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Improved Stimulating Efficacy in Transcranial Magnetic Stimulation(TMS) with Semi - ellipse Coil

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I INTRODUCTION

Transcranial magnetic stimulation (TMS) is a procedure based on electromagnetic induction to excite nerves noninvasively and painlessly without the need of surgery. TMS has great potential in treatment of physical and mental disorders whose mechanisms have been explored.

However, inadequate coil configuration innovation and optimization lead to lower effectiveness and limit its wider range of applications. Ideal therapeutic effect comes from hyperpolarization or depolarization of neural responses which means the induced field should be strong enough to cause neuromodulation at targeted tissues.

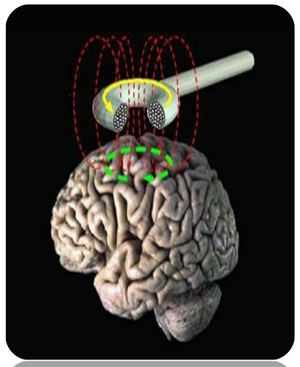

Fig1. TMS Schematic Diagram

II METHODS

In order to boost induced electric field intensity and improve the stimulation focalization, a semi-ellipse coil pair (SEP) of special coil configuration is designed and introduced. Projected onto a plane parallel to stimulating target, the two adjacent coils are in semi-ellipse shape. From the front view, the SEP is bended along a symmetrical axis at specific radians. The Finite-Element Method (FEM) is adopted to analyze the 3D spatial distributions of the induced electromagnetic field produced by SEP coil and the conventional Figure of Eight coil (FOE) under the same excitation condition. Comparison functions reflecting major medical concern have also been constructed to discuss the stimulating effectiveness. Stimulating coils and real human head are modeled on Comsol5.2 platform as shown in Fig.3. The origin of the coordinate system is set at the scalp vertex.

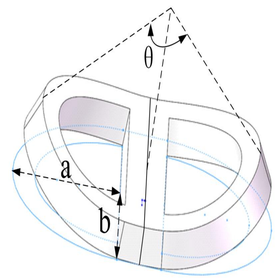

Fig2.Geometrical structure of SEP

- Firstly, in order to distinguish the planar structure between the special-shaped structure, the coil groups are divided into FOE group and SEP group.
- Secondly, In order to highlight the relations between the structure characteristics of semi-ellipse and the inducing field, the SEP group is separated in three experimental sets based on the different perimeter ,different ratio of a/b and different θ, respectively. Perimeter features the size of SEP coil .The ratio of a/b features the shape and asymmetry of SEP coil. θ features the curvature of SEP coil.

III. Spatial distribution of intracranial focusing field

Usually, the point of tangency is taken as the stimulation site of FOE. But it should be noticed that it may be inaccurate with the change of activating fibers and boundary conditions.

It has been suggested that when applied to a long fiber, the provoking site can be predicted by the maximum negative field gradient. The stimulating spot on longer nerve fiber produced by SEP and FOE are discussed.

A. Intensity and Focalization

Fig.3: From the perimeter of 219.9 mm to 342.98 mm, the stimulating intensity raises from 62.31 V/m to 119.9 V/m while the focusing field enlarges from 23.13 cm^2 to 35.62cm^2.

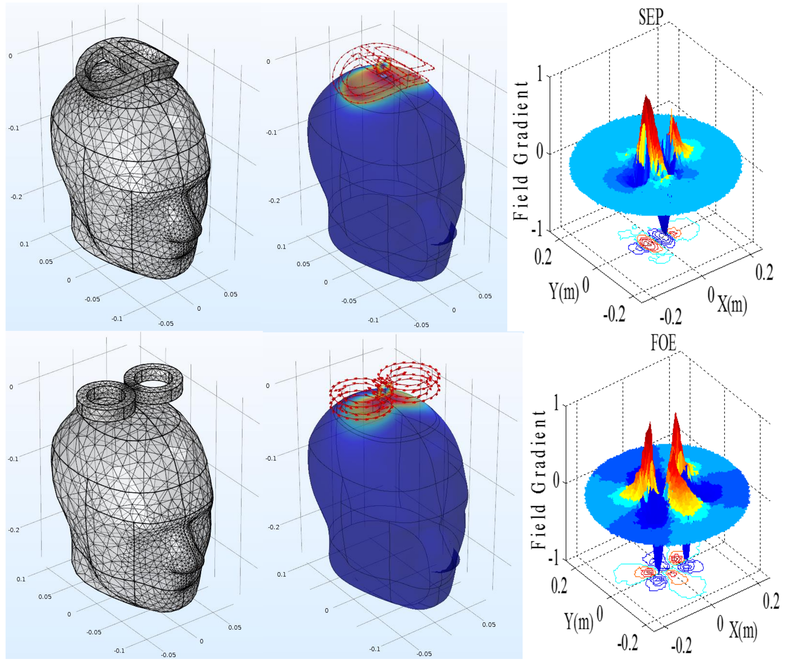

Fig. 3. Normalized distribution of on Z=-20mm of FOE and SEP

Fig.4: the intensification of asymmetry do have an influence on focalization. The maximum focusing area appears at the ration of nearly 1.6 which means, if a fixed perimeter of 287.58 and θ of 30° has been settled, the a/b ratio of 1.6 should be avoided from design.

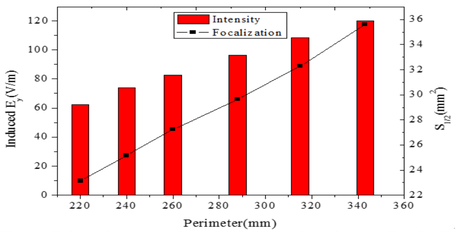

Fig. 4. Relation between perimeter and stimulus intensity as well as focalization.

Fig.5: As θ increases from 0° to 80°, the focalization has been improved by about 3cm^2 and the intensity is increased slightly. It should be noticed that with the SEP becomes more curved, the stimulus intensity and focalization are changing toward the direction of medical expectation and it also proves that the optimization of coil structure can realize the reduction of the focusing area without additional shielding.

B. Provoking Spot on Longer Nerve Fiber

It's obvious that there remains only one negative peak produced in SEP but double negative peaks have been produced in FOE.

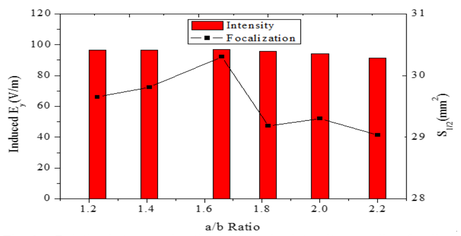

Fig. 4. Relation between a/b ratio and stimulus intensity as well as focalization.

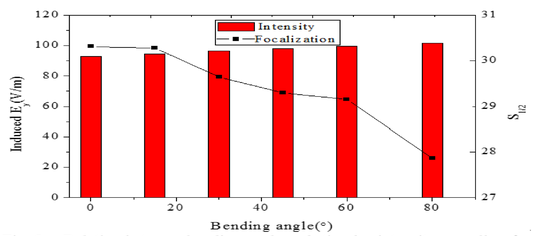

Fig. 5. Relation between bending angle and stimulus intensity as well as focalization.

IV. Discussion

Since idea curative effect demands both intensity and focalization in rTMS, the specific value of $E_{y.max}$ to S1/2 is used to define the overall efficacy of the coil. The optimum coils in the three sets of SEP are: 70×57 of 30°, 71×39 of 30°, 58×47 of 80° in which efficacy are 120(V/m)/36 cm^2, 96(V/m)/29(cm^2),102(V/m)/28(cm^2).

V. Conclusion

The purpose of this paper is to design and introduce a new stimulating coil pair that can be used in rTMS based on the inspiration of special-shaped magnet.

TABLE I
DATA OF SEP AND FOE

Coil	Intensity (V/m)	Focalization (cm^2)	Efficacy	ξ_x	ξ_y	$\xi_x \times \xi_y$
FOE_1	73.44	29.6	2.48	1.27	0.69	0.89
SEP_1	62.31	23.1	2.69	1.40	0.65	0.92
SEP_2	101.4	27.8	3.65	1.98	0.85	1.68

The relationship between the geometry structure characteristics of SEP coil and the distributions of induced intracranial field are presented and fully illuminated. In contrast to FOE, under the identical excitation and approximately equal loss power per pulse, the SEP coil of 58×47 at 80° can enhance stimulation strength and improve focalization simultaneously while increase the overall efficacy by 50%.

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PRESENTATION ID NUMBER
153
MT25-Wed-Af-Po3.04-15