Anatomica: Engineering an anatomical model

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

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Background

- Approximately 50% of adults diagnosed with type 1 or 2 diabetes suffers from some form of painful peripheral neuropathy [1].
- Shortwave diathermy is an energy-based nerve stimulation technique commonly used to treat chronic pain from peripheral neuropathy.
- The tuning process of energy-based medical devices utilizes medical phantoms to represent the properties of the patient within the system [2].
- Research pertaining to the behavior of various materials has led to the development of medical phantoms suitable for tuning of medical devices [2].
- Despite this effort, few medical phantoms exist specifically for applications in the electromagnetic diathermy.

Mission Statement

Precision Phantoms remains dedicated to addressing the industry need for anatomical phantoms that emulate dielectric properties of human tissue at diathermy frequency through the development of a 3-layered anatomical phantom made from solid agar-based gels and elementary anatomical structure.

Product Specifications

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Product Specification	**Value**	**Unit**
Total Composite Impedance	9.8 + j101.5	Ohm
Frequency	27.12	MHz
Male Foot Dimensions	10.5	in
Bone Tissue Volume	0.40	L
Muscle Tissue Volume	0.51	L
Skin Tissue Volume	0.58	L
Agar Concentration	2	% w/v
Bone Concentrations (sugar, salt)	1.04, 0.34	mol/L
Muscle Concentrations (glycine, salt)	1.22, 0.12	mol/L
Skin Concentration (agar)	2	% w/v
Preservative (sodium benzoate at pH 4)	1.5	%w/v

Figure 1. Table of final product specifications.

Final Technical Model

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

Debye equation for complex permittivity

$$added\ conductivity = \frac{\sigma}{j\omega\varepsilon_0}$$

Added conductivity due to introduction of salt ions

→ Separation of real and imaginary components for permittivity and conductivity

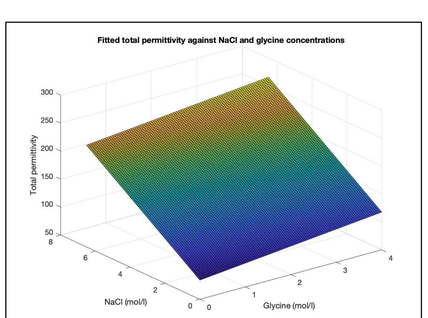


Figure 1. Fitted curves of total permittivity with varying concentrations of salt and glycine.

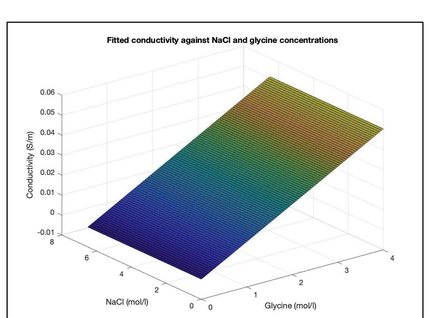


Figure 2. Fitted curves of total conductivity with varying concentrations of salt and glycine.

Prototype Construction & Development

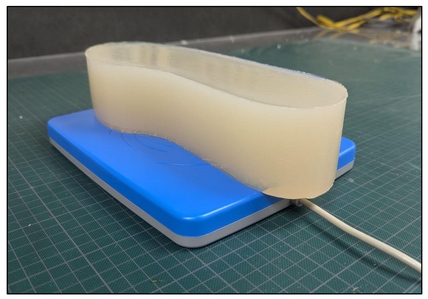
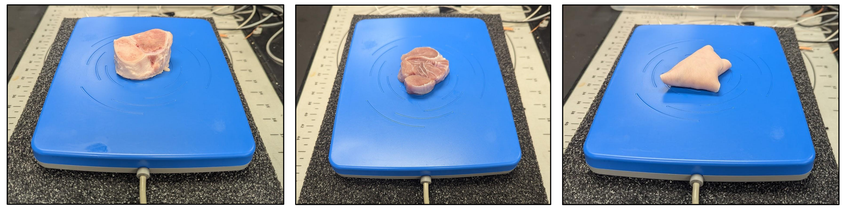


Figure 3. Final prototype on the diathermy applicator pad.

Figure 4. Second iteration of foot shaped negative molds.



Figures 5-7. Measuring impedance of porcine model as benchmark on diathermy applicator pad.

Porcine Benchmark Impedance Standardized by Volume	
Sample	**Average Standardized Impedance**
Bone	-0.00228 + j0.1870 Ω/ml
Muscle	0.00100 + j0.1770 Ω/ml
Skin	0.00500 + j0.2125 Ω/ml

Figures 8. Table of porcine benchmark impedances standardized by volume.

Develop solid gels with 2% agar → Measure impedance with applicator pad → Standardize impedances and analyze result → Determine ideal recipe against benchmark

Figure 9. Testing gels with glycine and salt as permittivity and conductivity modifiers.

Figure 10. Testing with vector network analyzer and Smith chart.

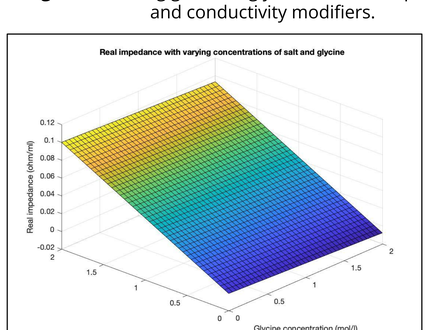


Figure 11. Fitted curves of real impedance with varying concentrations of salt and glycine.

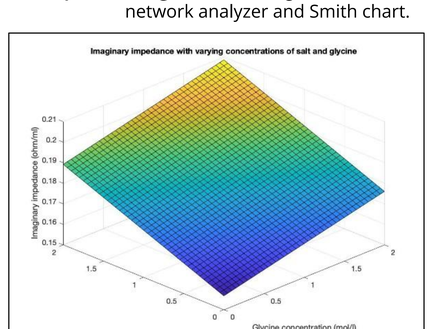


Figure 12. Fitted curves of imaginary impedance with varying concentrations of salt and glycine.

Verification Results

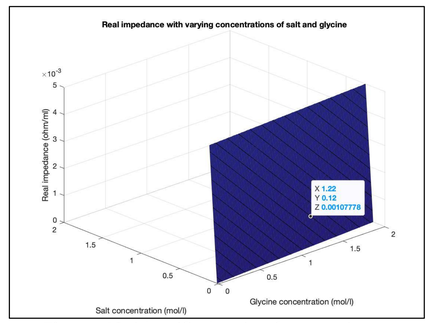


Figure 13. Identified recipe for muscle on enlarged graph of fitted curve of real impedance.

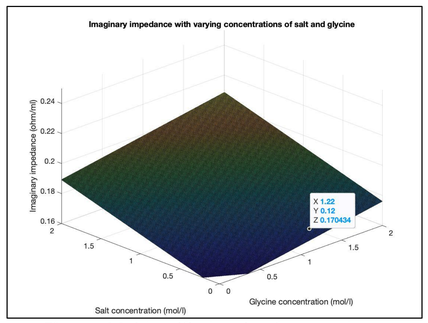


Figure 14. Identified recipe for muscle on enlarged graph of fitted curve of imaginary impedance.

Identified Recipes from Experimental Graphs	
Sample	**Identified Recipe**
Bone	Salt: 0.34 mol/L
	Sugar: 1.04 mol/L
Muscle	Salt: 0.12 mol/L
	Glycine: 1.22 mol/L
Skin	N/A

Figures 8. Table of porcine benchmark impedances standardized by volume.

Future Work

1. Improve integrity of impedance measurements
2. Dimensional tolerancing and analysis of molds and gels
3. Explore physical property simulation
4. Enhancing anatomical structures
5. Usability testing with diathermy device
6. Create other body parts
7. Longitudinal life cycle analysis
8. Further validate preservation effectiveness

Figure 15. Existing medical foot phantom [3].

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References

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