Transcranial electrical stimulation models using an emulated-CSF value approximate the meninges more accurately.

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Abstract

Understanding how current applied at the scalp during transcranial electrical stimulation (tES; including tDCS) reaches the brain, underpins efforts to rationalize outcomes and optimize interventions. To this end, computational models of current flow relate applied dose to brain electric field. Standard models, using a workflow established since 2009, have now been verified using a range of technique including intra-cranial recording to reasonable accuracy. Moderate residual efforts none-the-less may impact model utility.

The standard modeling workflow and parameters consider distinct tissue masks: skin, skull, cerebrospinal fluid (CSF), gray matter and white matter, and sometimes air, fat, muscle and other soft tissues. The properties of CSF, which is highly conductive by comparison, are known to be important. However, the representation of the space between the skull and the cortical surface as pure CSF is not an accurate representation of the anatomy. In actuality, the majority of CSF can be found in the subarachnoid space, and the space previously attributed to pure CSF actually contains the meninges (dura mater, arachnoid mater, and pia mater) which lower conductivity. The size and resolution required to describe both the full head and the layers of the meninges is computationally restrictive in an MRI-derived model.

To-scale models of the meninges layers were first developed in a spherical head model with spherical representations of dura mater, arachnoid mater, and pia mater. Then, an emulated CSF conductivity incorporating the effect of meninge layers on cortical electric field was optimized for multiple electrode positions. The emulated conductivity was applied to MRI-derived model. Compared to a model with standard literature values, the emulated CSF conductivity produced cortical electric fields statistically better correlated to experimentally recorded intra-cranial values (previously published).

Updating the standard model with emulated CSF conductivity enhances modeling precision without increasing model complexity. Therefore this should become the new standard in all forms of tES modeling including the evaluation of new techniques and in personalized neuromodulation.