Anatomica: Engineering an anatomical model

A medical phantom for tuning and calibration of energy-based therapies

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Introduction & Background

Medical Phantoms are:

- Used for the testing and calibration of energy-based diagnostic and therapeutic devices (magnetic resonance imaging and shortwave diathermy systems).
- Designed to mimic the electrical and physical properties of their corresponding biological structures.
- Designed to either provide anatomical structure or model electrical/physical properties but usually not both.

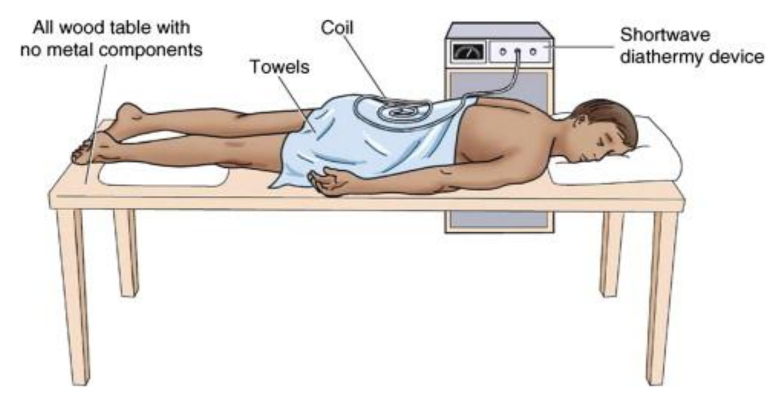


Figure 1. Shortwave diathermy for chronic lower back pain.

Mission Statement

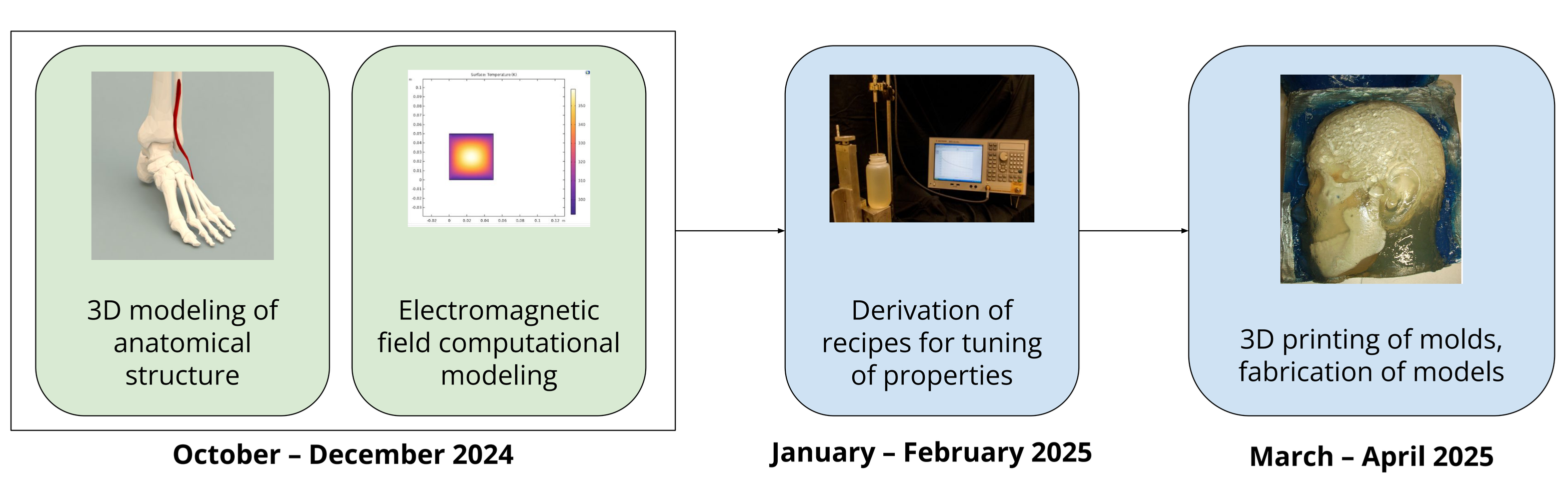
The team aims to develop an **anatomically accurate biomimetic model that will enhance the tuning and calibration of shortwave diathermy devices** as well as provide a means to better understand how patients are affected by these therapies. The team is committed to developing an innovative and reliable anatomical modeling approach that is representative of all affected patients.

The team's broad goals include:

- **Representation of Dielectric Properties of Tissues**
- **Soft Materials Design for Electromagnetic Field Mapping**
- **Representation of Basic Anatomical Structure in the Foot**
- **Cost Effective, Simple & Reliable Fabrication Process**

Project Timeline & Planning

Project development and timeline from October through April:



Design Inputs

Customer Needs:

- Standardization of models across patient characteristics
- Dielectric properties match those of tissues
- Electric/Magnetic sensor hosting capabilities
- Easy, inexpensive fabrication process

Cost of Production Goal: <$75 per unit

Tissue	Conductivity (S/m)	Relative Permittivity
Dermis	0.32887	165.03
Muscle	0.65417	95.764
Cortical Bone	0.051577	21.784
Fat	0.032923	8.452
Tendon	0.43963	78.203

Foot dimensions		
Gender	Length Range (in)	Width Range (in)
Male	9.84-11.54	3.70-4.37
Female	8.90 - 10.55	3.35 - 3.98

Figure 2. Target parameters for electrical properties and dimension ranges both the male and female foot.

Product Architecture & Technical Models

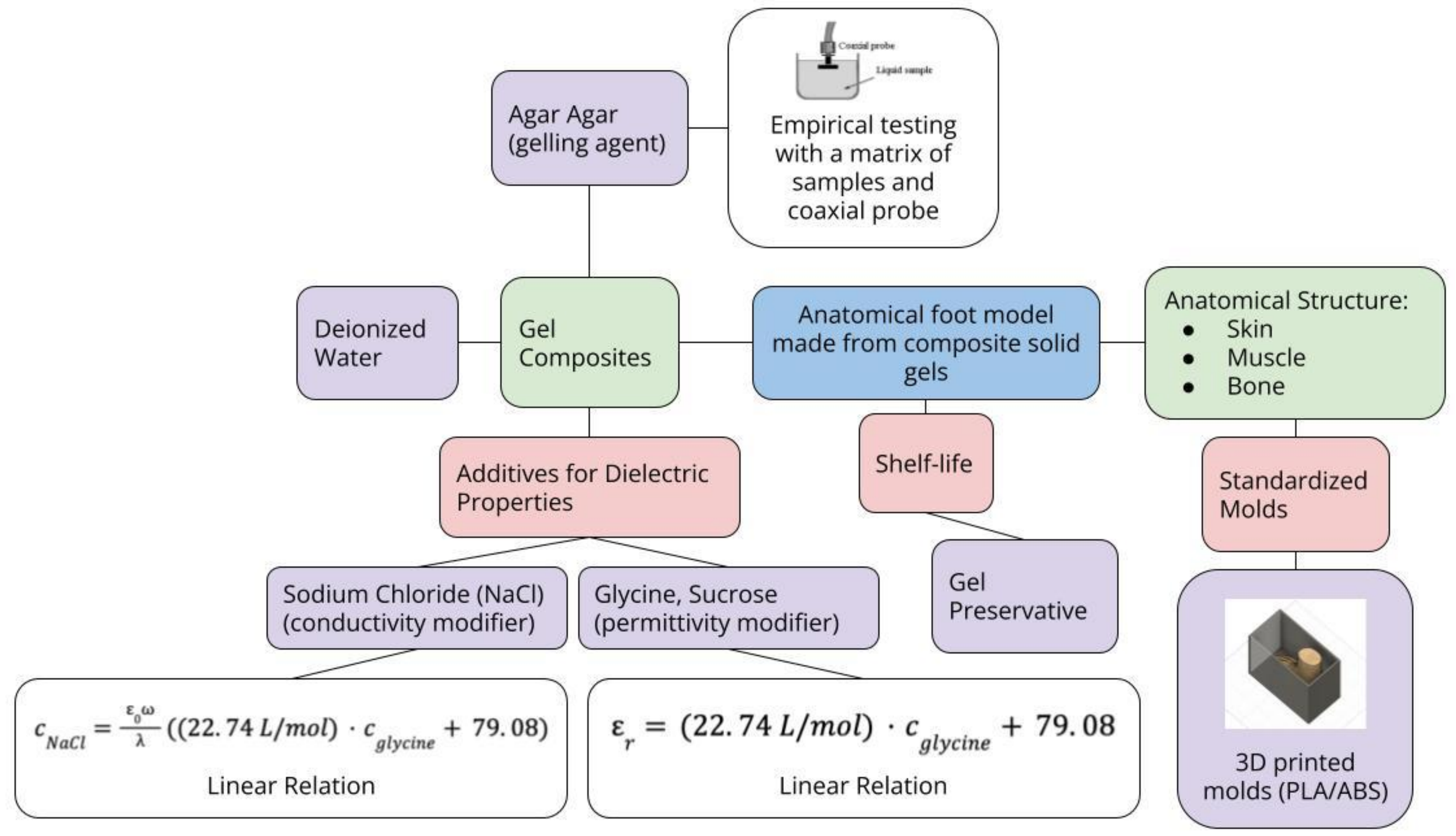


Figure 3. Product Architecture of anatomical model containing major components and areas of development.

$$\varepsilon_r^*(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}$$

Debye Equation for Complex Permittivity

Since the gel solutions contain water (dipolar molecule), their dielectric properties are affected by both the glycine concentration and frequency of electromagnetic field. Hence, the Debye Equation is used to model this phenomena at the standard 27.12 MHz frequency using empirical data.

$$\varepsilon_r^*(\omega) = \varepsilon_r'(\omega) - j\varepsilon_r''(\omega)$$

Complex Relative Permittivity

$$\varepsilon_r'(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + (\omega\tau)^2}$$ Real Component

$$\varepsilon_r''(\omega) = \frac{\varepsilon_s - \varepsilon_\infty}{1 + (\omega\tau)^2}(\omega\tau)$$ Imaginary Component

$$\varepsilon_r = (22.74\ L/mol)\cdot c_{glycine} + 79.08$$

Linear relation between total permittivity and glycine concentration obtained from empirical data

$$\varepsilon_r^*(\omega) = \varepsilon_r'(\omega) - j\frac{\sigma}{\omega} \longrightarrow \sigma = \lambda \cdot c_{NaCl} \longrightarrow \lambda \cdot c_{NaCl} = \varepsilon_0\omega\varepsilon_r \longrightarrow c_{NaCl} = \frac{\varepsilon_0\omega}{\lambda}((22.74\ L/mol)\cdot c_{glycine} + 79.08)$$

Relation between Imaginary Component, Frequency, and Conductivity

Relation between conductivity and electrolyte concentration

Linear relation between concentration of glycine and concentration of NaCl

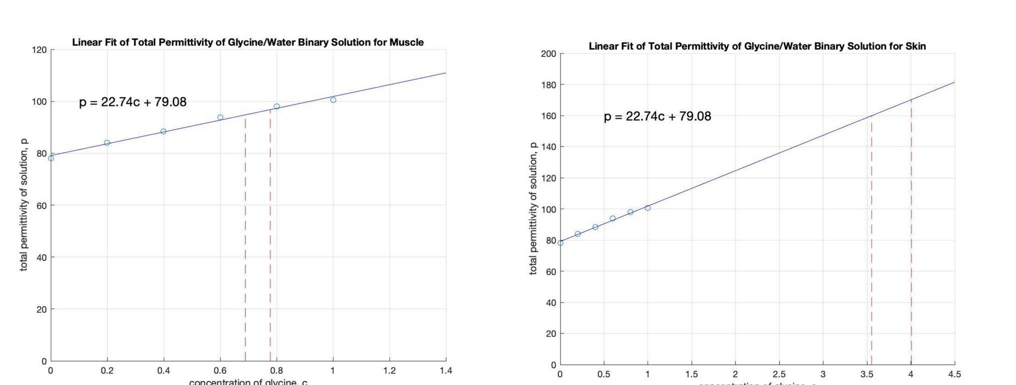


Figure 4. Total permittivity vs glycine concentration in a binary water/glycine solution. +/-6% variation ranges are shown for muscle (left) and skin (right).

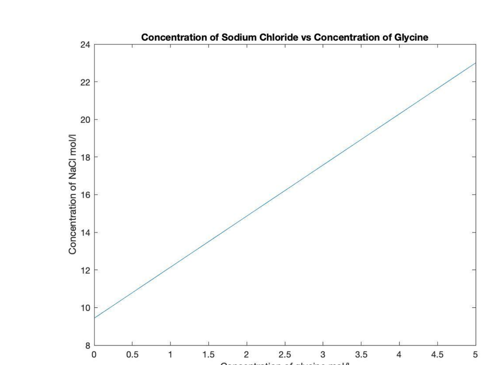


Figure 5. Concentration of NaCl vs concentration of glycine (mol/l).

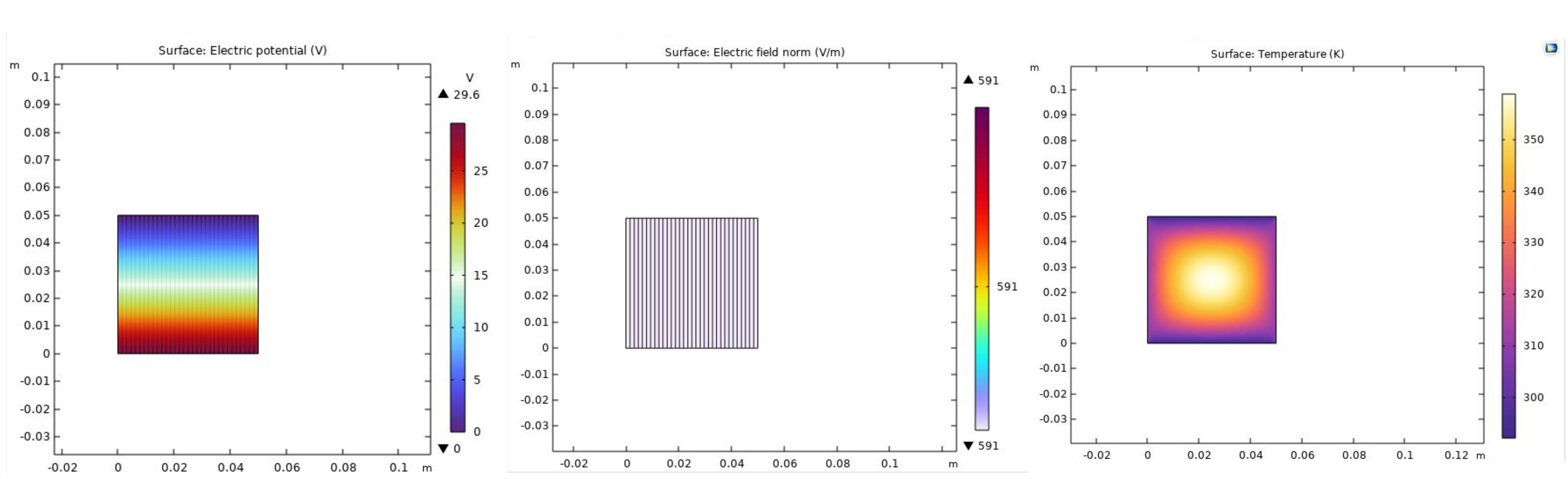


Figure 6. Analysis of heat generation in skin and relation of surface temperature to electric potential and electric field strength.

Design for Manufacturing

Projected total material costs (first time manufacturing): ~$105.00

Material	Purpose	Quantity	Cost	Supplier	Potential Alternatives	Advantage of This Material Over Others
Deionized water	Basic ingredient for gel base in muscle, bone, skin fat	~1 gal	$16.49	Amazon	N/A	N/A
Sucrose	Permittivity modifier (lowers permittivity of water)	500 g	$25.19	Amazon	N/A	Inexpensive, easy to obtain
Glycine	Permittivity Modifier (raises permittivity of water)	500 g	$23.96	Amazon	Aluminum powder	Inexpensive, easy to obtain
NaCl (table salt)	Conductivity modifier in muscle, bone, skin, fat	52 oz	$3.38	Amazon	N/A	Inexpensive, easy to obtain
Agar Agar	Gelling agent in muscle, bone, skin, fat	500 g	$29.96	Amazon	TX-151, PEG, HEC, etc.	Concentration of this gelling agent does not affect the conductivity or permittivity of the material. This is easy to fabricate.
Acetone	Calibration substance for the coaxial probe/network analyzer measurement setup	4 oz	$3.50	Amazon	N/A	N/A
Total	**~$105.00**					

Tools for Manufacturing (Standard Equipment):

- Standard 3D Printer (prints ABS/PLA)
- Hot Plate
- Magnetic Stir Rod
- Thermometer
- Scale (0.01 g)
- Glass Beakers (1 liter)
- Small Plastic Containers
- Coaxial Probe
- Network Analyzer
- Plastic Wrap

Product Specifications

The two main components of the model are the molds for the gels and the gels themselves.

Component	No. of Parts	Material	Specifications
3D Molds	3 (bone, muscle, skin)	PLA/ABS	Male: Length: 10.75 in Width: 4.20 in Height: 6.00 in Female: Length: 9.50 Width: 4.00 in Height: 4.75 in
Gels	3 (bone, muscle, skin)	Agar agar Deionized Water Glycine Sucrose NaCl	Bone (Concentrations): Sucrose: TBD NaCl: TBD Muscle (Concentrations): Glycine: [0.6896, 0.7776] mol/l NaCl: [0.00113, 0.0011545] mol/l Skin (Concentrations): Glycine: [3.553, 4.006] mol/l NaCl: [0.0019075, 0.0020304] mol/l Solidity of gels: Agar agar: 10-25 g/l

Design Status & Future Work

Design Considerations:

- Soft materials as alternatives to hydrogels for easier mixing
- Preservatives for longer shelf-life

4 stages of development for prototyping:

1. Empirical derivation of recipes for gels
2. Refinement of 3D models and 3D printing molds
3. Fabrication of materials and assembly of models
4. Development of a standard operating procedure for future fabrications

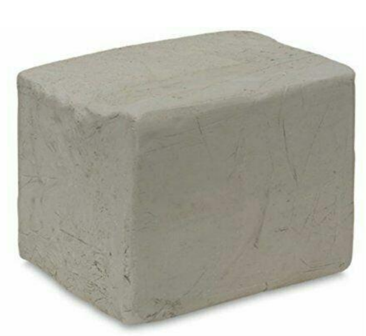


Figure 7. Plasticine (modeling clay).

Acknowledgements

A thank you to our industry mentors:

- Dr. Erica Tassone
- Jenna Bonitz
- Porter Derrick
- Nicole Jacobsen

A thank you to our academic mentors:

- Dr. Rosalind Sadleir (Faculty Mentor)
- Dr. Brent Vernon
- Dr. Bradley Greger

Arizona State University, Ira A. Fulton Schools of Engineering, School of Biological and Health Systems Engineering

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