5 mm. The conventional round coil for rat TMS with different coil positions are shown in Figure 1. In Figure 1(a), the coil is oriented parallel to the head, centered above the cerebral hemisphere (case-1). The next arrangement is due to the same coil but vertically placed surrounding the rat head (Figure 1(b)) (case-2). In Figure 1(c), the coil was oriented to be erect above the rat head (case-3). Rat model with inclined round coil is shown in Figure 1(d) (case-4). The round coil has inner and outer radii of 25 mm and 45 mm, respectively. The number of the wire turns for the coil is 10. The injected currents with the magnitude of I=7.7 kA and working frequency of f =3.6 kHz was fed into the coil.

The time variation of the applied magnetic field causes induced currents in rat 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 [6], and the induced electric fields were calculated using Ohm's Law. The electrical properties of rat tissues were modeled using the 4-Cole-Cole method [7] and obtained by fitting to experimental measurements [8].

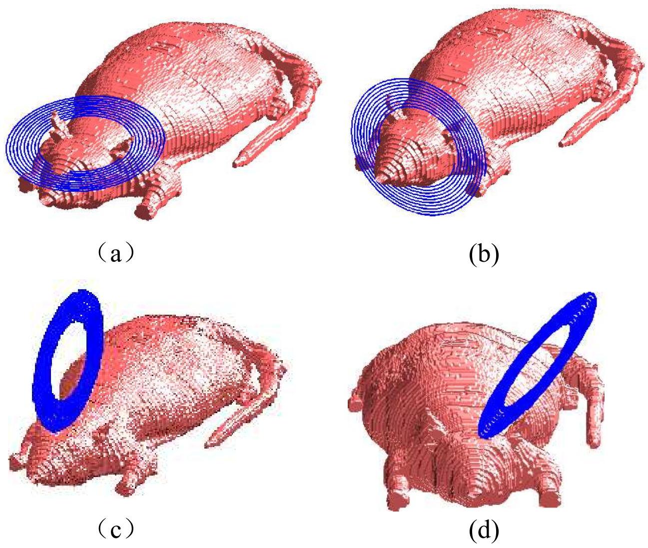


Figure 1. Rat model with conventional round coil at different positions: (a) case-1, (b) case-2 (c) case-3, and (d) case-4.

3 Results and discussions

Figures 2 shows the typical head slice in the coronal plane of y=52 mm. Where the brain tissues were indicated in the figure.

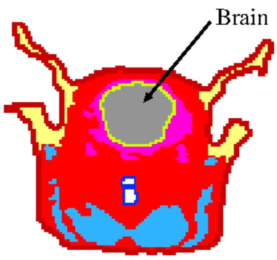
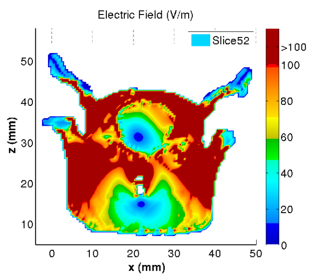


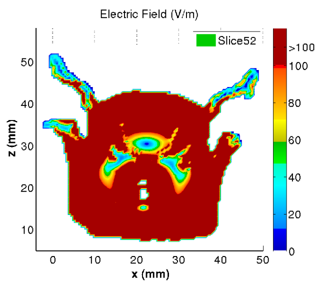
Figure 2. Head tissues at coronal slice of y=52 mm.

Distributions of induced electric field (E-field) in typical coronal slices of y=52 mm are shown in Figure 3. To keep the dynamic range in the picture while still being able to discuss the region of large field values, nonlinear color bars are employed in these figures. The color palette is linear up to stimulation threshold 100 V/m (neuron excitation threshold) and then constant (dark red color) above threshold.

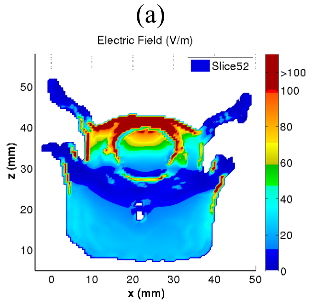
For the coil horizontally placed on the surface of the rat head (case-1), the induced fields in head tissues are larger than that in rat brain (Figure 3(a)). It means the coil in this position is not favorable for stimulation. While for the coil placed around the rat head (case-2), the induced electric fields are too strong resulting in the whole brain excitation (Figure 3(b)). Only for the case that the coil was oriented to be erect on the surface of the rat head (case-3), the focal stimulation were realized (Figure 3(c)). For the coil position of case-4, the better stimulation depth was achieved (Figure 3(d)).



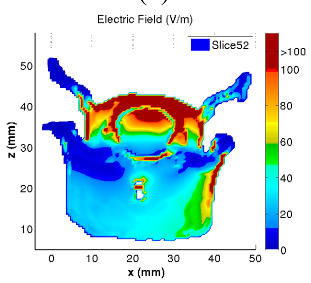
(a)



(b)



(c)



(d)

Figure 3. Distribution of E-field (V/m) in the coronal slice of y=52 mm for different coil positions. (a) case-1, (b) case-2, (c) case-3, and (d) case-4.

Results in this paper show that the coil position have serious effects on the field distributions in rat brain. The conventional human round coil can be directly used in rat TMS by setting the coil oriented to be erect on the surface of the rat head. The reasonable stimulation focality and penetration depth can be achieved by placing the coil with different inclination angles.

Acknowledgements

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