Intracranial EEG Phantom for Brain Stimulation Studies

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Background and Project Application

Physiological Background

- Epilepsy is a neurological disorder, characterized by the regular appearance of uncontrollable seizures, that often manifests within 12 months [1]
- There is a lack of clinical explorations in pediatric patients, given added complications surrounding child participation in human studies [2]
- Two brain mapping techniques utilized prior to surgical epilepsy management include intracranial electroencephalography (iEEG) and transcranial magnetic stimulation (TMS) [3]

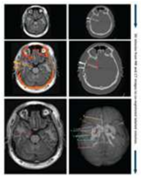

Figure 1. Inserted iEEG electrodes [4].

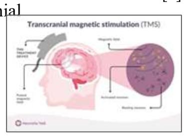

Figure 2. TMS pulse application [5].

Project Applications

- Using both techniques prior to surgery provides the most accurate representation possible
- Constructing a physiologically accurate brain phantom model allows for simulation of TMS treatment while iEEG electrodes are in place
- Special emphasis will be put on representing a pediatric population

Figure 3. Adult iEEG TMS phantom [3].

Problem Statement

The goal of this project is to develop a pediatric brain phantom model that can be used to simulate the following effects of TMS on iEEG electrodes:

- Induced currents
- Changes in temperatures
- Displacement

These observations will determine the relative safety of using these brain mapping techniques in tandem.

Design Specifications

- Represents accurate physiology of average 5-7 year pediatric brain and skull
  - Skull circumference: 50-54 cm [6]
  - Overall brain matter volume: 1,300 cm^3 [7]
- Brain material must have similar electrical conductivity as brain tissue: 0.2-0.5 S/m [8]
- Brain material must have similar thermal properties to brain tissue: 0.536 W/m-K [9]
- After completion of TMS testing, electrodes must have:
  - Charge density: <30 μC/cm^2
  - Temperature change: <1 °C
  - Displacement: ~0 mm
- Must comply with MTR Standards 2.4 and 3.3, CFR Standards 882.5802, and ASTM F2182 [10] [11] [12]
- $500 budget

Brain Tissue Material

The final model for this project will be a pediatric-sized hydrogel brain encased in a clear resin skull.

Option I:

- 6% Gelatin Type A [13]
- 0.25-0.75% NaCl [14]
- Poor thermal properties
- Well-characterized mechanical properties

Option II:

- 1.2% Agar [14]
- 0.25-0.75% NaCl [14]
- Difficult to characterize mechanically
- Thermally stable
- Prone to contamination

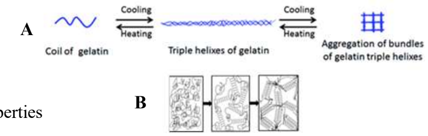

Figure 4. Microstructure of gelatin (A) and agarose (B) hydrogels [15, 16].

Figure 5. Hydrogel synthesis process.

Skull Material

- 3D-printable, photocurable resin:
  - Acrylate (50-70%)
  - Urethane Dimethacrylate (25-45%)
  - Methacrylate (7-10%)
- Elastic modulus: 2.8 GPa [17]
- Ideal optical properties
- Available to 3D print at the Design Innovation Lab at Wendt Commons

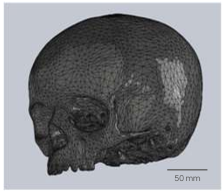

Figure 6. SolidWorks model of a pediatric skull from processed CT scans.

Figure 7. File processing pipeline for 3D printable skull model.

Testing

Thermal Conductivity Testing

- Wrap hydrogel sample in insulating material
- Place sample on hotplate set to 35 °C
- Insert thermocouple to take temperature measurements periodically
- Choose material and concentration with thermal conductivity closest to 0.536 W/m-K [9]

Shrink-Swell Testing

- Fabricate gels with varying concentrations
- Cut uniformly shaped cylinders
- Submerge each sample in 100% EtOH
- Take mass measurements over 60 minutes
- Qualitatively compare polymer density

Figure 8. Shrink-swell testing on agar hydrogel.

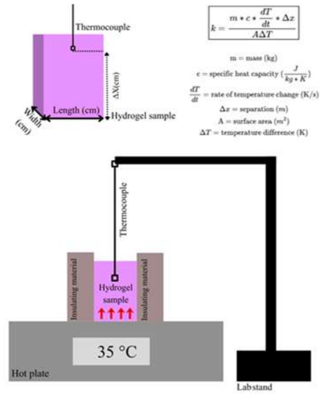

Figure 9. Thermal conductivity testing setup and governing equations.

Results

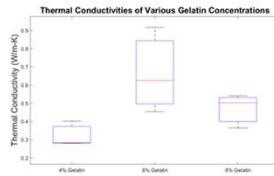

Figure 10. Varying gelatin thermal conductivities.

Table I. Gelatin thermal conductivity results.

Gelatin Conc.	Average Thermal Conductivity (W/m-K)
4%	0.32 ± 0.07
6%	0.67 ± 0.23
8%	0.47 ± 0.09

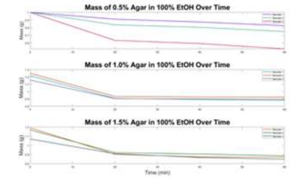

Figure 11. Agar behavior submerged in 100% EtOH.

Table II. Agar shrink-swell results.

Agar Conc.	Average Percent Decrease
0.5%	30.3 ± 15.9
1.0%	25.3 ± 2.46
1.5%	23.9 ± 3.14

Discussion and Future Work

Discussion

- Complications with rheological testing
- MRI scans better for soft tissue
- Consider fabricating models with both agar and gelatin for head-to-head testing
- $214.51 spent of $500 budget

Future Work

- Perform electrical conductivity testing
- Characterize NaCl-tuned gelatin on rheometer using Franck Lab protocol
- Process MRI scans and create brain tissue mold
- 3D print final skull model
- Perform TMS testing on final phantom with implanted electrodes

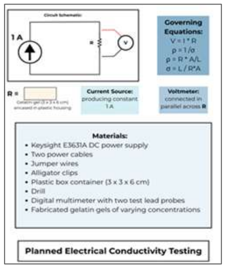

Figure 12. Proposed protocol for testing electrical conductivity of hydrogels.

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References

[1] T. A. Milligan, "Epilepsy: A Clinical Overview," Am. J. Med., vol. 134, no. 7, pp. 840–847, July 2021, doi: 10.1016/j.amjmed.2021.01.038.
[2] G. Askari, M. Vajdi, S. Jafari-Nasab, and S. Golpour-Hamedani, "Ethical guidelines for human research on children and adolescents: A narrative review study," J. Res. Med. Sci. Off. J. Isfahan Univ. Med. Sci., vol. 29, p. 53, Aug. 2024, doi: 10.4103/jrms.jrms_610_23.
[3] J. B. Wang et al., "Effects of transcranial magnetic stimulation on the human brain recorded with intracranial electrocorticography," Mol. Psychiatry, vol. 29, no. 5, pp. 1228–1240, May 2024, doi: 10.1038/s41380-024-02405-y.
[4]"iEEG Imaging and Analysis - Persyst." Accessed: Dec. 01, 2025. [Online]. Available: https://www.persyst.com/technology/ieeg-imaging-analysis/
[5] "TMS Treatment for Depression in Perth | TMS Therapy Clinic." Accessed: Dec. 01, 2025. [Online]. Available: https://www.neuraliatms.com.au/tms-therapy/for-depression/
[6] "Head circumference for age." Accessed: Sept. 13, 2025. [Online]. Available: https://www.who.int/tools/child-growth-standards/standards/head-circumference-for-age.
[7] E. Lüders, H. Steinmetz, and L. Jäncke, "Brain size and grey matter volume in the healthy human brain," Neuroreport, vol. 13, no. 17, pp. 2371–2374, Dec. 2002, doi: https://doi.org/10.1097/01.wnr.0000049603.85580.da.
[8] G. Halnes, T. V. Ness, S. Næss, E. Hagen, K. H. Pettersen, and G. T. Einevoll, Electric Brain Signals: Foundations and Applications of Biophysical Modeling, 1st ed. Cambridge University Press, 2024. doi: 10.1017/9781009039826.
[9] "Measurement of Ex Vivo Liver, Brain and Pancreas Thermal Properties as Function of Temperature." Accessed: Oct. 13, 2025. [Online]. Available: https://www.mdpi.com/1424-8220/21/12/4236.
[10] T. N. Tsuchida et al., "American Clinical Neurophysiology Society Standardized EEG Terminology and Categorization for the Description of Continuous EEG Monitoring in Neonates: Report of the American Clinical Neurophysiology Society Critical Care Monitoring Committee," J. Clin. Neurophysiol., vol. 30, no. 2, p. 161, Apr. 2013, doi: 10.1097/WNP.0b013e3182872b24.
[11] "eCFR :: 21 CFR 882.5802 -- Transcranial magnetic stimulation system for neurological and psychiatric disorders and conditions." Accessed: Sept. 17, 2025. [Online]. Available: https://www.ecfr.gov/current/title-21/chapter-I/subchapter-H/part-882/subpart-F/section-882.5802
[12] Standard Test Method for Measurement of Radio Frequency Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging, F2182-19e2.
[13] E. C. Bremer-Sai, J. Yang, A. McGhee, and C. Franck, "Ballistic and Blast-Relevant, High-Rate Material Properties of Physically and Chemically Crosslinked Hydrogels," Exp Mech, vol. 64, no. 4, pp. 587–592, Apr. 2024, doi: 10.1007/s11340-024-01043-3.
[14] M. A. Kandadai, J. L. Raymond, and G. J. Shaw, "Comparison of electrical conductivities of various brain phantom gels: Developing a 'Brain Gel Model,'" Mater Sci Eng C Mater Biol Appl, vol. 32, no. 8, pp. 2664–2667, Dec. 2012, doi: 10.1016/j.msec.2012.07.024.
[15] X. Yan et al., "High strength and self-healable gelatin/polyacrylamide double network hydrogels," J. Mater. Chem. B, vol. 5, no. 37, pp. 7683–7691, Sept. 2017, doi: 10.1039/C7TB01780D.
[16] N. Russ, B. I. Zielbauer, K. Koynov, and T. A. Vilgis, "Influence of Nongelling Hydrocolloids on the Gelation of Agarose," Biomacromolecules, vol. 14, no. 11, pp. 4116–4124, Nov. 2013, doi: 10.1021/bm4012776.
[17] "BioMed Clear Resin," Formlabs. Accessed: Dec. 02, 2025. [Online]. Available: https://formlabs.com/store/materials/biomed-clear-resin/