

Healing in Alignment

Bioelectric Dressing for collagen alignment in keloid scar modulation

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Client: Dr. Jasmine Craig

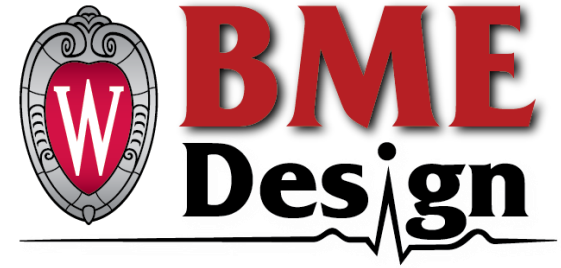
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Overview

- Problem Statement
- Background Information
- Product Design Specifications
- Previous Work
- Preliminary Designs & Design Matrices
 - Electrode
 - Circuit
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- Future Work
- Acknowledgements
- References



Introduction

- Keloid scars are scars that heal abnormally (protrude outward)
 - Keloid scars are poorly understood
- Keloids are painful and aesthetically displeasing
- Treatments are invasive, painful, and carry high recurrence rates
 - 50-100% [1]



Figure 1. Keloid Scar

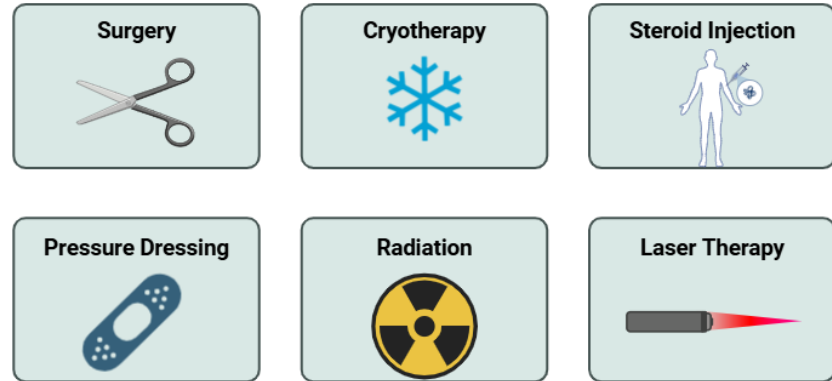


Figure 2. Keloid treatments (developed with Biorender)

Keloid Anatomy and Wound Healing

- Keloids have extracellular matrix (ECM) and fibroblasts **abnormalities**
 - **ECM:** Disorganized collagen
 - **Fibroblasts:** Unaligned and produce excess ECM [2]
- **Fibroblast alignment:** help reduce ECM deposition and promote ECM organization [3]
- **Galvanotaxis:** Endogenous electric fields that direct cell migration [4]
 - Produced within human body

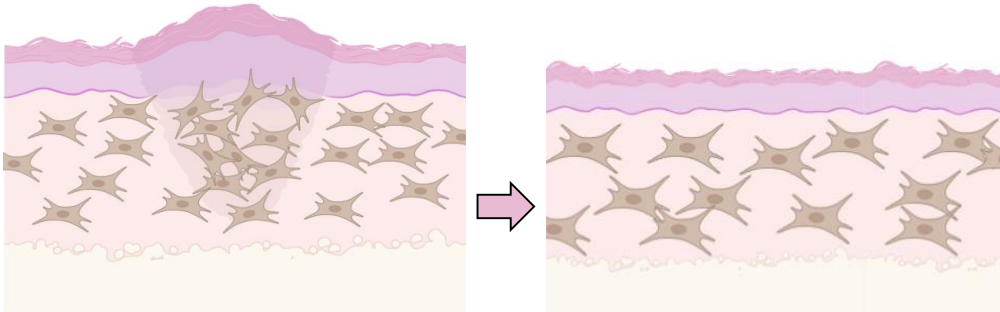


Figure 3. Fibroblast alignment (developed with Biorender)

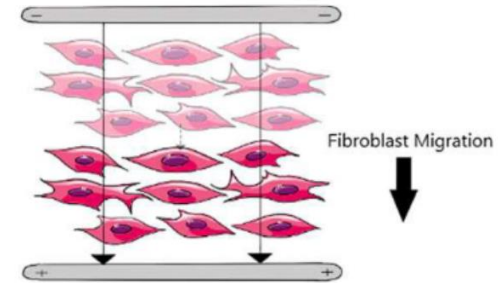


Figure 4. Representation of galvanotaxis

Problem Statement

- **Client:** Dr. Jasmine Craig MD MPH
 - Division of Plastic Surgery - UWSMPH
- **Adjunctive therapy** applied post-excision of keloid
 - Cellular and ECM level
- Design a **bioelectric bandage** to promote proper healing and reduce recurrence
 - Low intensity electric fields (biphasic stimulation) [3]
 - Mimic galvanotaxis endogenous field
 - Emphasis on safety



Figure 5. Dr. Jasmine Craig MD MPH

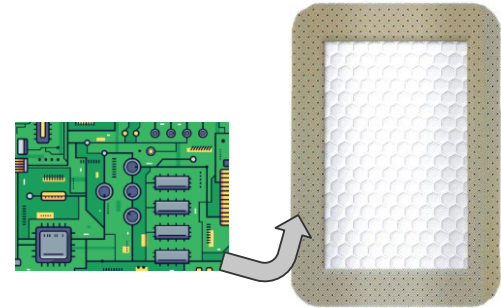


Figure 6. Example Bandage with electronics incorporated

Product Design Specifications

- Consistent and prolonged electrical stimulation
- Pulsed DC, 60Hz, 50-300 mV/mm [5]
- Max = 180 V/mm [6]
- Dressing
 - At least 1.88×1.96 cm to fit an earlobe [7]
 - Maximum = 10×15×5 cm
- Must be worn for at least 7 days
- Operate at 15-40°C
- Compressive force < 13kN [8]
- Mass < 300g
- Replacement only when contaminated
- Water-resistant and sterilizable
- Budget = \$500

Design Alternatives



Figure 7. Procellera [9]



Figure 8. CICA-CARE [10]

Previous Design

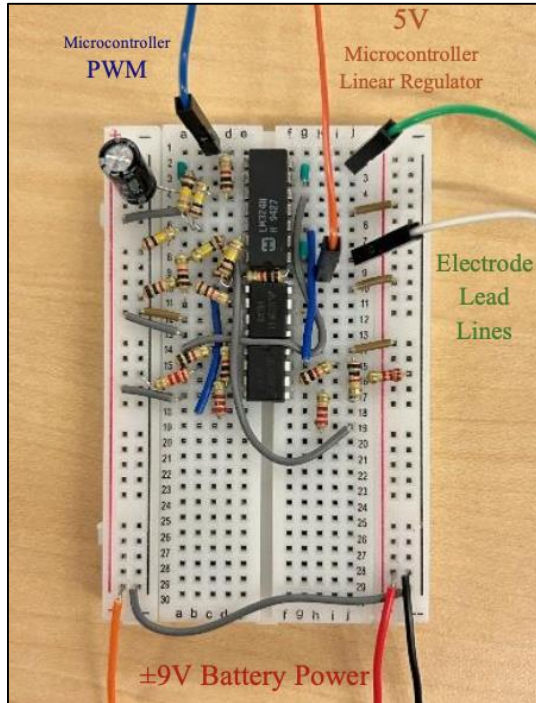


Figure 9. Previous group's board design

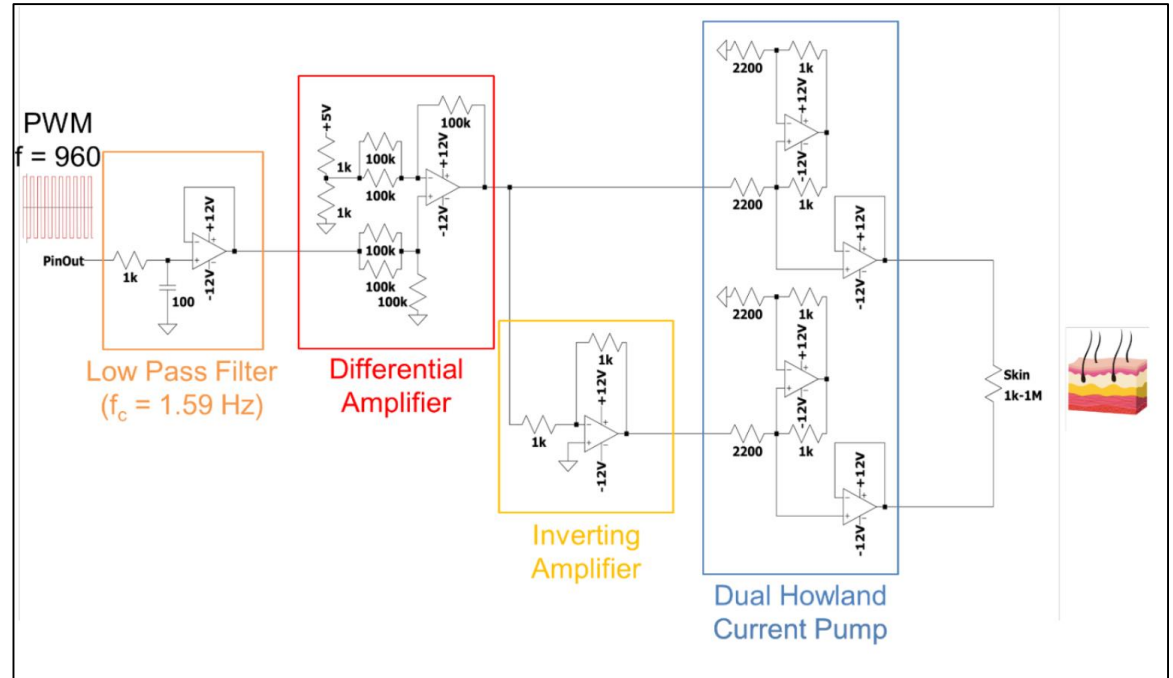


Figure 10. Previous group's circuit diagram

Full Design

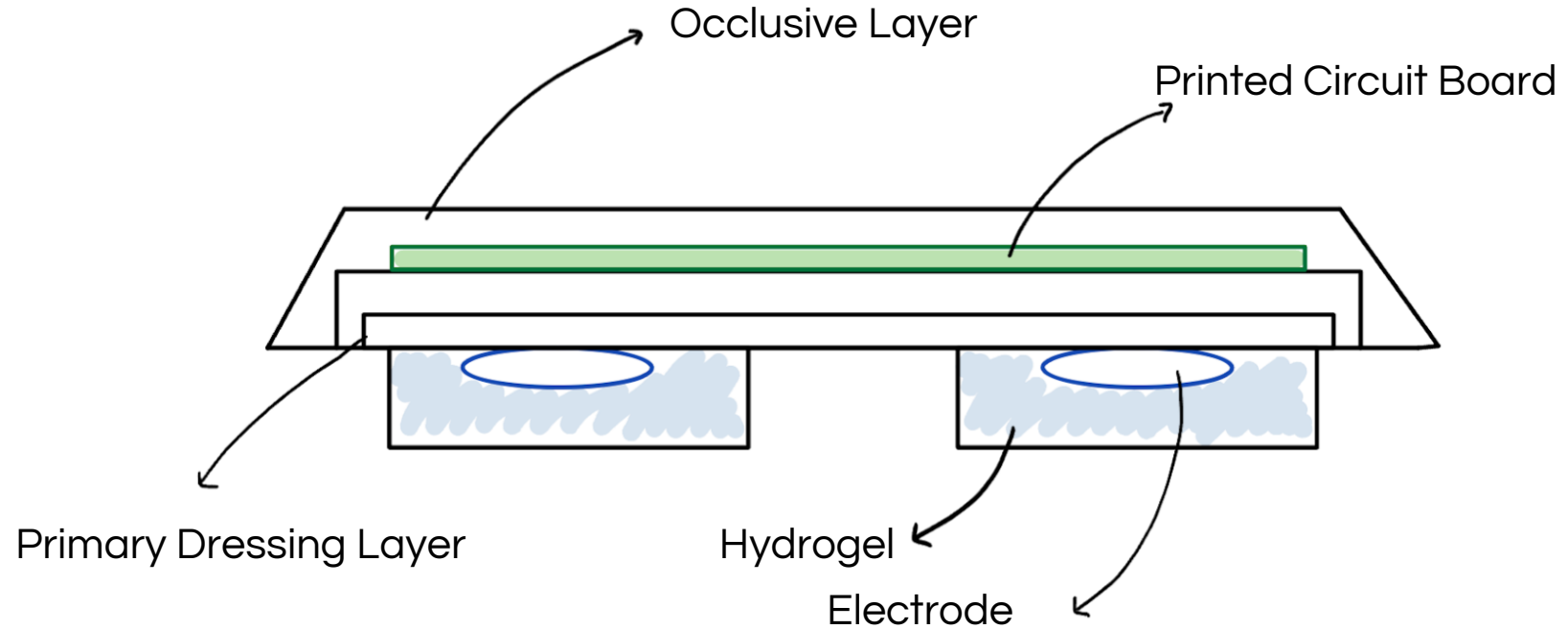


Figure 11. Final Design Drawing

Electrode Design Matrix

Table 1: Electrode Design Matrix

Criteria	Weight	Stainless-Steel Alloy Spiral	Carbon Impregnated Rubber	Ag/AgCl	Conductive Polymer	Conductive Textile
Biocompatibility	20	4	4	5	4	4
Electrical Performance	20	5	4	5	4	3
Field Control	20	5	4	5	4	3
Longevity	15	5	4	2	4	3
Flexibility & Conformity	15	3	5	3	5	5
Cost	10	4	4	3	3	5
Total	100	86/100	84/100	78/100	80/100	76/100



Final design electrode

- Spiral geometry for controlled electric field and current density
 - Adjustable geometry for field distribution
- 316L Stainless Steel for strength, durability, corrosion resistance, and low cost
 - Corrosion resistant passive oxide layer
- Conductive Hydrogel
 - Protective Interface

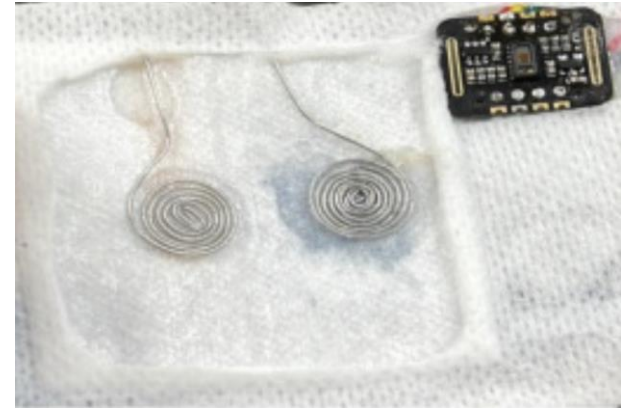
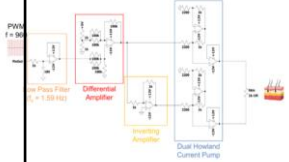
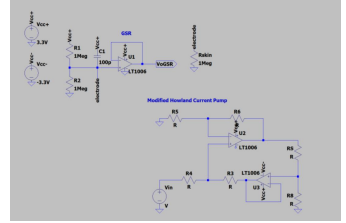
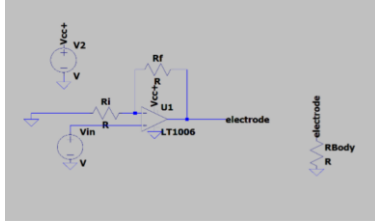


Figure 12. Spiral stainless steel electrodes

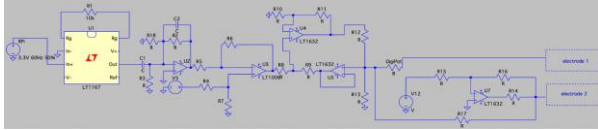
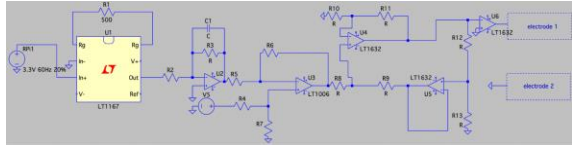
Circuit Design Matrix

Table 2: Circuit Design Matrix

Criteria	Weight			
Safety	30	4/5	3/5	1/5
Versatility	20	1/5	4/5	4/5
Accuracy	20	2/5	4/5	5/5
Size	10	3/5	3/5	4/5
Cost	10	3/5	3/5	4/5
Longevity	5	3/5	3/5	3/5
Power Draw	5	3/5	3/5	4/5
Total	100	54/100	68/100	65/100

Circuit Design Matrix

Table 2: Circuit Design Matrix Continued

Criteria	Weight		
Safety	30	4/5	1/5
Versatility	20	3/5	2/5
Accuracy	20	4/5	4/5
Size	10	1/5	2/5
Cost	10	2/5	3/5
Longevity	5	4/5	2/5
Power Draw	5	3/5	1/5
Total	100	65/100	43/100

Final Circuit Design

- Howland Current Pump to push a constant current
- Biofeedback using Galvanic Skin Resistance circuit
- Rheostat as R_{Sense} to adjust current in accordance with variable skin resistance

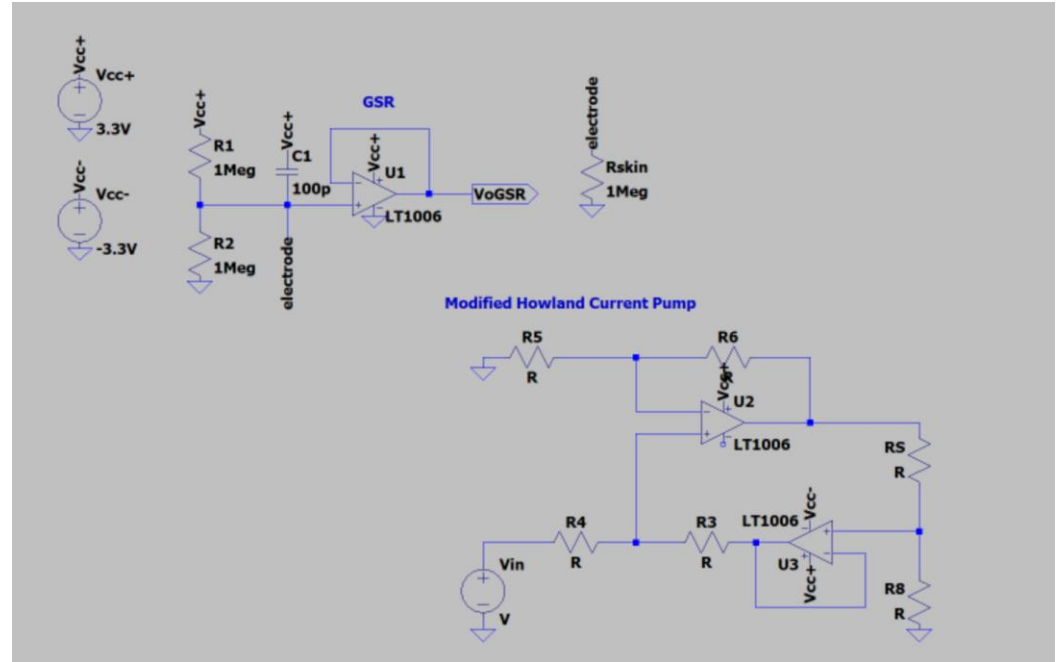


Figure 13. LTSpice schematic of Final Circuit Design.

DC Biphasic Square Waveform

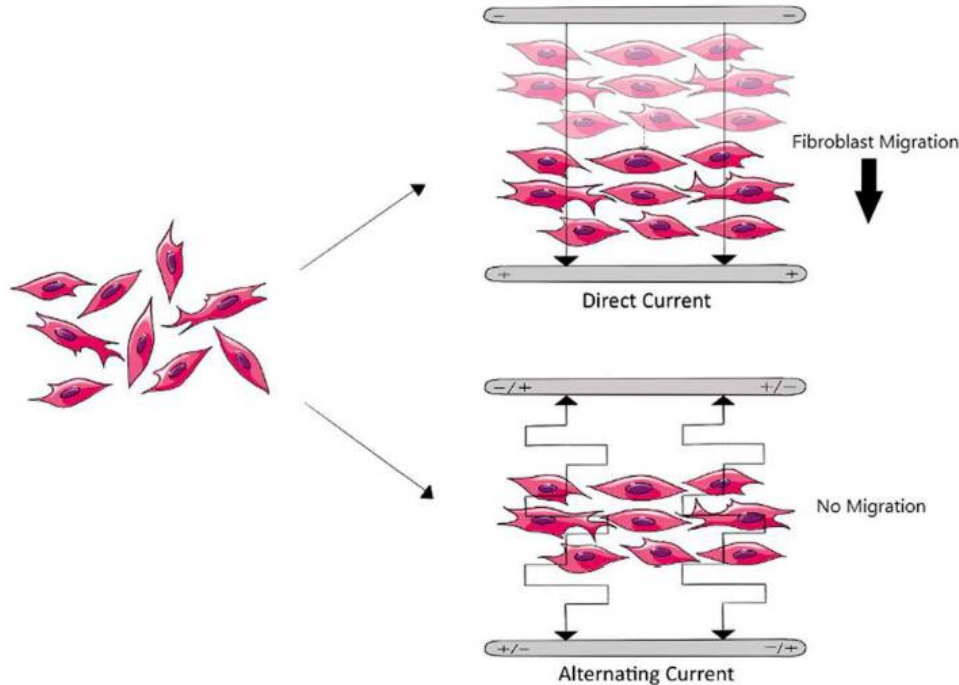


Figure 14. Visual representation of cell migration [3]

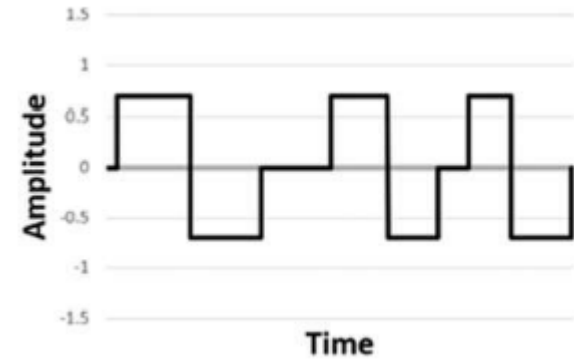


Figure 15. DC Biphasic waveform using constant current [3]

COMSOL Models

- Stratum corneum, epidermis, dermis, fat, and muscle
- Elliptical PBS-filled surgical wound
- 1 mm conductive hydrogel interface
- Two 8 mm electrodes, 20 mm apart. ± 0.6 V potentials
- Electric Currents + Bioheat Transfer physics

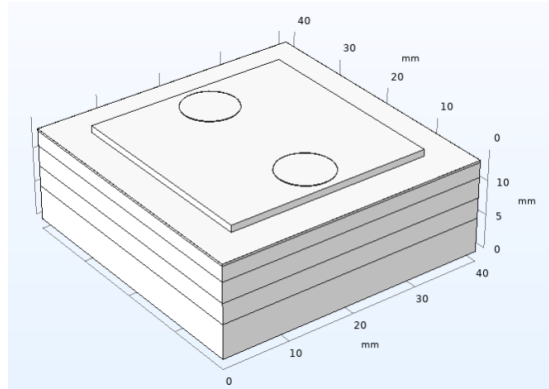


Figure 16. COMSOL 3D wound model

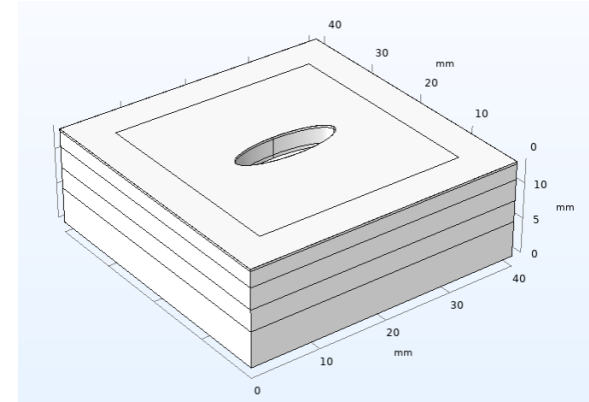


Figure 17. COMSOL 3D wound model. Hydrogel and electrodes hidden

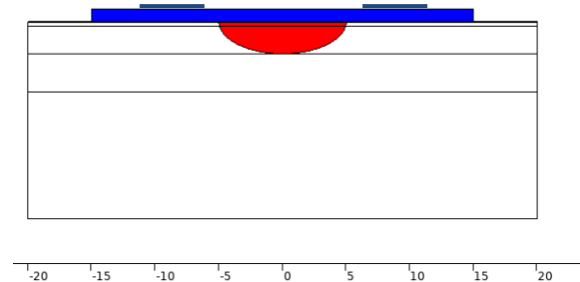


Figure 18. COMSOL 2D wound model

Model Parameters

Table 3: Model Bioheat & EC parameters [11][12][13][14]

Material / Domain	Electrical Conductivity (S/m)	Relative Permittivity (-)	Density (kg/m ³)	Specific Heat (J/(kg·K))	Thermal Conductivity (W/(m·K))
Stratum Corneum	2.000E-06	5.000E+02	1109	3391	3.720E-01
Epidermis	2.600E-02	1.000E+06	1109	3391	3.720E-01
Dermis	2.220E-01	1.000E+08	1109	3391	3.720E-01
Subcutaneous Fat	8.000E-02	1.000E+07	911	2348	2.120E-01
Muscle	2.000E-01	1.000E+07	1090	3421	4.950E-01
PBS (Wound)	1.400E+00	80	1000	4180	6.000E-01
Conductive Hydrogel	2.500E-01	80	1000	4180	5.000E-01

Parameter	Value	Units
Arterial blood temperature	3.102E+02	K
Blood specific heat	4180	J/(kg·K)
Blood density	1060	kg/m ³
Skin/fat blood perfusion rate	1.000E-03	1/s
Muscle blood perfusion rate	5.000E-03	1/s
Metabolic heat source	0	W/m ³
Initial/body temperature	3.102E+02	K
Ambient temperature	3.102E+02	K
Convective heat-transfer coefficient	10	W/(m ² ·K)

Table 4: Model geometries [11][14]

Component / Layer	Dimension	Value	Units
Overall tissue block	Width	40	mm
Overall tissue block	Height / depth	15	mm
Stratum corneum	Thickness	0.014	mm
Epidermis	Thickness	0.3	mm
Dermis	Thickness	2.2	mm
Subcutaneous fat	Thickness	3	mm
Muscle	Thickness	10	mm
Hydrogel	Thickness	1	mm
Hydrogel	Width	30	mm
Wound	Shape	Ellipse	
Wound	Length	10	mm
Wound	Depth	2	mm
Wound	Width	8	mm
Electrode	Width / diameter	8	mm
Electrodes	Center-to-center spacing	20	mm
Electrodes	Positive electrode position	-10	mm
Electrodes	Negative electrode position	10	mm

Preliminary Model Results

- Electric Field reaches wound region
- Heating localized near electrodes & minimal temperature rise throughout tissue

Assumptions/Shortcomings

- Homogeneous tissue layers with constant properties
- Simplified elliptical wound
- Constant ± 0.6 V DC instead of biphasic pulses
- Approximate blood perfusion rates
- No metabolic heat generation
- Simplified thermal boundary conditions

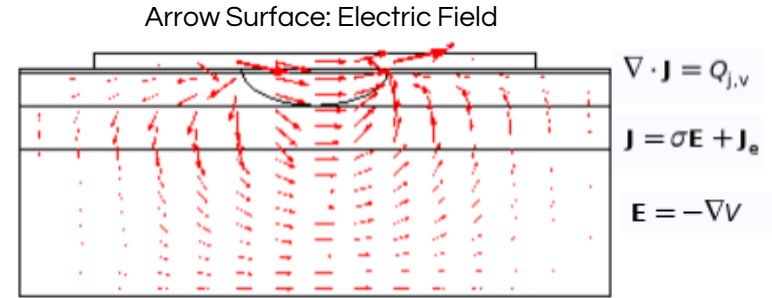


Figure 19. Electric field penetration, relative magnitudes and governing equations

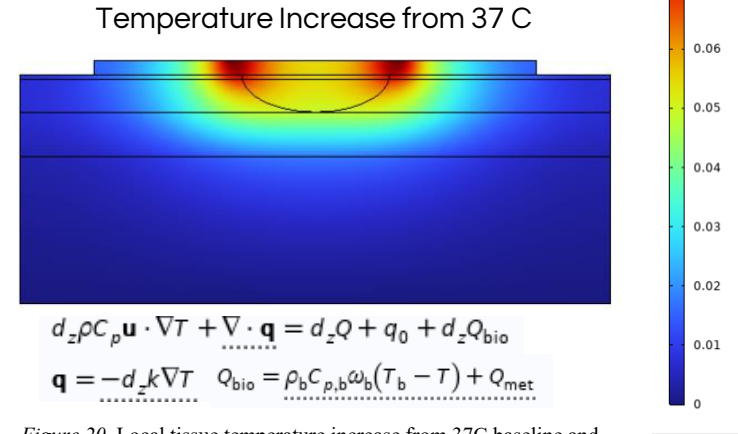


Figure 20. Local tissue temperature increase from 37C baseline and governing equations

Future Work

- Conductive hydrogel selection
- Electrode performance testing
- Benchtop circuit testing using rubber skin analog
- Ex vivo human skin testing
 - Thermal safety and electric field penetration
- COMSOL model validation
- PCB design and integration
- Final bandage assembly

Acknowledgements

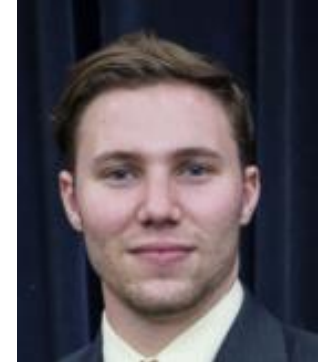
Advisor

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Clients

Dr. Jasmine Craig & Dr. Robert George & Dean Spyres



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