Intracranial EEG Phantom for Brain Stimulation Studies

BME 400

October 3rd, 2025

Clients: Dr. Raheel Ahmed, Dr. Arun Manattu
UW School of Medicine and Public Health

Advisor: Dr. Paul Campagnola

Avery Schuda, Lilly Mackenzie, Orla Ryan, Helene Schroeder, Corissa Hutmaker

Department of Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Background

- Dr. Ahmed, as a pediatric neurosurgeon at the American Family Children's Hospital, has a special focus in pediatric epilepsy [1]
- Epilepsy, a neurological disorder characterized by the appearance of regular, unprovoked seizures, can often be controlled through medication
- Sometimes, however, surgical treatment is required to achieve proper seizure control [2]

Figure 1: Dr. Raheel Ahmed [1].

Motivation

- Current methods of brain mapping include:
  - Intracranial electroencephalography (iEEG) [3]
  - Transcranial magnetic stimulation (TMS) [4]
- Can these be used in tandem? We are seeking to offer the most comprehensive care possible for pediatric patients!

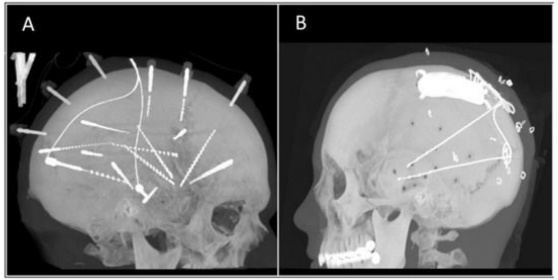


Figure 2: iEEG electrode placement [5].

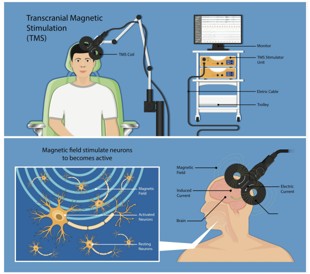


Figure 3: TMS procedure [6].

Figure 4: Providing the best possible care [7].

Problem Statement

- The goal of this project, therefore, is to develop a **pediatric** brain phantom model
- It will be used to simulate the main effects of TMS on iEEG electrodes:
    - Currents
    - Temperature changes
    - Changes in position

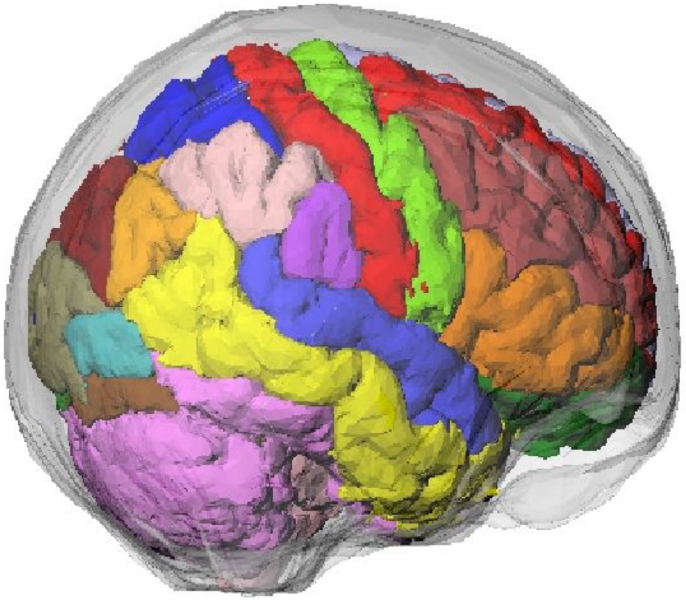


Figure 5: Example brain phantom model [8].

Competing Designs

University of Iowa Gel-Based Brain Phantom

- Phantom to prove safe use of combined iEEG and TMS use in **adults**
- Poly(acrylic acid) (PAA) gel base with poly(methyl methacrylate) (PMMA) wall
- Fails to consider **pediatric** patients

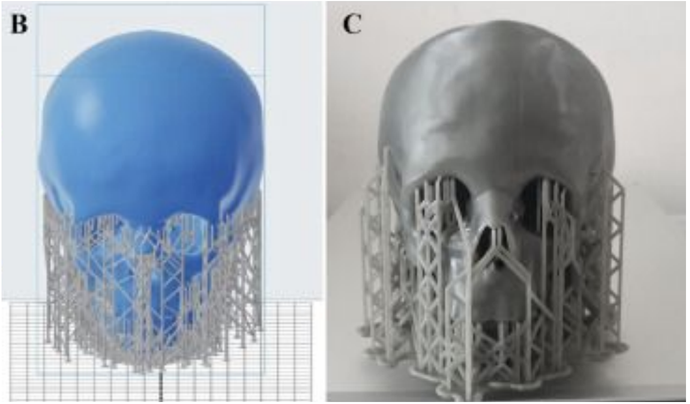


Figure 7: 3D-printed pediatric phantom [10].

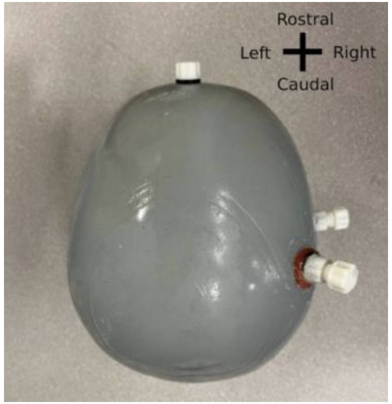


Figure 6: Iowa's gel-based phantom [9].

3D-Printed Pediatric Head Phantom

- Phantom to develop optimized pediatric computed tomography (CT) protocol
- Grey V4 resin and plaster skull with epoxy resin brain
- Purpose of phantom does not meet scope of this project

Product Design Specifications

- Represents physiology of average pediatric brain and skull
  - Skull circumference: 50-54 cm [11]
  - Overall matter volume: 1,300 cm^3 [12]
- Brain material must have similar conductivity to brain tissue, 0.2-0.5 S/m [13]
- After TMS testing, electrodes must have:
  - Temperature change: <1 °C
  - Displacement: ~0 mm
  - Charge density: <30 $\mu C/cm^2$
- Must comply with MTR Standards 2.4 and 3.3, CFR Standards 882.5802, and ASTM F2182 [14] [15] [16]
- $500 budget

Material Choices

The team chose to go ahead with a hydrogel material for the brain phantom, and a synthetic, 3D printable polymer for the skull base.

What is a hydrogel?

- Interconnected network of polymers
- Majority water
- Can be natural or synthetic

Why choose a hydrogel?

- Highly adjustable
  - Electrical conductivity [9]
  - Mechanical properties
- Precedence in literature [9] [17]

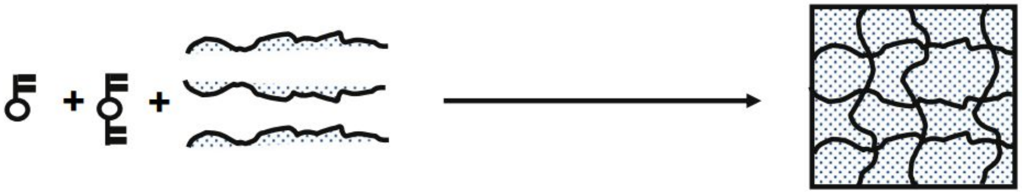


Figure 8: Example synthesis of hydrogel from a monomer and crosslinkers [18].

Category 1: Hydrogel Material

Gelatin
- Natural
- Inexpensive
- Poor thermal properties

Poly(acrylic acid)
- Synthetic
- Highly tunable
- Precedence [9]

Agar
- Natural
- Very common in research
- Precedence [17]

Agarose
- Natural
- More expensive
- Purified form of agar

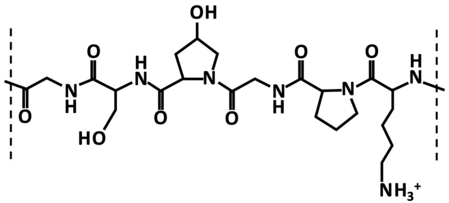


Figure 9 : Example Chemical structure of gelatin [19].

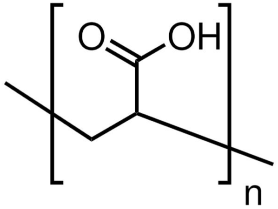


Figure 10: Chemical structure of acrylic acid monomer [20].

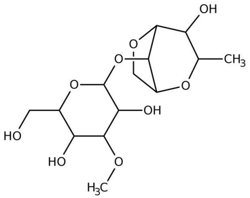


Figure 11: Chemical Structure of Agar [21].

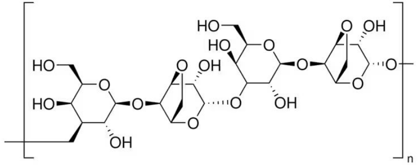


Figure 12: Chemical structure of Agarose [22].

Category 1: Hydrogel Material

Other important factors were considered:

- Electrical conductivity
- Mechanical properties
- Availability

Agar scored the highest; however, **all are strong possibilities**

Design Criteria	Weight	Gelatin		Poly(acrylic acid)		Agar		Agarose	
Thermal Conductivity	20	2/5	8	3/5	12	5/5	20	1/5	4
Preparation Method	20	2/5	8	4/5	12	5/5	20	4/5	16
Tunability	20	1/5	5	5/5	20	3/5	12	3/5	12
Reactivity	15	4/5	12	3/5	9	2/5	6	3/5	9
Shelf Life	15	1/5	3	4/5	12	3/5	9	3/5	12
Cost	10	5/5	10	2/5	4	4/5	8	2/5	4
Total	100	46		69		75		57	

Table I: Design matrix for brain phantom hydrogel materials.

Category 2: Phantom Base Material

Poly(lactic acid) (PLA)

- Accessible
- Inexpensive
- Lower quality prints

Poly(methyl methacrylate) (PMMA)

- Good shelf life
- E = 2.35 GPa [24]
- Outsourcing required

Formlabs BioMed Clear

- Acrylate, UDMA, methacrylate copolymer
- E = 2.08 GPa [26]

Formlabs Standard Resin

- UDMA and methacrylate copolymer
- Lower cost

Figure 13: PLA 3D print [23].

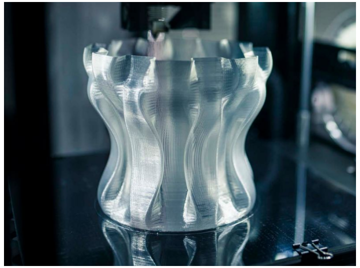


Figure 14: PMMA 3D print [25].

Figure 15: BioMed Clear Resin 3D print [27].

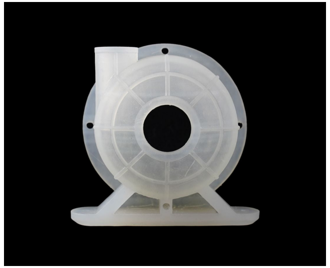


Figure 16: Formlabs Standard Resin 3D print [28].

Category 2: Phantom Base Material

Design Criteria	Weight	Poly(lactic acid) (PLA)		Poly(methyl methacrylate) (PMMA)		FormLabs BioMed Clear		FormLabs Standard Resin	
Reactivity and Shelf Life	25	3/5	15	5/5	25	4/5	20	3/5	15
Transparency	20	1/5	4	5/5	20	5/5	20	3/5	12
Permittivity	20	2/5	8	3/5	12	5/5	20	5/5	20
Accessibility	15	5/5	15	1/5	3	4/5	12	4/5	12
Mechanical Properties	10	2/5	4	5/5	10	5/5	10	3/5	6
Cost	10	5/5	10	1/5	2	3/5	6	4/5	8
Total	100	56		72		88		73	

Table II: Design matrix for 3D printed phantom base material.

Final Chosen Designs

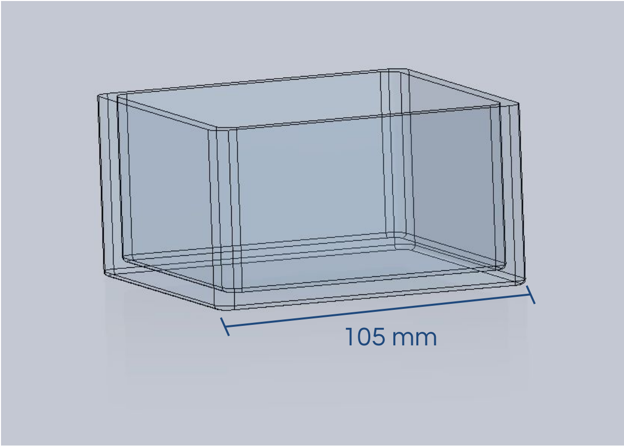


Figure 17: Pediatric sized gel box phantom design for preliminary displacement testing.

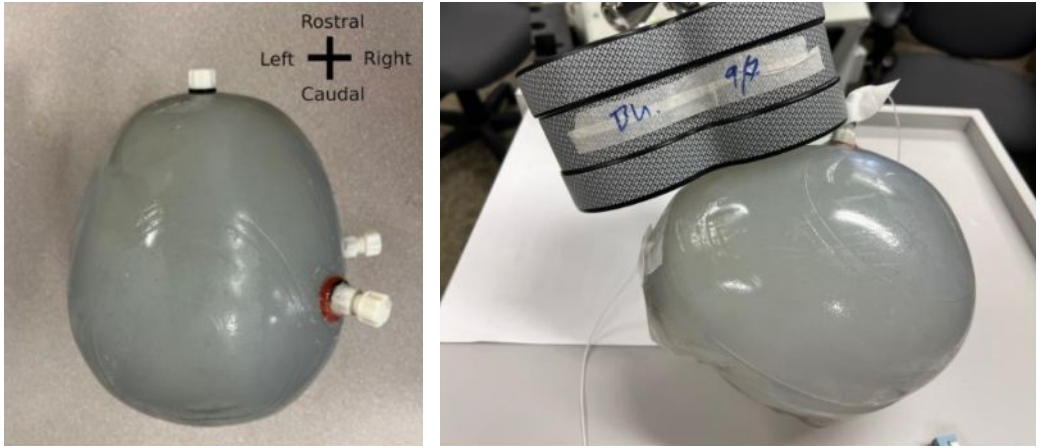


Figure 18: Phantom for testing combined use of TMS and iEEG for adults [9]. Design to be modified for pediatric patients.

Planned Material Testing

- Mechanical properties
  - Elastic modulus
  - Shear modulus
  - Viscoelastic properties
- Integrity testing
- Electrode heating
- Electrode displacement
- Conductivity and electric field generation

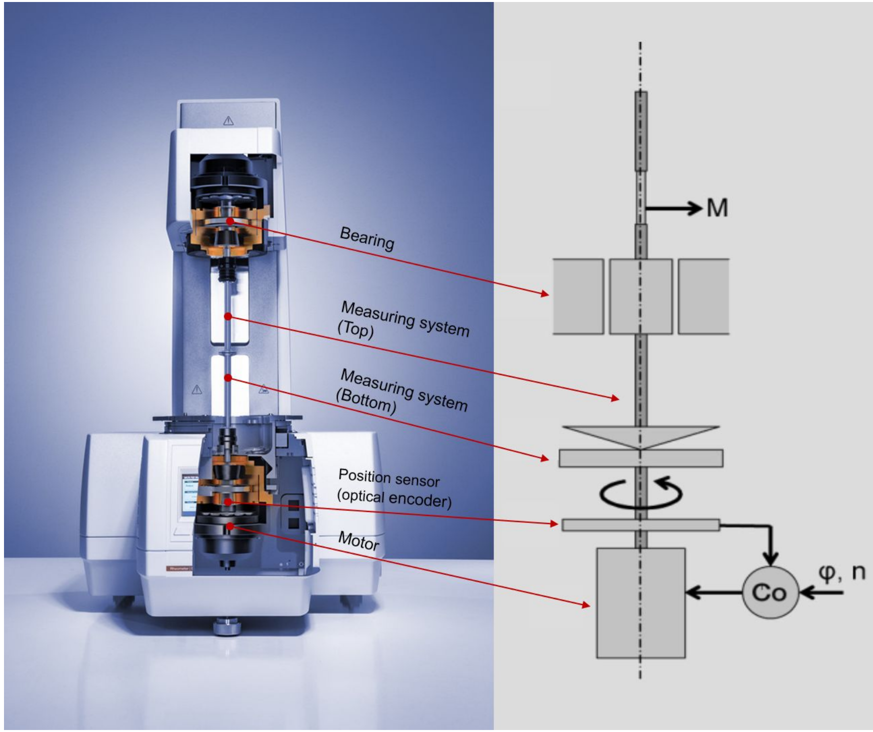
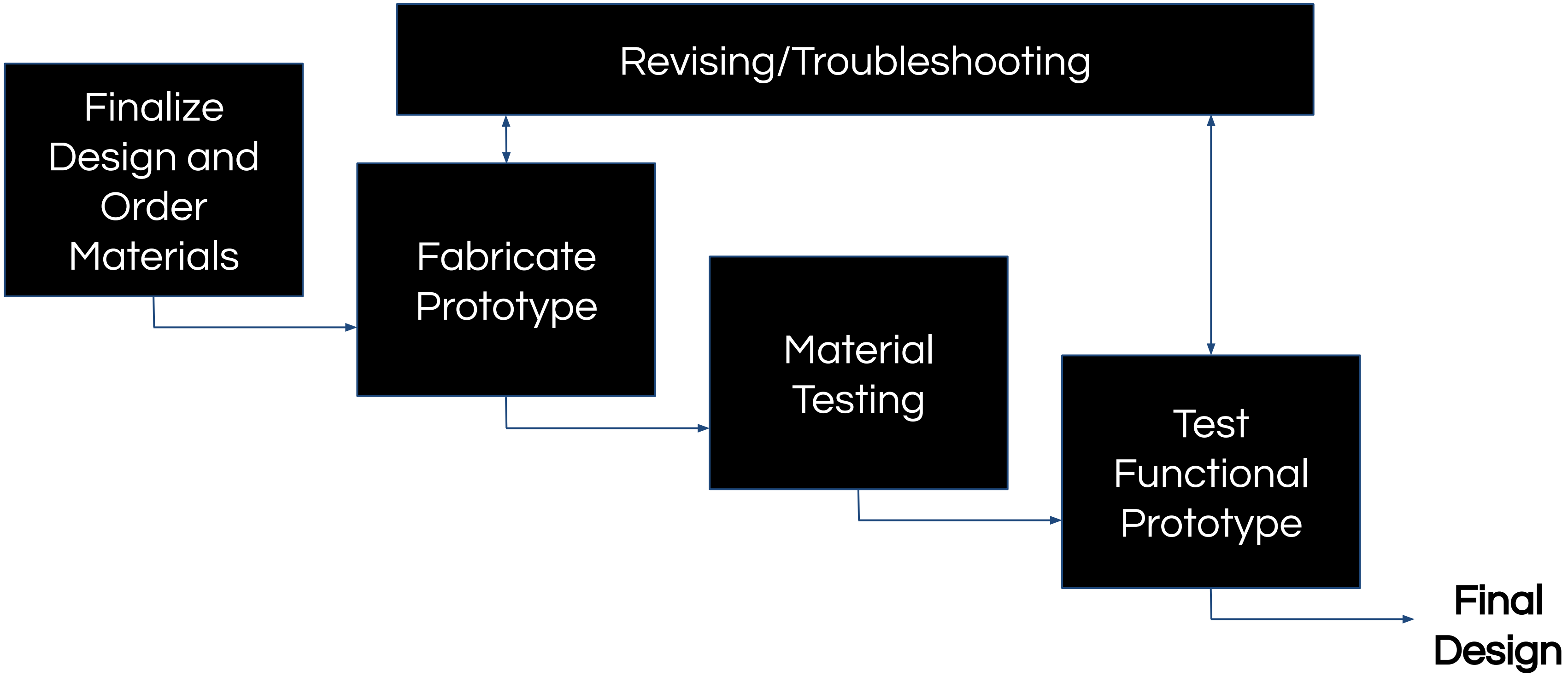


Figure 19: Strain-controlled rheometer [29].

Future Work


Revising/Troubleshooting
Finalize Design and Order Materials
Fabricate Prototype
Material Testing
Test Functional Prototype
Final Design

Acknowledgements

We would like to thank our clients, Dr. Raheel Ahmed and Dr. Arun Manattu, our advisor, Dr. Paul Campagnola, Brooke Volkman, and the BME Department.

Figure 20: BME Design logo [30].

Figure 21: Waisman Center logo [31].

Figure 22: UW-Madison SMPH logo [32].

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Questions?