

Intracranial EEG Phantom for Brain Stimulation Studies

BME 402

February 20, 2026

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Project Overview

- The goal of this project is to develop a **pediatric** brain phantom model.
- Client: Dr. Raheel Ahmed, a pediatric neurosurgeon [1]
 - Surgery can be a highly effective treatment for focal epilepsy [2]
- Two methods of presurgical brain mapping include iEEG and TMS [3] [4]
 - Investigating simultaneous usage: induced currents, temperature changes, and displacement
 - University of Iowa conducted similar research, but with an **adult** model [5]
- Important constraints/specifications:
 - Temperature change: $<1\text{ }^{\circ}\text{C}$
 - Displacement: $\sim 0\text{ mm}$
 - Charge density: $<30\text{ }\mu\text{C}/\text{cm}^2$ [5]
 - \$500 budget
 - Represent **5-7 year old** physiology and accurate brain tissue properties [6] [7]



Previous Prototype

- Two components:
 - Representative food-grade gelatin gel housed within printed box holder (**Fig. 1**)
 - 3D printed 5-7 year-old skull based upon computed tomography (CT) scans (**Fig. 2**)

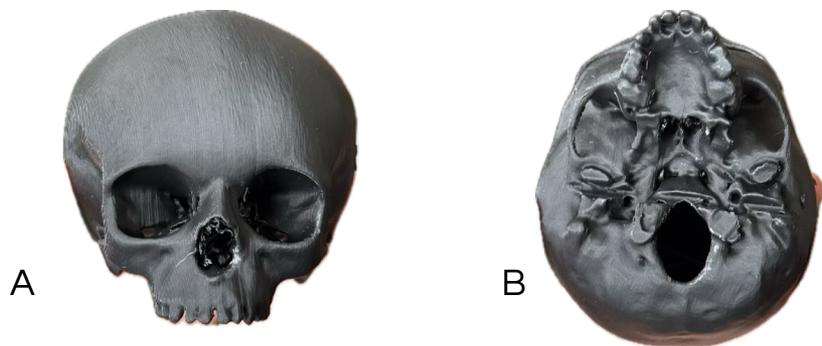
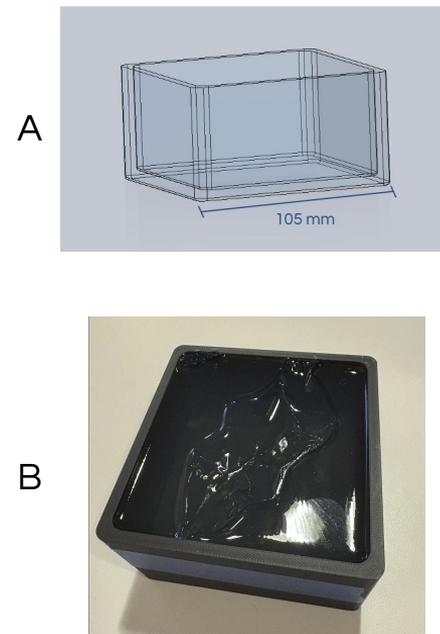


Figure 2 . Front (A) and bottom (B) view of scaled-down 3D printed skull for proof-of-concept

Figure 1 . CAD model (A) and photo (B) of the box phantom for material testing



Fall Semester Testing

Last semester, we completed two types of testing. Due to timing constraints, we were only able to complete one type of testing per gel.

Shrink/swell testing: Agar

- Cut symmetrical cylinders from 0.5%, 1%, 1.5% agar gels, take mass (n=3)
- Submerge in 200 proof ethanol
- Measure mass at 20 minute increments for 1 hour
- Rehydrate in water overnight and measure again the following day



A



B

Figure 3 . Samples (A) and testing conditions (B) for shrink-swell testing

Fall Semester Testing (cont.)

Thermal conductivity: Gelatin

- Cut equal size rectangles from 4%, 6%, 8% gelatin. Take all measurements. (n=3, 4)
- Set hot plate to 35 °C
- Using a thermocouple circuit, we took measurements every minute for 10 minutes

$$k = \frac{m * c * \frac{dT}{dt} * \Delta x}{A \Delta T}$$

m = mass (kg)

c = specific heat capacity ($\frac{J}{kg * K}$)

$\frac{dT}{dt}$ = rate of temperature change (K/s)

Δx = separation (m)

A = surface area (m²)

ΔT = temperature difference (K)

Eq 1. Calculations for thermal conductivity

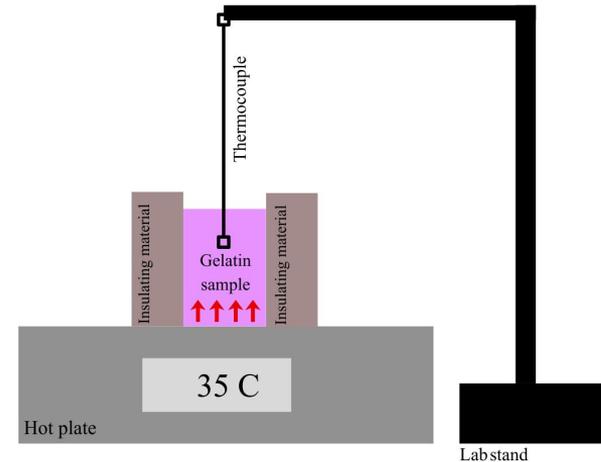
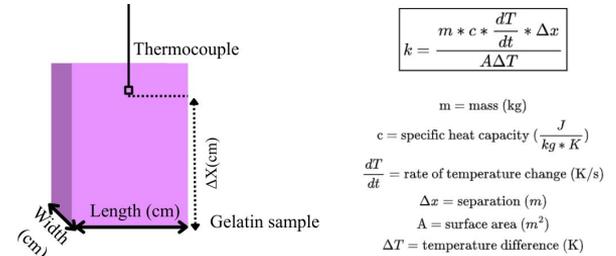


Figure 4 . Testing set up for thermal conductivity



Fall Semester Results

Shrink/swell

- General trend expected
- Results not as valuable for our project application

Thermal conductivity

- Average thermal conductivity about where we expect, 0.536 W/m-K
 - 4% - 0.32 ± 0.07
 - 6% - 0.67 ± 0.23
 - 8% - 0.47 ± 0.09
- Very high standard deviation
- Confounding factors

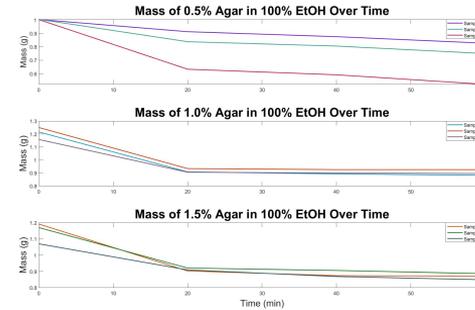


Figure 5 . Results of agar shrink/swell testing

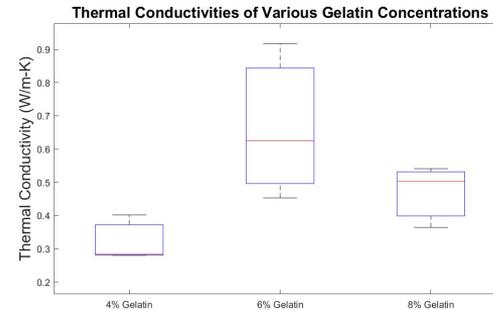


Figure 6. Results of gelatin thermal conductivity testing

Planned Fabrication

- Process MRI scans into matching skull and brain CAD model
- 3D print final skull model using Formlabs clear resin
- 3D print brain and use to create mold using ecoflex
- Can 3D print brain in ABS and vapor smooth using acetone if texture is an issue

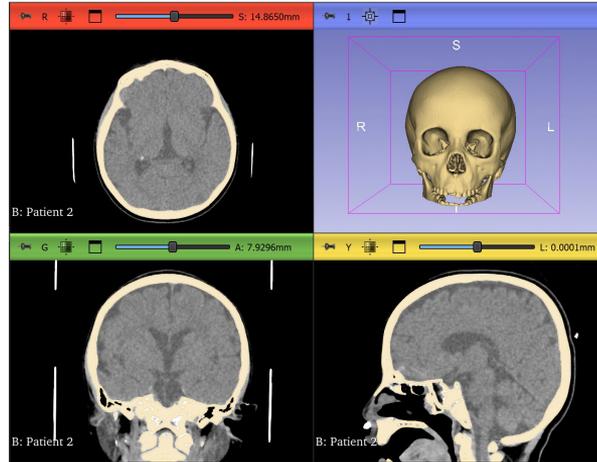


Figure 7 . Processing DICOM data in 3D Slicer from 5-7 year old patient CT



Figure 8 . Skull CAD model created from CT data of 5-7 year old patient



Spring Semester Testing

Thermal conductivity

- Repeat previous protocol
- Agar and gelatin
- Altering saline concentration

Electrical conductivity

- Measure voltage drop across gels
- 0.2-0.5 S/m [9]

Rheometer

- Shear modulus
- Viscoelastic properties

Final evaluation of iEEG with TMS

- Displacement
- Heating
- Generation of electric field

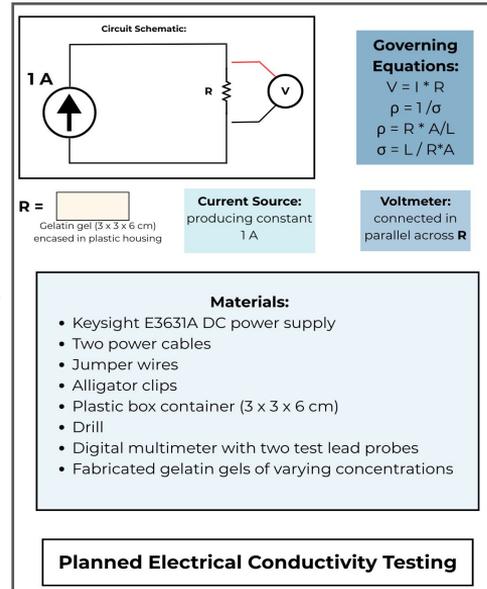


Figure 11. Protocol for conductivity testing



Figure 12. Phantom for testing combined use of TMS and iEEG for adults [5]

Thermal Conductivity Results

Table 1. Average agar thermal conductivities

Agar Concentration	Saline Concentration	Thermal Conductivity (W/m-K)
0.6%	0.2%	1.16
	0.4%	1.66
1.2%	0.2%	1.94
	0.4%	1.86

Table 2. Average gelatin thermal conductivities

Gelatin Concentration	Saline Concentration	Thermal Conductivity (W/m-K)
6.0%	0.0%	2.06
	0.3%	1.77
	0.6%	2.11

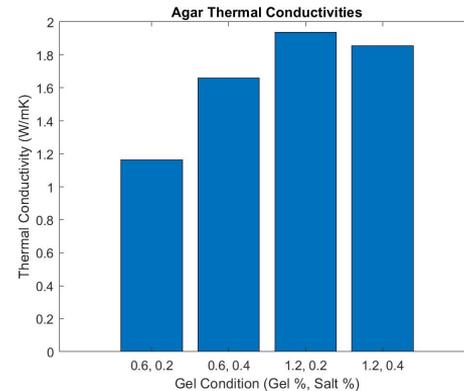


Figure 13. Results of agar thermal conductivity testing

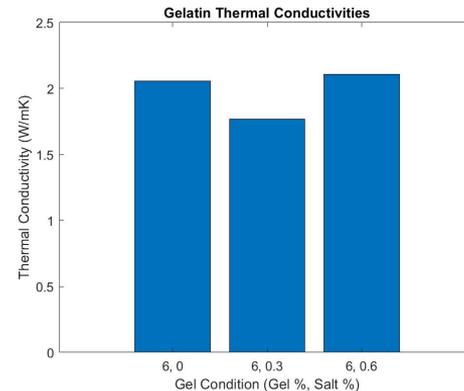


Figure 14. Results of the second round of gelatin thermal conductivity testing



Budget

- **\$500 budget**
- Amount spent thus far: **\$214.51**
 - \$11.96 – 3D prints
 - \$149.15 – 500g agar
 - \$53.40 – 100g type A gelatin
- Future planned purchases:
 - Materials for testing
 - Electrodes
 - AD5933 chip [10]
 - Additional type A gelatin
 - Final pediatric skull 3D print



Figure 15. Type A gelatin bottle [11]

Miscellaneous

Packaging

- Phantom must be portable for transport to TMS equipment
- Structural integrity must be maintained during transport and testing
- Includes portable equipment for measuring displacement, field generation, and heating

Documentation

- A detailed testing protocol will be developed prior to use
- Protocol will include:
 - Step-by-step testing instructions
 - Safe operating guidelines of the phantom with iEEG/TMS
- TMS will be operated by trained individuals; TMS-specific user manuals are not required



Acknowledgements

We would like to thank our clients, Dr. Raheel Ahmed and Dr. Arun Manattu, our advisor Dr. Paul Campagnola, Brooke Volkman, Dr. Brandon Coventry, Dr. Christian Franck, Arvin Chen, Ido Haber, the Pediatric Neuromodulation Laboratory (PNL), and the BME Department.



Figure 16. BME Design logo [12]



Figure 17. PNL logo [13]



Figure 18. UW-Madison SMPH logo [14]

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Questions?

