Development of a pediatric brain phantom for the investigation of combined intracranial electroencephalography and transcranial magnetic stimulation

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Highlights

- OUTLINE (as most of the highlights will pertain to end-of-semester results):
- We successfully characterized gelatin material with ___ saline to match conductivity of ___.
- Utilizing real brain scan data, a physically accurate pediatric hydrogel brain and matching 3D-printed skull were fabricated.
- Stimulation was applied through a MagStim coil, resulting in…

Abstract

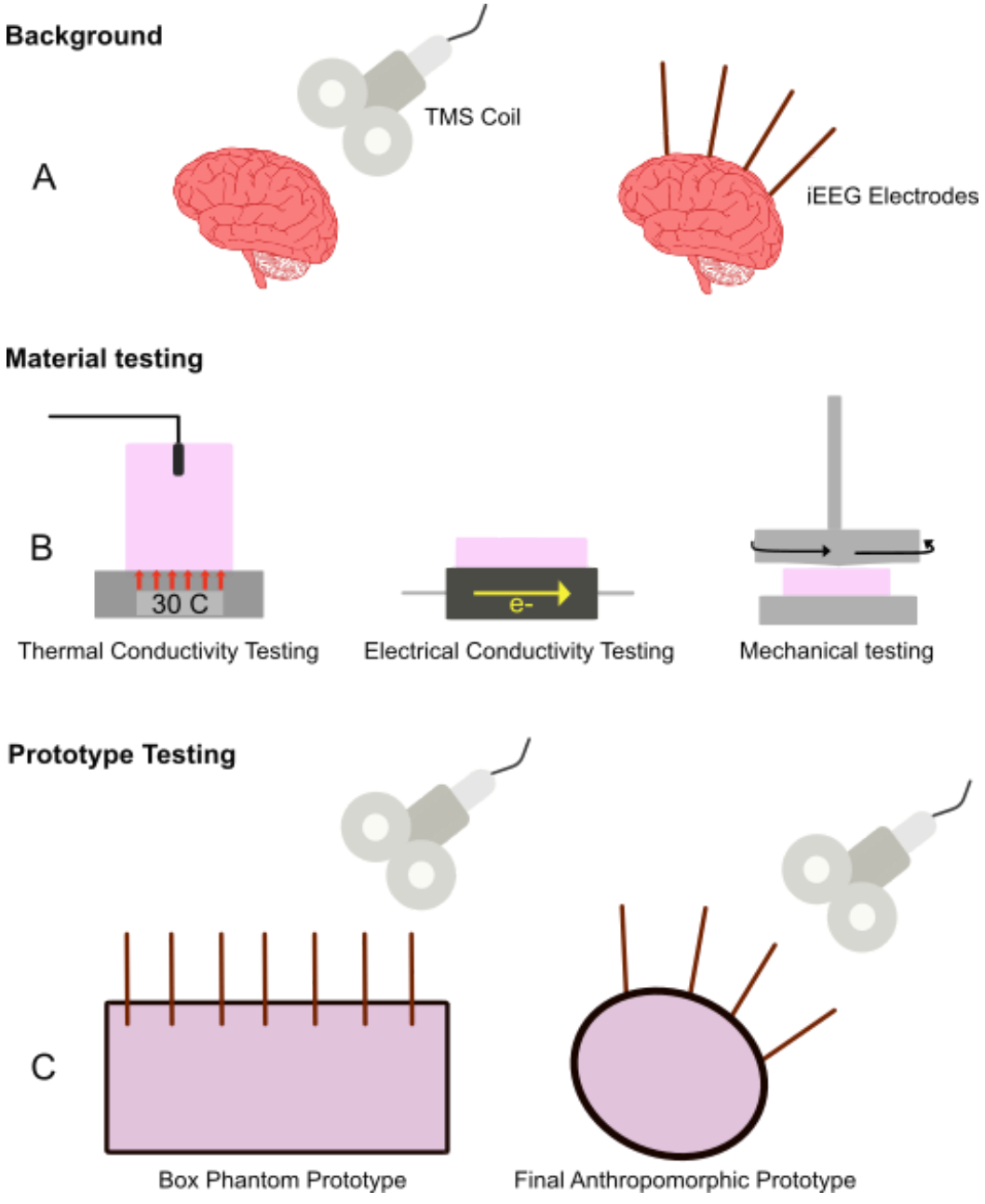
Epilepsy is a prevalent neurological condition marked by the occurrence of repeated, uncontrollable seizures. This disorder can present in individuals of all ages, but commonly manifests in children. One main treatment method is that of surgical intervention, in which neurosurgeons identify and disconnect cranial regions involved in seizure generation. Before operation, brain mapping techniques such as intracranial electroencephalography (iEEG) and transcranial magnetic stimulation (TMS) are utilized to delineate brain connectivity. We investigated the safety of using these methods in tandem via the fabrication of a brain phantom model: a hydrogel brain encased in clear resin. The model was then stimulated to depict any effects of TMS pulses on iEEG electrodes. Preliminary testing was performed to characterize the hydrogel of choice in terms of mechanical, thermal, and electrical properties. We aimed for anatomical accuracy by utilizing both pediatric magnetic resonance imaging (MRI) and computed tomography (CT) scans. Assembly of the final model, composed of a ____ hydrogel and 3D-printed skull receptacle, consisted of _____. Through final testing, in which the completed model was stimulated with TMS pulses whilst containing inserted iEEG electrodes,..

- OUTLINE/to add for final report:
    - Add more detail on final model assembly (which we will take vigorous notes of)
    - Describe end results (observations of any indication of electrode displacement, temperature change, or induced currents.)

Keywords

Epilepsy, neuroscience, neuromodulation, phantom, hydrogel, pediatrics.

Graphical abstract - detail to be added in final report



1. Introduction

Epilepsy, the fourth most common neurological disorder, is characterized by the regular appearance of uncontrollable seizures. These seizures occur as a result of short, excessive electrical discharge in neurons and can either be focal in nature, involving a local neuronal network, or generalized, engaging a larger bilateral network. People of all ages can be affected by epilepsy, but it often manifests before the age of one year; not only is the disorder detrimental to patients' ability to thrive, with a strong correlation to increased injury and accident rates, but it is also associated with a higher risk of depression and death [1].

An area of exploration tied to epilepsy is that of various treatment methods. Aside from the use of medication, surgical management is an oft-investigated treatment tool in the control of epileptic seizures. Procedures such as temporal lobectomies, or removal of certain portions of the brain, are preceded by a variety of brain mapping techniques such as iEEG and TMS. iEEG, routinely used in surgical planning, utilizes electrode systems that are either connected across the surface of or implanted into the brain. This method provides high spatiotemporal resolution and is especially advantageous for epileptogenic foci localization [2]. TMS assesses brain circuit excitability through electromagnetic induction, inducing currents to produce action potentials and painlessly activate brain networks [3].

Both TMS and iEEG provide complementary information for mapping out critical brain regions that should be avoided during surgery. However, there are several safety concerns around the simultaneous use of TMS in patients with iEEG: that of secondary electrical currents, heating of the implanted electrodes, and electrode array displacement, all of which would have severe consequences for the affected individuals [4]. There has been prior research on potential interactions between the techniques, in which representative pulses have been administered on phantom models, before being applied to human subjects to certify their level of risk and effectiveness. For example, researchers at the University of Iowa created a gel-based brain phantom to prove that TMS and iEEG can be safely used in tandem, specifically in adult patients. The brain of this phantom was made of poly(acrylic acid) (PAA) saline gel, and the skull was made of poly(methyl methacrylate) (PMMA) [4] .

While there exist brain phantoms that have been used for similar research, none have addressed pediatric populations, contributing to a significant treatment knowledge gap. There are complicated ethical challenges surrounding the participation of children in human studies, such as informed consent, enforcing strict safety standards, and incorporating in-depth risk assessment. In part due to these more rigorous expectations, there is a clear lack of research and clinical explorations in the pediatric population [5].

Focusing on this underrepresented population introduces different physiological properties for consideration in addition to extensive safety demands [5], [6], [7]. We chose to address this specific demographic in the creation of our own phantom model, opting to consider these added constraints, mainly because of the urgent need for a solution: the mortality rate in children affected by epilepsy is 5 to 10 times higher than the rest of the population, so properly treating and controlling these unprovoked seizures is paramount [8]

We structured our approach similarly to the research team at the University of Iowa, by constructing a detailed brain phantom, inserting iEEG electrodes and applying single-pulse TMS (spTMS), and finally analyzing the implanted electrodes' change in temperature, displacement, and secondary electric current buildup. Our ongoing goal has been to verify that these brain mapping techniques can be used in tandem for cases of pediatric epilepsy.

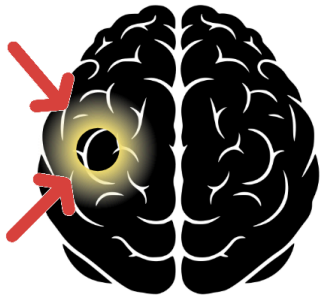


Figure 1: Focal epilepsy involves seizures generated from localized regions of the brain. Through neurosurgery, it is possible to minimize this abnormal neuronal activity by removing the area.

2. Materials and Methods

2.1 Hydrogel Synthesis

Porcine skin gelatin Type A, 300g bloom (Lot 0000518727), was purchased at 500 grams from Millipore Sigma [9]. Saline solutions were prepared using sodium chloride (NaCl) powder from Thermo Fisher Scientific [10]. NaCl was dissolved at 0.17% w/v at 65 ℃ in MilliQ ultrapure water. Gelatin powder was dissolved at 4%, 6%, and 8% w/v conditions for at least 20 minutes. Gelatin was dissolved in saline kept at 65 ℃ and spun with stir bars at 400 RPM to prevent clumping. After dissolution, gels were poured into silicone molds [11] and cooled at 4 ℃. Before use, molds were wiped down with 70% ethanol (EtOH).

2.2 File Processing Pipeline

- Exporting the STL files and processing the CAD model of the skull are still ongoing, so more details will be added in the final report

To create 3D models of the brain and skull for 3D printing, patient-derived MRI scans were processed. Anonymized MRI scans from 5-7 year old patients were imported into 3D Slicer in digital imaging and communications in medicine (DICOM) format and converted into T1-weighted images. T1 data was then processed in SimNIBS 4.5.0, a Python-based program that automates creating a 3D head model of 51 tissues. Using SimNIBS GUI and Gmsh, programs internal to SimNIBS, skull and brain tissues were segmented into separate models and exported in stereolithography (STL) format. The brain STL was then used directly for 3D printing, while the skull STL was imported into SolidWorks to allow the model to be further edited.

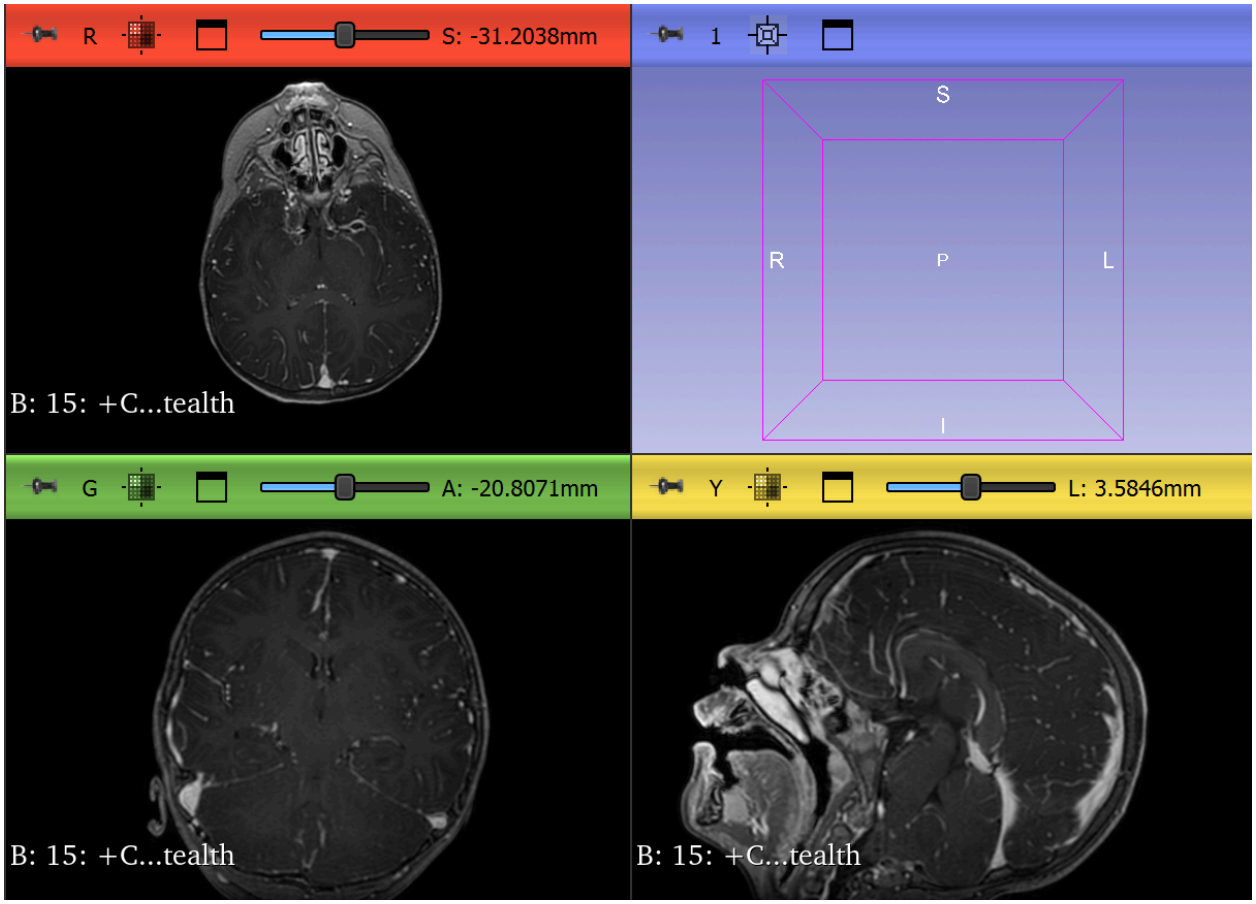


Figure 2: 5-7 year old patient DICOM data in 3D Slicer prior to segmenting T1-weighted MR images and exporting into SimNIBS.

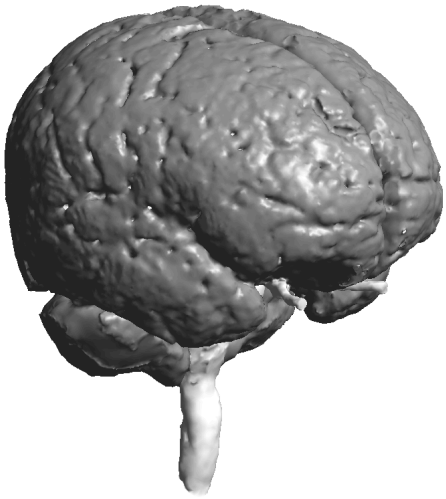


Figure 3: 3D model of brain surfaces in Gmsh created by processing 5-7 year old patient-derived MRI scans in SimNIBS 4.5.0.

2.3 Thermal Conductivity Configuration

$$k = \frac{m*c*\frac{dT}{dt}*\Delta x}{A*\Delta T} \quad \text{(I)}$$

A detailed procedure of thermal conductivity calculations and measurements can be found in the supplementary information. Briefly, gel samples were prepared in silicon ice cube trays approximately 2.5x 2.5 x 2 cm^2. Mass, surface area, and height measurements were taken from each gel before beginning testing. A schematic of experimental setup, measurements, and circuitry can be found in Figure 4. Samples were placed on a hot plate pre-heated to 30 ℃, whose temperature was periodically confirmed with an infrared thermometer. Initial gel temperatures were recorded, and subsequent measurements were taken every two minutes over a 10 minute period. From the data obtained, calculations of thermal conductivity were made as described in Equation I.

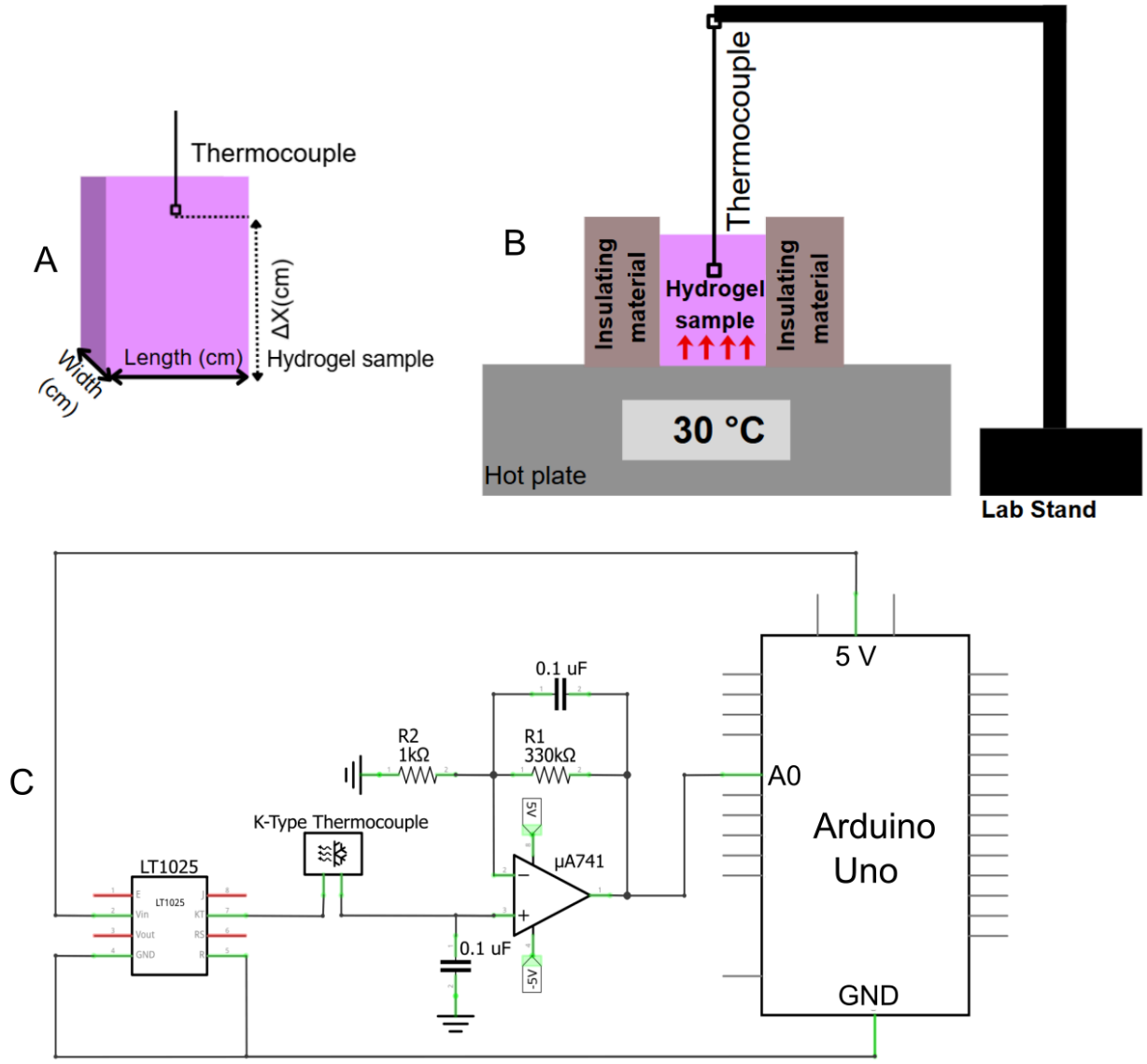


Figure 4: Hydrogel thermal conductivity testing. (A) Gel measurements compared to (B) conductivity testing setup. Panel (C) shows a schematic of the circuit used to take temperature measurements.

2.4 Electrical Conductivity Configuration

OUTLINE:

- As this testing is meant to begin Thursday, 3/5 (the day after this report is to be submitted), we will be writing up an outline for this portion as well; this will soon be updated as we complete various stages of this testing.

A final important consideration for the brain phantom material was that of its electrical conductivity, or its ability to conduct electric current [12]. Measuring the material's ability to allow flow of electric charge is essential prior to final phantom assembly, given the desired testing metric of secondary current build-up. Once again, the goal is to match values similar to those of brain tissue in literature: 0.2-0.5 Siemens per meter (S/m) [13]. To characterize the various gel concentrations' conductivities, an induced-voltage set-up was configured, making use of the relationships displayed in Equations II-IV:

$$V = IR \tag{II}$$

$$\rho = \frac{R*A}{L} \tag{III}$$

$$\sigma = \frac{1}{\rho} \tag{IV}$$

Gel samples of ___, ___, and ___ saline concentrations were formed and set within 3D-printed housings of __ x __ x __ dimensions and left for 12 hours overnight. At the onset of testing, pairs of silver electrodes were inserted within opposite ends of each gel sample and attached to an oscilloscope. By generating a sine wave of _____…. and measuring induced voltage at each electrode with a digital multimeter, calculations for each sample's conductivity were made simple.

- An in-depth description of testing assembly can be found in the supplementary information, including the equipment models and sample measurements.

2.5 Final Phantom Assembly

- OUTLINE:
    - The final model is made up of an anatomically accurate 3D-printed pediatric skull component, based off of MRI scans and processed through SimNibs, as well as a ____-based hydrogel with ____ added saline.
    - To achieve this structure, the outer skull component was printed first at the Design Innovation Lab on the UW-Madison campus….

- A mold was fabricated out of Ecoflex so as to form the brain component; again utilizing the MRI scans to ensure a matching shape. After pouring the ___-based hydrogel into this mold, it was allowed to rest for ____.
- Final assembly of the phantom model, combining both the skull and brain components into one prototype, occurred at the site of the TMS testing equipment, the Pediatric Neuromodulation Laboratory (PNL) at the Waisman Center. The brain was fitted snugly within the skull receptacle immediately prior to the onset of testing.
- Another undertaking was that of creating a protocol for pulse administration in order to measure baseline and experimental values…
- [Insert figures taken during actual testing]

3. Results

3.1 Thermal Conductivity

Initial thermal conductivity testing for 4%, 6%, and 8% gelatin were 0.32 ± 0.07, 0.67 ± 0.23, and 0.47 ± 0.09 W/m-K, respectively. The concentration of NaCl was held fixed in each sample at 0.17%. There was no significant trend expressed in these results to relate gelatin concentration to the corresponding thermal conductivity value, as this outcome suggested 6% gelatin had the highest thermal conductivity of the three. 8% gelatin most closely resembled pediatric brain tissue, with only a 13.1% difference compared to 42.9% and 26.6% in the 4% and 6% groups. One-way ANOVA analysis gave a p-value of 0.082, showing no significant difference between sample groups.

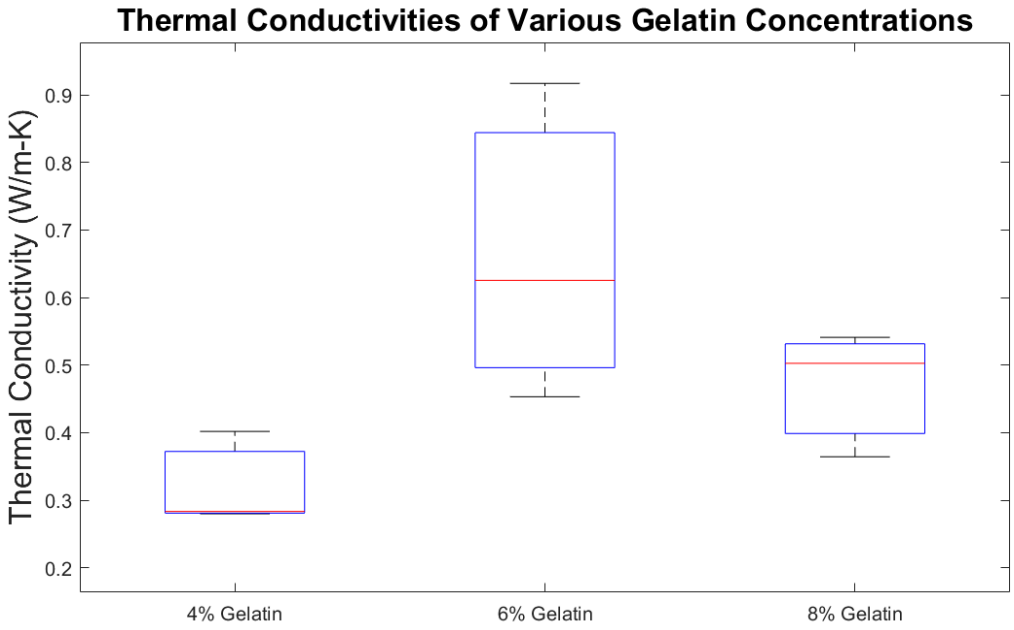


Figure 5: Boxplot of Knox unflavored, food-grade gelatin showing the thermal conductivities of 4%, 6%, and 8% hydrogel concentrations with 0.17% Thermo Fisher Scientific NaCl. The respective results were 0.32 ± 0.07, 0.67 ± 0.23, and 0.47 ± 0.09 W/m-K. An ANOVA analysis revealed no significant difference between groups ($p = 0.082$).

- The final chosen hydrogel of _____ with _____ saline and _____ gelatin/agar offered a thermal conductivity of _____ W/m-K, which has a _____% difference from that of brain tissue, 0.536 W/m-K [14].
- A one-sample t-test revealed the experimental value of ____ is/is not significantly different from that of native pediatric brain tissue with a p-value of _____.
- Figure: Photo of testing setup, results by gel %

3.2 Electrical Conductivity

- OUTLINE:
    - To further characterize the electrical properties of the chosen hydrogel, the voltage drop across samples was measured and used to find electrical conductivity.

- ____ equipment revealed an electrical conductivity of _____ S/m for a frequency sweep from 10 to 20 MHz.
- These results were repeatable and showed a ____% difference from the goal range of 0.2-0.5 S/m [13].
- Statistical analysis
- Figure: photo of testing setup, schematic of circuit used, etc.

3.3 Mechanical Testing

- OUTLINE:
  - Rheometer testing was performed to verify mechanical characteristics of _____. Using a frequency range of _____ MHz, the hydrogel revealed a shear modulus of _____ kPa.
  - In addition, the sample had an elastic modulus of _____ kPa.
  - Figure: photo of testing set up, potentially a schematic to better depict the concept of rheology, and graph of results

3.4 Phantom Testing

- OUTLINE:
  - Single-pulse TMS (spTMS) was administered to the phantom while iEEG was occurring simultaneously through previously inserted depth electrodes at ____ MHz. After spTMS, the electrodes in the phantom moved _____ mm.
  - Heating of ____ °C was documented, as well as a charge density of ____ $\mu C/cm^2$.
  - Statistical analysis
  - This figure would include: full testing setup and three graphs of the tests performed, including statistical analysis

4. Discussion

4.1 Hydrogel Testing

- This is going to be heavily edited based on the results of further testing and statistical analysis for the final report, I just wanted to get the style correct.

ANOVA analysis on initial thermal conductivity results for gelatin hydrogels did not show statistically significant differences across conditions. While our main priority with hydrogel prototyping was to match the specified properties of pediatric brian tissue, these results indicated the need for further testing. Initial testing was done on food-grade gelatin powder, while the planned final prototype will be created out of 300g bloom, cell-culture grade, Type A gelatin powder [9]. This is a ballistics-grade gelatin, and the results from testing may vary greatly from our initial testing. When repeating testing, we will prioritize consistency in gelatin formation, including solution temperature. We expected to see an observable, measurable trend in gelatin thermal conductivity as gelatin percentage increases, and the lack of this trend indicates error in either fabrication or testing protocols.

- Discussion of electrical conductivity results

Statistical analysis of electrical conductivity testing results revealed _____. _____ had the closest match to native brain tissue, so we selected this hydrogel composition to continue on to mechanical testing.

  - Here, I would also discuss anything that could have affected imperfect testing, whether the gel is out of the expected/desired range, whether there are conductivity trends with saline concentration as expected, etc. Based on the testing we just did, there are no trends when it comes to

- Discussion of mechanical results

Analysing the results of the rheological testing confirmed/revealed _____.

  - Here, I am hoping to say that our own mechanical testing confirmed the Franck Lab's findings, and also that the salt concentration did not have a significant effect on the mechanical properties of the gel. If other results occur, I will discuss those here as well.

- Discussion of TMS/iEEG results

The gel composition was tested as a box phantom (Figure reference here) encased in a polymer housing with TMS and iEEG before completing the final prototype. Applying single-pulse TMS to implanted electrodes on this box phantom revealed _____.

  - Here I will hopefully say that this testing confirmed minimal heating/displacement/current generation etc. If this is not the case, we will have to do further evaluation of our chosen hydrogel. Considering the

positive results from the Iowa paper, it is expected that there will be minimal negative effects of TMS on iEEG, so if something were to go drastically wrong we may have to consider that our fabrication or choice of materials were incorrect.

4.2 Phantom Testing

- OUTLINE:
    - The pediatric brain phantom underwent testing using TMS and iEEG in tandem to assess electrode displacement, heating, and electric field generation.
    - The aim is to have limited electrode displacement, heating, and electric field generation.
    - While transporting and assembling the phantom at the testing facility, located in the PNL, we encountered issues with _____.
        - Potential issues:
            - Maintaining consistent temperature to keep the hydrogel stable
    - Setting up the phantom at the PNL involved ____. We encountered issues with _____. In future testing, _____ should be implemented for better results.
        - Potential issues:
            - Limited space for all equipment necessary
            - Limited resources for properly testing displacement, heating, and field generation
            - Issues with total assembly of phantom including the skull and brain
    - As seen from the results of testing, it can be seen that…
        - Discuss results for electrode heating, displacement, and field generation and if they were ideal
        - If not ideal, what we could do to improve
    - This section will also include figures of the testing setup.

4.3 Assumptions and Simplifications

- OUTLINE:

- Primarily, while creating this brain phantom model we have greatly simplified the physiology and anatomy of the human brain and skull. While we are prioritizing matching the thermal conductivity, electrical conductivity, and mechanical property values of pediatric brain and skull tissue, there are a wide variety of tissue types in-vivo that present very different properties.
- By deciding to aim for ranges of ___ S/m, ____, and ____, we must acknowledge that this cannot act as a full representation of relevant human anatomy.

4.4 Limitations

- OUTLINE:
    - There are several factors in various areas that limited the successful creation of the pediatric brain phantom.
    - First, equipment used for the preparation and testing of the hydrogels were not operating in a consistent manner, making it difficult to precisely fabricate and test the gels. Specifically, hot plates used to heat and stir the gels during sample preparation did not reliably hold a consistent temperature, nor were displayed temperatures accurate when compared to those of a heat gun. This hot plate issue was also presented as a difficulty during thermal conductivity testing where we needed to raise the temperature of the gels over time. During testing, we had to continuously measure the actual temperature of the hot plate using an infrared thermometer and adjust the displayed temperature of the hot plate based on the thermometer's reading, which potentially led to inconsistent results. Additionally, there were issues with the functionality of the thermocouple and the Arduino software in tandem with the gels. Oftentimes, using the thermocouple in the gels caused the Arduino software to malfunction and display temperatures that were not accurate.
    - Second, there is currently limited literature regarding the fabrication of a pediatric brain phantom. The most closely related previous literature is for testing the safety of iEEG and TMS in tandem in adult patients, not pediatric. Other pediatric brain phantoms exist but do not serve a purpose relevant to using TMS and iEEG.

- Third, time and budget constraints limited the success of the brain phantom's creation.

5. Conclusions

- For the final report, major updates will be needed for this section, particularly regarding the results of the final TMS testing and what conclusions this allows us to make about the safety of combined TMS and iEEG in pediatric patients.

Completion of this phantom will allow for us to validate the use of TMS in conjunction with iEEG for pediatric patients. While previous studies have addressed concerns with using TMS and iEEG in conjunction in adult patients, they fail to consider more stringent safety standards and physiological differences present in pediatric patients [4]. Epilepsy is the fourth most common neurological disease, often manifesting in pediatric patients before the age of one year [1]. iEEG is routinely used in surgical planning for epilepsy in adult and pediatric patients, and TMS may provide complimentary information for mapping critical regions of the brain that should be avoided during surgery. However, there are still many safety concerns around the use of TMS in patients with iEEG electrodes actively implanted. Our aim was to develop a phantom for validation of use of TMS in pediatric patients with implanted cortical electrodes.

Moving forward, gelatin will be tested for thermal, electrical, and mechanical properties using the protocols described previously to tune concentrations for the final brain gel. In the future, there may be some benefit of exploring an agar-based brain. The final goal is to complete TMS testing on the phantom to make a recommendation to identify if any of the three potential risks, electrode displacement, electrode heating, current generation, are present.

Acknowledgements

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Supplementary Information

Electrical Conductivity Testing Protocol

Materials:

- Keysight MSOX3024T Mixed Signal Oscilloscope and scope probe
- Keysight 34450A Digital Multimeter and test leads
- Silver electrode pair
- Alligator clips
- 3x 3D-printed ___ box of dimensions _ x _ x _
- Fabricated gelatin gels of varying concentrations:
    - _ %
    - _%
    - …

Methods:

1) After ensuring that all necessary power supply and measuring components are accessible, fabricate gels of desired concentrations and leave to set overnight within the 3D-printed boxes at a temperature between 1°C to 4°C.
2) Collect the starting volumetric and mass measurements of gels to be tested.
3) Assemble the testing set-up, focusing on one gel at a time:
    a) Insert one silver electrode at each end of the gel's length
    b) Record the distance between both points of insertion
    c) Connect the test leads on either end of the gel's length, ensuring that there are no points of connection between the electrodes and test leads
    d) Record the distance between these components (each end's electrode insertion and test lead)
4) Before turning power on, ensure that all devices are running and working properly.
    a) ***Insert troubleshooting here? I.e. check the digital multimeter by recording resistance of a resistor with known value?***
5) Generate a waveform on the Keysight Oscilloscope of _____ frequency (blah blah blah… need to figure out specs)

6) Measure the induced voltage using the Keysight Digital Multimeter and record the reported value(s).
7) Repeat ___ times per gel, at frequencies __, __, and __.
8) To solve for resistance of each gel, utilize Ohm's Law and the reported induced voltage values corresponding with each signal.

Governing equations:

$V = I * R$

Resistivity (ρ) = 1 / conductivity (σ)

$\rho = R * A/L$ (resistivity = resistance * length / surface area)

$\sigma = L / R*A$

Protocol for Processing a CT Scan in 3D Slicer

1. Open 3D Slicer → Load DICOM file
2. Go to "Segment Editor"
3. Add a new segment → choose "Threshold"
4. Use slider to find bone thresholds (~150-3000 HU) and apply
5. Preview model and refine using tools like:
6. Smoothing
7. Islands → Keep largest
8. Scissors/Paint for manual cleanup
9. When satisfied: Segmentations → Export to 3D Model
10. STL for direct 3D printing
11. OBJ for editing in CAD software such as SolidWorks

File Processing from STL to Workable CAD

1. Obtain STL file or process DICOM file into STL (see procedure for doing this in 3D Slicer)
2. Import STL file into Fusion360
3. Manually remove any artifacts from scan (you can also do this in 3D slicer before exporting as STL)
4. Use repair mesh --> close holes, wrap, and stitch and remove
5. Compress model to smaller ratio to avoid crashing with larger file
    a. Generally, want less than 50k triangles, the smaller the better, but with more compression you lose detail
6. Convert mesh to solid body (prismatic)

7. Export as STEP file
    a. If you want to stay in Fusion360 to edit the CAD model stop here!
8. Import STEP file into SolidWorks
    a. This step can take around 30 minutes to import, especially if the file has a lot of triangles
9. Use internal repair tools to fill any remaining gaps
10. Save as a SLDPRT (part) file

To edit the CAD file:

11. Create sketch on surface
    a. Sometimes you need to create a plane along the surface by creating individual points and anchoring them to the surface
    b. SolidWorks is nice because it allows you to create 3D sketches, which is why we are using it over Fusion360
12. Extruded cut from shape to create top half of the skull
13. Save a separate copy of the same file
14. Reverse the extruded cut to leave the bottom half of the skull
15. Additional extruded cuts to remove any undesirable components
16. Save both files and exported at STL or STEP file for 3D printing

Thermal Conductivity Protocol

Before you begin:

Pour hydrogels at 4, 6, 8% gelatin, 0.17% NaCl
Allow gels to firm overnight. These gels were swelled with an excess of DI water to reach equilibrium overnight

Testing protocol:

Cut n>3 samples from the hydrogel mold. For consistency, they should all be approximately the same size. **Make these as close to rectangular as possible.** Weigh samples and take their dimensions, making sure you know which face of the sample will be in contact with the hot plate.. This will be the surface area (A) dimension. Measure the length of the thermocouple you will be inserting into the sample. Mark this value, and subtract it from the height (measured as the dimension orthogonal to the face in contact with the hot plate) to get your ΔX value.

Set the hot plate to 35 C and allow it to come to temperature. Wrap the sample in an insulating material and insert a thermocouple. Measure and record starting temperature.

Allow the sample to sit on the hot plate for 10 minutes. Each minute, take a temperature measurement and record it. After 10 minutes, the sample at the location of the thermocouple will not be 35 C, but it should be increased by a number of degrees C.

Take the sample of the hot plate and calculate thermal conductivity from the given equation.

Thermal Conductivity Thermocouple Testing Code

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int sensorPin = A0;   // select the input pin for the potentiometer
int sensorValue = 0;  // variable to store the value coming from the sensor
float tempSum = 0.0;
int count = 0;

void setup() {
  // declare the ledPin as an OUTPUT:
  Serial.begin(9600);
  pinMode(ledPin, OUTPUT);
}
void loop() {
  // read the value from the sensor:

  sensorValue = analogRead(sensorPin);
  float voltage = (sensorValue * 0.0049);
  float temp = (voltage + 0.267) / 0.0143;
  //Serial.print("Temp: ");
  //Serial.println(temp);

  count++;
  tempSum = tempSum + temp;
  float temp_ave;
  if (count == 100) {
    temp_ave = (tempSum/100);
    //Serial.println(tempSum);
```

```
    Serial.println(temp_ave);
    tempSum = 0;
    count = 0;
  }
  delay(10);

}
```

Gelatin Fabrication Protocol 03/01/2026

Weigh out gelatin and NaCl.

4% gelatin, 0.17% NaCl - 2.045g gelatin, 0.087g NaCl

6% gelatin, 0.17% NaCl - 3.03g gelatin, 0.084g NaCl

8% gelatin, 0.17% NaCl - 4.05g gelatin, 0.086g NaCl

Before beginning, wash glassware out with DI water three times. Dissolve gelatin powder for 5 minutes in 50 mL of room-temperature MilliQ water. Increase temperature to 37 ℃ and add NaCl after 20 minutes. Once dissolved, bring temperature of solution up to 65 ℃ and continue to mix for one hour. Use transfer pipettes to divide solution into 4 silicone molds. Leave an empty row between samples to minimize cross-contamination and ensure gels maintain a uniform shape.

Gelatin Thermal Conductivity Data 03/01/2026

Sample ID	Percent Gelatin	Percent Saline	Surface Area (cm^2)	X (cm)	Initial temp (C)	Final temp (C)	D_temp (C)	Mass (g)	Width (cm)	Length (cm)	Height
g_401	4	0.17	5.52	1.1	18.97	20.72	1.75	10.06	2.3	2.4	1.9

g_402	4	0.17	5.98	1.1	19.5	20.7	1.2	10.16	2.6	2.3	1.9
g_403	4	0.17	5.75	1.2	20.03	20.62	0.59	9.92	2.3	2.5	2
g_404	4	0.17	5.29	1.15	20.62	21.11	0.49	9.37	2.3	2.3	1.95
g_601	6	0.17	5.75	1.2	20.2	20.68	0.48	10.38	2.5	2.3	2
g_602	6	0.17	5.52	1.2	20.55	21.27	0.72	9.92	2.4	2.3	2
g_603	6	0.17	5.52	1.1	20.61	21.15	0.54	10.45	2.4	2.3	1.9
g_604	6	0.17	5.5	1.3	20.18	20.84	0.66	10.2	2.5	2.2	2.1
g_801	8	0.17	5.5	1.1	20.3	21.12	0.82	10.84	2.2	2.5	1.9
g_802	8	0.17	6.24	1	20.41	21.55	1.14	11.14	2.6	2.4	1.8
g_803	8	0.17	6.25	1.2	20.33	21.19	0.86	11.09	2.5	2.5	2
g_804	8	0.17	5.52	1.1	19.9	20.61	0.71	9.09	2.3	2.4	1.9