Title

Measurements and models of electric fields in the *in vivo* human brain during transcranial electric stimulation

Authors & Affiliations

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Introduction

Transcranial electric stimulation (TES) aims to stimulate the brain by applying weak electrical currents at the scalp. However, the magnitude and spatial distribution of electric fields in the human brain are unknown. Despite increasing sophistication in the computational models for TES, none of them have been directly validated to-date. Here we aim to address this with in vivo intracranial recordings in humans by directly measuring field intensities produced by TES at the cortical surface and deeper brain areas.

Methods & Results

Electric potentials were recorded intracranially from ten patients undergoing invasive monitoring for epilepsy surgery, with subdural grids, strips, and depth electrodes. These recordings were then compared to various detailed computational models, including differential conductivity between skull spongiosa and compacta, and white matter anisotropy. Models were also calibrated using the recordings to minimize the difference between measurements and model predictions. In doing so, we obtain calibrated models that conclusively answer outstanding questions about stimulation magnitudes, spatial distribution, and modeling choices.

A summary of the model validations is shown in Fig. 1. The distribution accuracy is indicated by the correlation r between recorded and model-predicted values, and magnitude accuracy by the slope s of the best linear fit with predicted value as "independent" and measurement as "dependent" variables. Conductivities reported in the literature used in existing models tend to overestimate the voltages and electric field magnitudes (Fig. 1CD under "literature"). The measured voltages are tightly correlated with the predicted electric potentials (Fig. 1A). The correlation of predicted and measured electric fields is lower than for the raw potentials (Fig. 1B), as the calculated field is the difference of two close-by measurements, each with some inherent noise. The best fitted conductivity values vary across individuals (Fig. 1EFG). The median of these optimal conductivities differ from the literature values, but are largely in the same proportions. Compared to models using literature conductivities, the models with median values across subjects give significantly better accuracy in terms of predicting the electric field distribution and the magnitude (Fig. 1BD). Fig. 2A--E shows the recorded data and the predictions from the calibrated head model for one subject. When collapsing all recordings across subjects (Fig. 2FG) we find correlation between measured and predicted field projections of r=0.89 and r=0.84 for cortical and depth electrodes respectively.

Conclusion

After calibrating the models using recorded data, we found that the electric field intensities in the brain reach 0.4 V/m when using 2 mA transcranially, approximately half as strong as previous predictions using computational models. Individualized models provide predictions that are highly correlated with actual recordings (r>0.8). Including variables such as anisotropic white matter and inhomogeneous bone compartments does not improve prediction performance.

Clinical Relevance

This is the first study to validate and calibrate current-flow models with *in vivo* intracranial recordings in humans, providing a solid foundation to target transcranial stimulation and interpret clinical trials.

Presentation category, please mark your preference [ ]Cancer [ ]Cardiac [ ]Nano [**X**]Neuro

Figures and tables

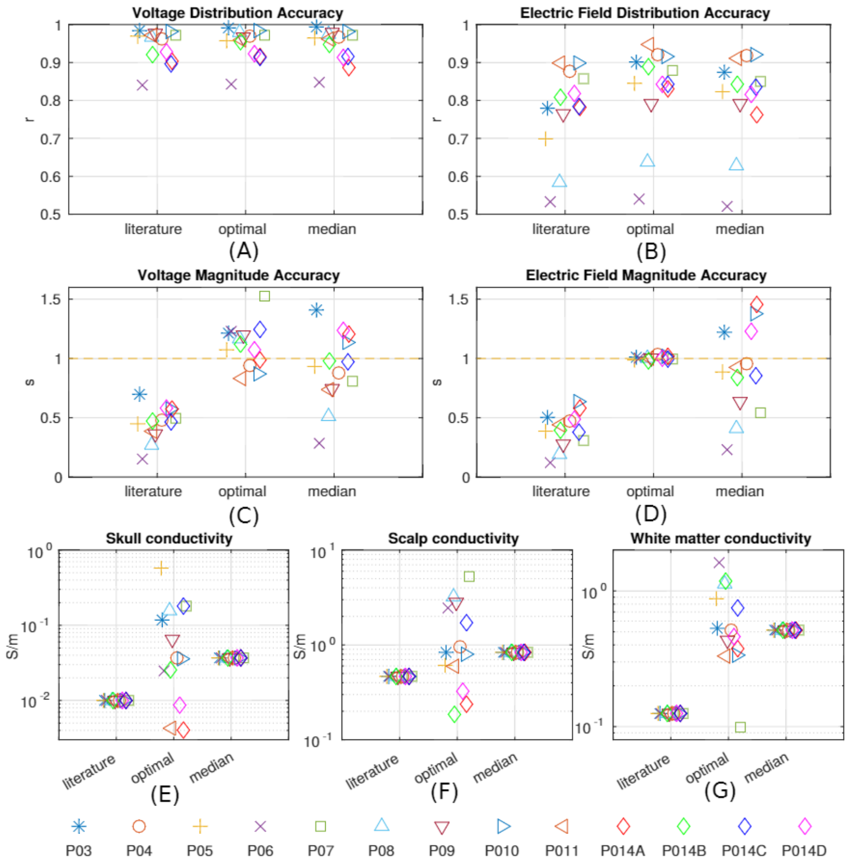

Fig. 1

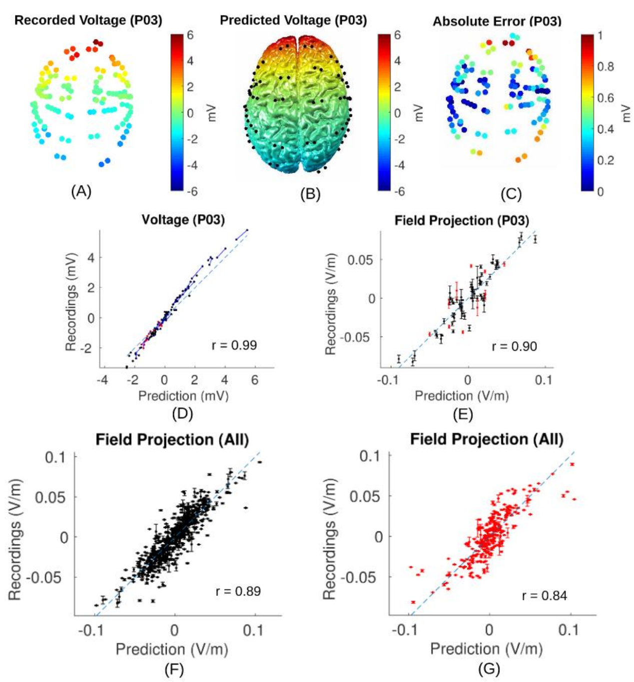

Fig. 2