Intracranial EEG Phantom for Brain Stimulation Studies

Motivation

This project aims to develop a pediatric brain phantom for use in examining major effects of transcranial magnetic stimulation (TMS) on implanted intracranial electroencephalography (iEEG) electrodes: induced currents, temperatures, and changes in position. TMS and iEEG are two techniques utilized prior to surgical interventions for focal epilepsy, which target and remove regions of the brain involved in uncontrollable seizure generation. To evaluate patient safety in simultaneous iEEG and TMS application, it is essential to observe any impacts of TMS electromagnetic pulses on iEEG depth electrodes within a phantom brain before progressing to clinical use.

Prior Work

A similar phantom was constructed at the University of Iowa in 2022. Tested in tandem with human participants, this gel-based phantom was fabricated to investigate the safety of applying TMS while recording iEEG. While valuable, this study left a gap in knowledge: translatability to pediatric patients. Shifting focus to a younger population necessitates new considerations for physiology, anthropometry, and safety guidelines, thus requiring an individual investigative project.

Materials

Gelatin was chosen to model the phantom brain due to high tunability of its mechanical, thermal, and electrical properties. Literature values for thermal and electrical conductivity of pediatric brain tissue were used as testing benchmarks, and prototype compositions of both gelatin and saline were established by modifying previously published tissue phantom gel compositions. Final gel composition was determined by evaluating thermal and electrical conductivity testing and selecting the closest matches that exceeded pediatric brain tissue, to ensure an adequate factor of safety.

Methods

The resulting phantom is composed of 6% gelatin and 1.2% NaCl. Sample skull and brain CT and MRI scans from a 5-7 year old patient were modeled and 3D printed out of Formlabs Clear Resin V5 and PLA, respectively. The PLA brain was further used to create a silicone mold for the final gelatin brain fabrication, which was encased in the resin skull. The selected phantom composition approximates the thermal, electrical, and mechanical properties of pediatric brain tissue, validating its application as a tool to evaluate safe use of iEEG and TMS in tandem.

Impact

While previous studies address concerns of simultaneous TMS and iEEG use in adult patients, they fail to consider more stringent safety standards and physiological differences present in pediatric patients. Through the development of our pediatric neurosurgical phantom we aimed to address such critical safety concerns as current generation, electrode displacement, and heating. This phantom serves as a research tool validation of the safety of using TMS in conjunction with iEEG in pediatric patients with focal epilepsy before human trials are performed, for the overall goal of developing more comprehensive care for this patient population.