

Calculated nerve rheobase values for peripheral nerve stimulation in head gradient coils

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Introduction: Rapidly varying magnetic gradient fields induce electric fields that can cause peripheral nerve stimulation (PNS) in human subjects. The electric field required for stimulation of a peripheral nerve (E_{stim}) in a time τ is well approximated by the following strength-duration relationship [1]:

$$E_{stim} = E_r \cdot (1 + \tau_c / \tau)$$

E_r is called the electric field rheobase and it is the minimum electric field required for stimulation of the nerve. The chronaxial time (τ_c) is the electric field pulse duration for which the threshold is twice the rheobase value. When translated in terms of gradient coil operation parameters relevant to MRI, the above relationship becomes the following [2]:

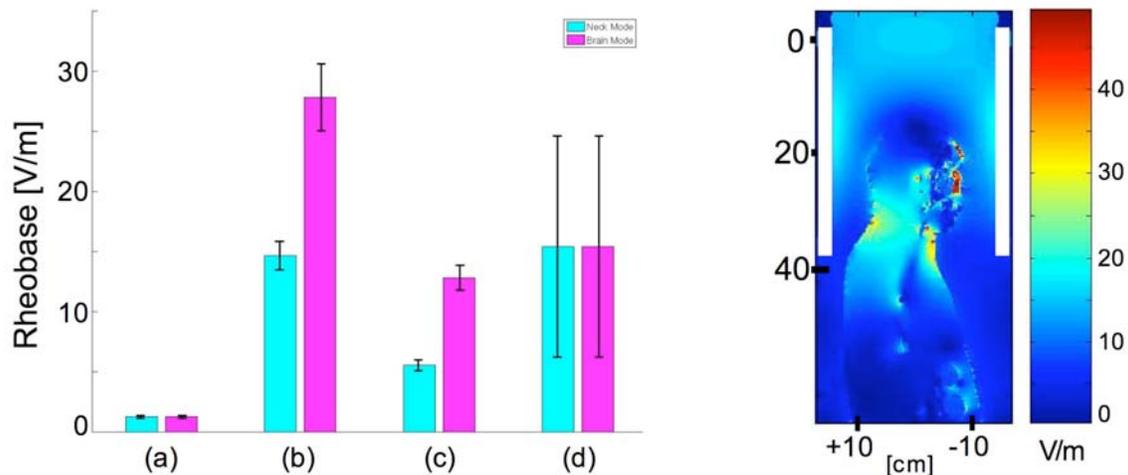
$$\Delta G_{stim} = SR_{min} \cdot \tau + \Delta G_{min}$$

where ΔG_{stim} is the change in gradient field required to cause stimulation, SR_{min} is the minimum slew rate required to cause stimulation, τ is the duration over which the gradient is switched, and ΔG_{min} is the minimum change in gradient strength required to cause stimulation. In order to obtain values for E_r and τ_c , experiments must be conducted with human subjects in MRI gradient coils to obtain measurements of SR_{min} and ΔG_{min} , and these results must be combined with accurate calculations of the electric field induced in the subject. Specifically, E_r is given by:

$$E_r = SR_{min} \cdot (E_o / \eta)$$

where E_o is the total calculated electric field at the location of stimulation, and η is the gradient field efficiency [mT/m/A] for the gradient coil.

Methods: A three dimensional, voxelated data set approximating the human torso was used as a model of the human body [3]. Experimental data for human PNS was taken from a previous study [4] and analyzed using electric fields calculated using a quasi-static finite difference method [5]. The total electric field produced by the simultaneous application of the x and y axes of the gradient coil (driven with 100A at 10 kHz) was calculated. The torso was positioned within the coil in two different locations, corresponding to the locations reported in the PNS threshold study [4]. The maximum total electric field at the surface of the object was extracted for areas around the mouth and the nose regions, corresponding to the reported locations of stimulation from the threshold study.



Results and Discussion: The total calculated electric field for a sagittal slice through the centre of the object is shown in the above right figure. The E_r values obtained are summarized in the above left figure. For each case, the bar on the left indicates the results for the subject located as far into the head gradient coil as possible, while the bar on the right indicates the results for the subjects located with eyes just at the edge of the gradient coil. Parts (a), (b), and (c) show the rheobase values obtained when: (a) the effects of the human body are ignored, (b) the electric fields in the vicinity of the nose are used for analysis, (c) the electric fields in the vicinity of the mouth are used for analysis. Part (d) summarizes the rheobase results predicted by Reilly [6].

Consistent nerve stimulation parameters can only be obtained from experiment when accurate electric field calculations are employed, as above. These results are critical if we are to develop methods for the design of new gradient coils with reduced stimulation properties.

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