NUMERICAL INVESTIGATION OF THE ELECTRIC FIELD DISTRIBUTION INDUCED IN THE BRAIN BY TRANSCRANIAL MAGNETIC STIMULATION (TMS)

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INTRODUCTION

There has been considerable interest over the years in the treatment of serious physiological and clinical conditions, such as depression and pain relief, by utilising electromagnetic fields through Transcranial Magnetic Stimulation (TMS) of the human brain [1]. Most of the effort has recently focused on the attempt to stimulate neurons deep inside the brain mass and to limit any hazards posed by this treatment. As a result, there is a need for new TMS coil configurations to generate sufficient and localized electric fields to achieve deep stimulation.

The advent of more powerful computers and the emergence of more accurate models for the electric properties and shape of the human brain have enabled numerical modelling to become a significant and reliable tool for the design and optimisation of such new TMS devices in order to achieve the above requirements. The experimental prediction of the electric field distribution is still a formidable task so simulation of the fields induced inside the brain, is crucial in the optimisation and design of the stimulus coils.

This paper presents results on the simulation of TMS by using the Finite Element Method (FEM) in three dimensions and looks at the effects of the stimulation coils and geometrical model of the head on the distribution and penetration of the electric field induced in the brain during TMS. It is revealed that the incorporation of an accurate brain model in terms of shape as well as conductivity values is crucial for an improved estimation of field distribution and threshold fields inside the brain.

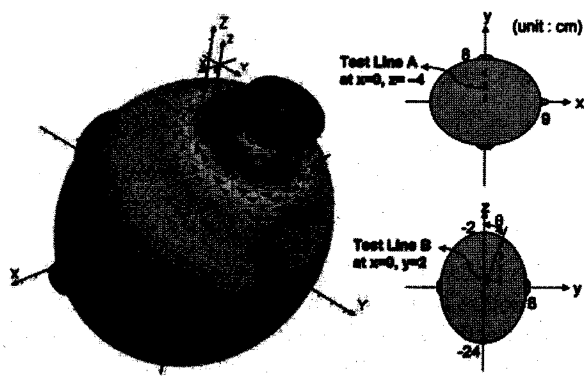
FIELD COMPUTATION

The quasi-static approximation of electromagnetic fields generated inside the brain is valid for most biological tissues at low frequencies and linear material properties and hence has been adopted here. The calculations of the three-dimensional electric field and current distributions induced in the brain have been performed by using the FEM and in order to reduce the computing time required without any loss of accuracy, the hybrid formulation has been implemented. In the air region linear tetrahedral elements have been used for the reduced scalar potential, whereas in the brain, quadratic tetrahedral elements have been employed.

RESULTS

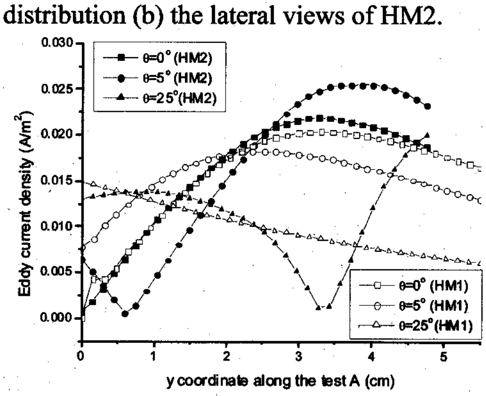
In order to look at the effects of the geometrical shape of the head, two different models have been used. The first is the traditional sphere model (HM 1) of radius 10 cm adopted in the majority of studies involving intracranial distribution of the induced electric fields and the second one (HM 2) incorporates different radii along the three axes as shown in Fig. 1. The stimulator consists of a 30-turn circular coil placed 2.0 cm above the vertex of the two models with a cross section of 0.1 cm × 0.1cm and effective radius of 2 cm. The coil was excited with an amplitude of 1 A and a frequency of 10 kHz. The homogeneous and isotropic conductivity of 0.4 S/m is assumed, here.

Fig. 1 shows the induced electric field distribution in HM2 when the coil was tilted by 25° against the rotating axis parallel to the x-axis and passing through the centre of the brain located at (0,0,-12 cm). It can be seen that the presence of ears in the head model affects the flow of the induced fields on the surface of the head. Fig. 2 depicts the effect of the tilting angle on the two head models and it is apparent that the outer shape of the head model significantly alters the current density distributions inside the brain. As the tilting angle increases, the difference in the field distribution obtained by the two head models increases, as can be seen clearly in Fig 2(a).

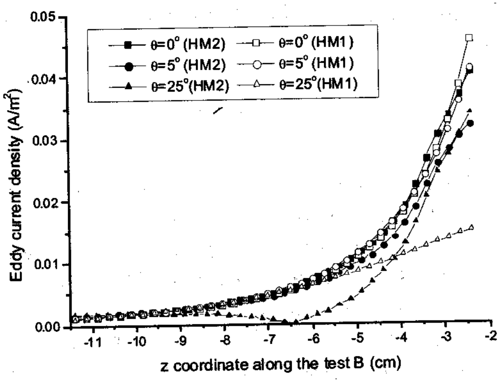


(a) (b)

Fig. 1. (a) Head Model HM2 and the induced electric field distribution (b) the lateral views of HM2.



(a)



(b)

Fig. 2. Comparison of the induced current density distributions between the two head models, HM1 and HM2 (a) along Test line A and (b) along Test line B specified in Fig. 1.

The single coil magnetic stimulator is then replaced by a figure-of-eight (FOE) coil also widely used in commercial devices [2]. This consists of an eight-shaped coil with a driving current in opposite direction and each coil plane has a slope of 30° to the x-y plane. The induced electric field distribution on the cutting surface is shown in Fig. 3.

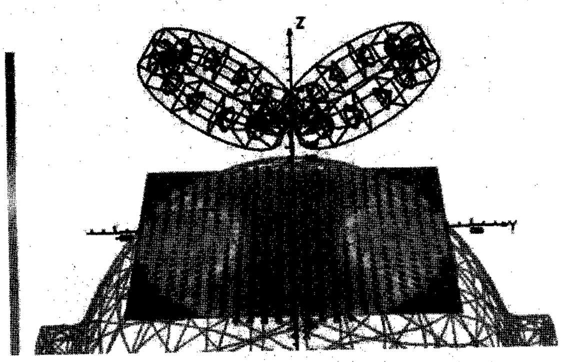


Fig. 3. The electric field distribution induced by the FOE coils on the x-y plane located at z=-4 cm.

The localisation of the induced fields, which is a very important parameter in the design of TMS stimulators is assessed by the half-power region (HPR), which is defined as the region within which the magnitude of the normalized field is greater than about 0.7. Fig. 4 presents the comparison of the field localization between the two coils with each coil plane being parallel to the x-y plane and it can be seen that the FOE coil produces a more focused pattern evidenced by the smaller value of HPR.

Finally, the effect of the head geometry and coil shape on the induced field distribution along test line A is presented in Fig. 5 for two different tilting angles, 0° and 30° against the x-axis. Fig. 5 clearly demonstrates that even though the coil was located right above the head, the different head models caused a field deviation of more than 17% in terms of HPR, which is quite significant. Furthermore, the slope between the coil plane and the x-y plane reduces the field intensity throughout, both inside and outside the HPR. This is attributed to the reduced mutual inductance obtained as the tilting angle is increased.

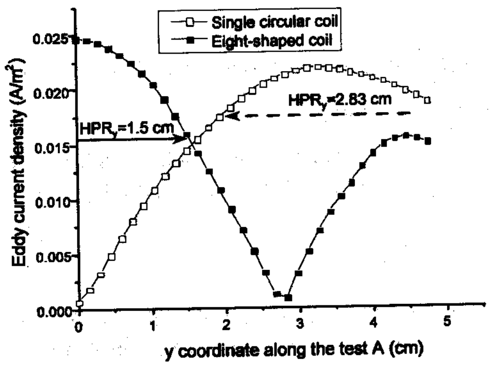


Fig. 4. Comparison of field localization along the Test line A where HPR$_y$ is the largest y component of HPR.

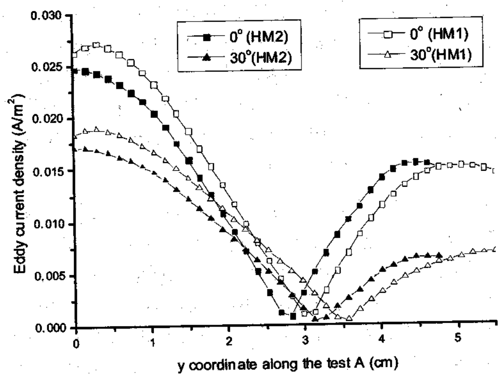


Fig. 5. The induced electric field distribution along the Test line A versus the two head models.

CONCLUSIONS

In this paper three-dimensional results of the field induced during TMS of the brain have been presented. Two different geometrical head models and coil configurations were considered in order to establish the effect of these parameters on the electric field distribution and more particularly on the localisation.

Work is under way to incorporate realistic geometrical models of the human head and anisotropic, inhomogeneous conductivity values. Finally, once an accurate model of the human head is established, design and optimisation of the stimulating coils for deep neuron stimulation will be carried out.

REFERENCES

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