

# ThermaAid: A Closed-Loop Isothermal Bandage for Chronic Wounds

Accelerating Simulated Wound Closure via Active Thermal Regulation  
and Flexible Additive Manufacturing

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# 1.5M Limbs Are Lost Due to Poor Wound Healing

Chronic wounds affect **18.6 million patients** globally [1].

Poor circulation causes wound beds to drop to **24–30°C**, far below the healing optimum of 37–39°C [2].

At depressed temperatures, **cellular repair mechanisms stall**: creating a self-perpetuating cycle of non-healing.

This non-healing of wounds **leads to 1.5 million limb amputations** annually [3].

I aim to **tackle this problem**.

→ **Impaired Circulation**

Reduced perfusion starves wound tissue of oxygen and nutrients.

→ **Cold Wound Beds**

Sub-therapeutic temperatures (24–30°C) stall cellular regeneration.

→ **Amputation Risk**

Non-healing ulcers are the leading cause of non-traumatic limb loss.



Photo of device during testing, captured by Ayan Arora

[1] Armstrong, David G., et al. "Diabetic Foot Ulcers: A Review." JAMA, vol. 330, no. 1, 2023, pp. 62–75.

[2] Huang, J., et al. "Exploring Thermal Dynamics in Wound Healing: The Impact of Temperature and Microenvironment." Clinical, Cosmetic and Investigational Dermatology, vol. 17, 2024, pp. 1251–58.

[3] Edmonds, Michael, et al. "The Current Burden of Diabetic Foot Disease." Journal of Clinical Orthopaedics and Trauma, vol. 17, 2021, pp. 88–93.

# Engineering Objectives & Design Criteria

ThermaAid was engineered to transform passive wound dressing to active heating with strict safety, cost, and flexibility constraints.

## Primary Objective

Maintain a stable **38.0°C ± 0.5°C** wound microenvironment using a closed-loop feedback system costing **under \$15** per unit.

## Isothermal Precision

Output ensures temperature stays within therapeutic range (37-39°C) without overshoot, critical for patient safety in wound care applications.

## Bio-Mechanical Flexibility

Enclosure printed in a bio-friendly **TPU filament**, a flexible thermoplastic, to conform to anatomical contours without restricting movement.

## Safety Fail-Safes

Safety circuit cuts heater power if surface temperature exceeds **40.0°C**, preventing thermal injury to surrounding tissue.

# System Architecture: Power, Heating, and Safety Circuitry

## Core Components

### Lithium Polymer (LiPo) Battery

Rechargeable battery rated at 3.7V with 250 mAh output.

### 5V 1W Polyimide Film Heater

Thin, flexible resistive heater. Supports a 30×30 mm active area.

### ATtiny85 Microcontroller

Low-power 8-bit microcontroller for heater regulation and shut off.

### Thermistor

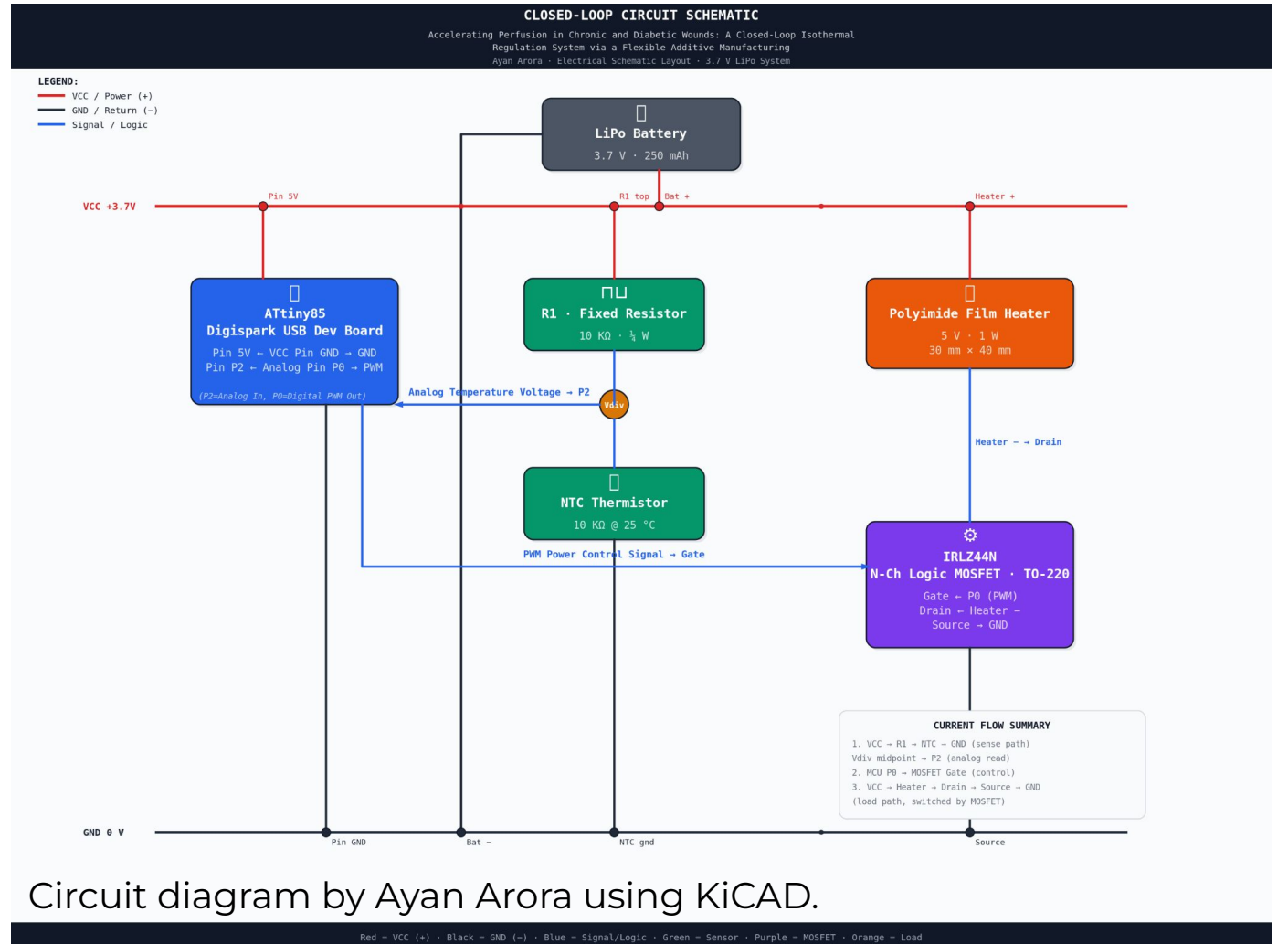
Provides analog voltage feedback to the microcontroller.

### Resistor

With thermistor, creates a voltage divider for microcontroller.

### MOSFET

Electronic switch, allowing the microcontroller to control the heater.



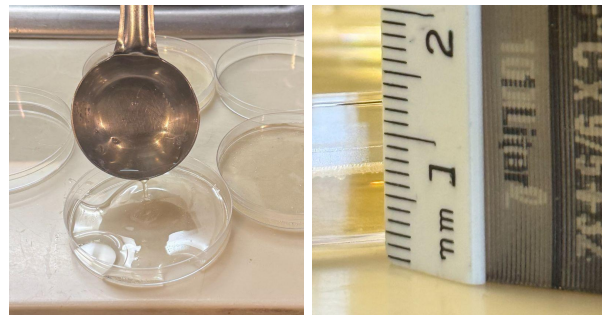
Circuit diagram by Ayan Arora using KiCAD.

**System Logic:** LiPo battery powers the circuit → the thermistor samples wound surface temperature → microcontroller inputs signal → MOSFET modulates the film heater

# Testing Against a Gelatin Hydrogel Model

To ethically simulate human chronic wound conditions without biological subjects, I used a **gelatin hydrogel phantom skin** model. This provides reproducible, standardized tissue analog properties.

**Three groups:** Active (ThermaAid), Passive (insulated bandage), and Untreated Control.



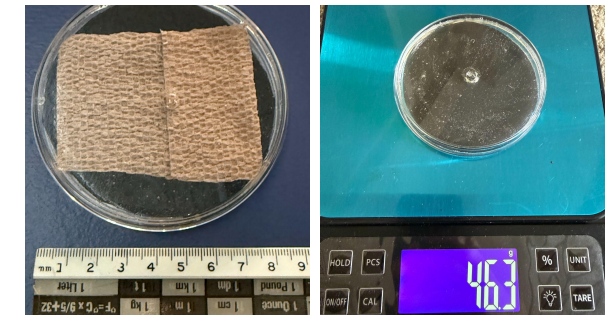
Photos by Ayan Arora



Photos by Ayan Arora



Photos by Ayan Arora



Photos by Ayan Arora

## Phantom Skin Substrate

**12% w/v gelatin hydrogel** formulation matched to human skin in thermal conductivity.

## Wound Standardization

**6 mm diameter circular excisions** created using dermal biopsy punch tool.

## Vascular Impairment Simulation

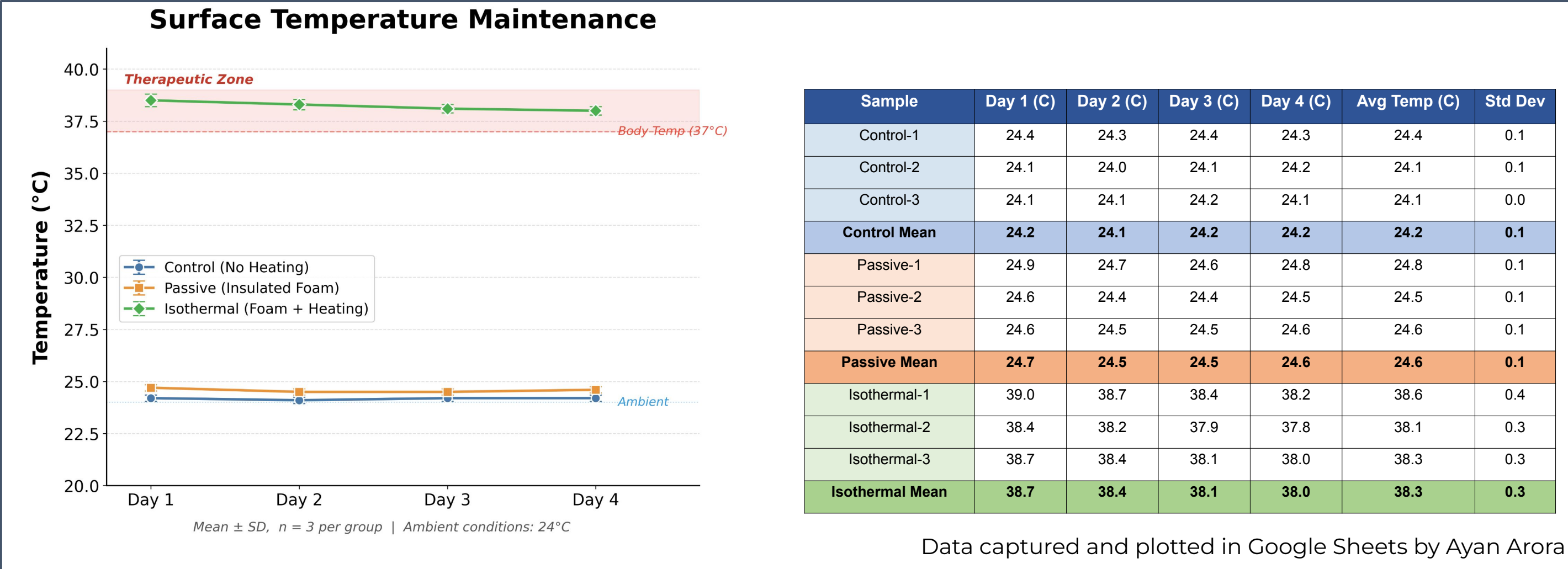
Conducted experiment at an ambient temperature of **24°C** to simulate wound bed.

## Daily Trial Protocol

**4-day continuous trial** with temperature, wound dimension, and weight measurements taken daily.

# Results: Thermal Performance

Surface temperature maintenance over the 4-day trial period. Active system (ThermaAid) achieved and sustained therapeutic target (38°C). Passive and control groups remained in the sub-therapeutic range (24–27°C) throughout.



Data captured and plotted in Google Sheets by Ayan Arora

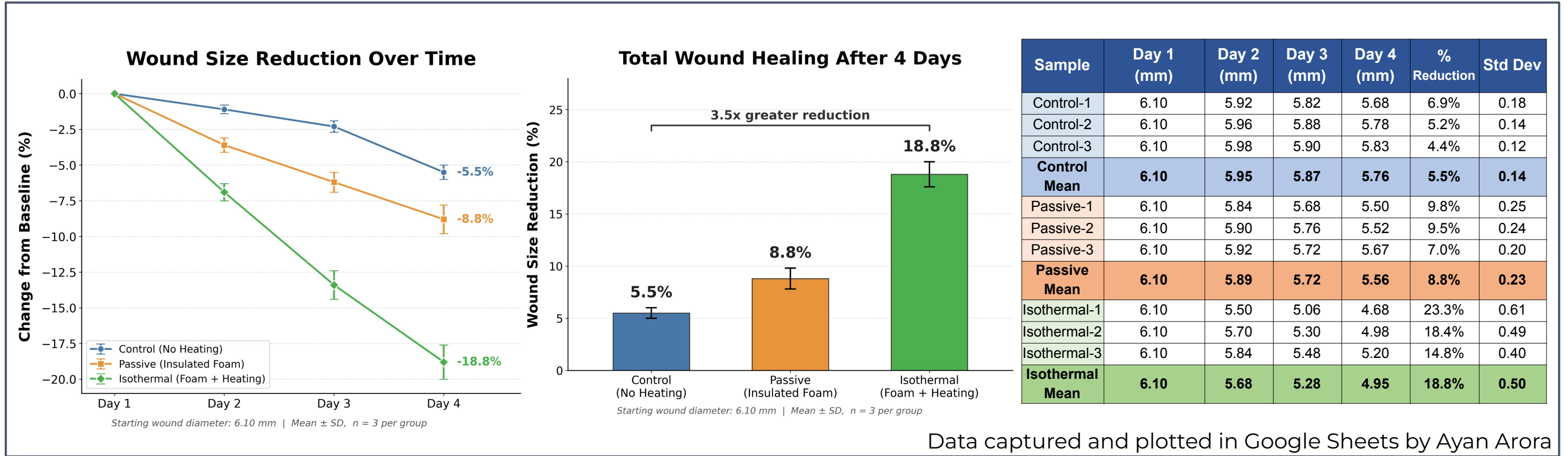
**38.3°C**  
**Mean Surface Temp**  
 Active system mean over 96 hours

**±0.3°C**  
**Standard Deviation**  
 Within ±0.5°C design spec

**100%**  
**Fail-Safe Activations**  
 Zero exceedances above 40.0°C

# Results: Wound Closure Efficacy

The ThermaAid device produced a substantial acceleration in simulated wound closure, the primary clinical outcome measure of the device's efficacy.



**18.8%**

Total wound size reduction in Active group over 4 days, the primary efficacy endpoint.

**3.5× Faster**

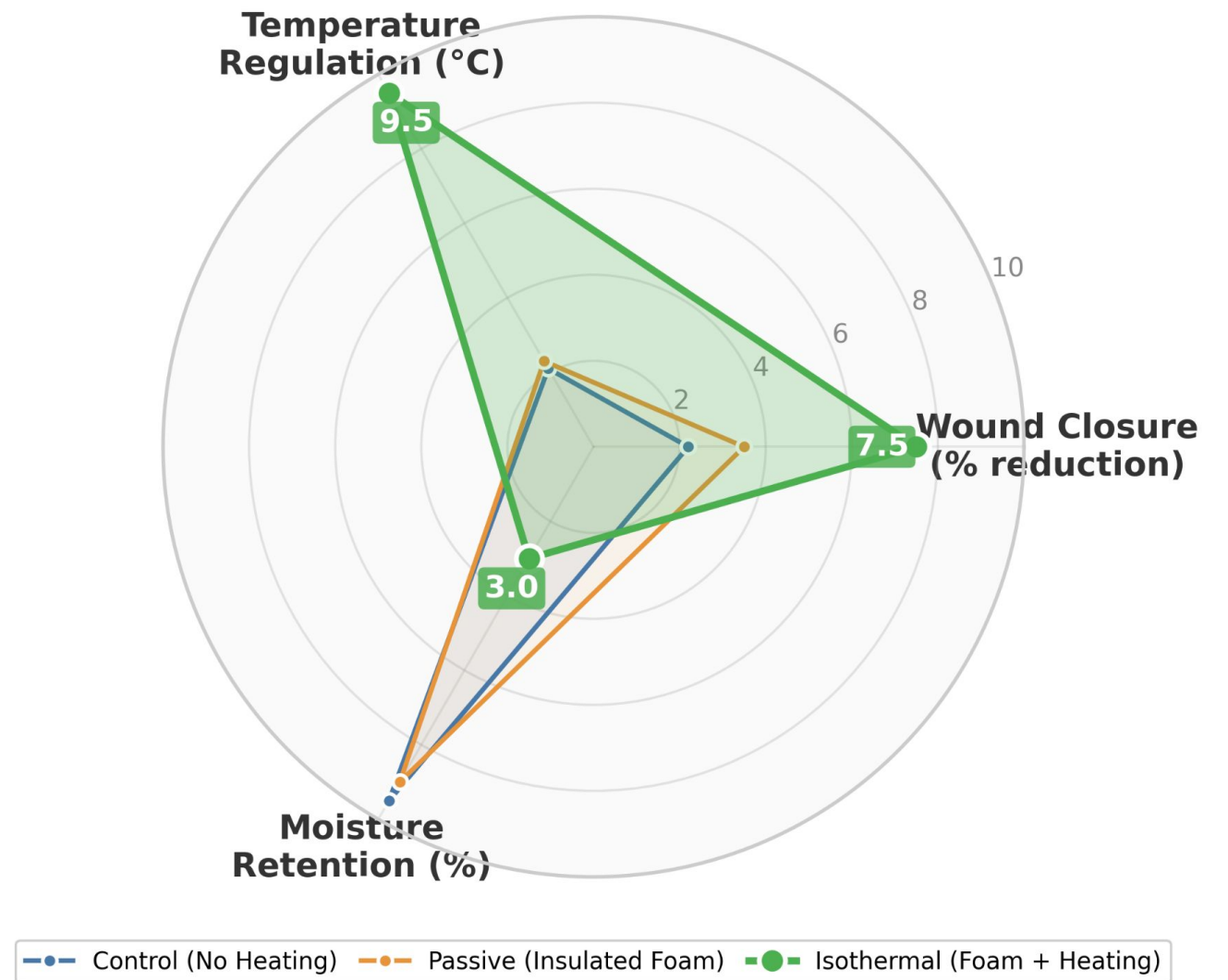
Closure rate vs. untreated controls (5.5%). Passive insulation (8.8%) showed marginal improvement, confirming the necessity of active thermal control.

# Results: Moisture Retention and Overall Performance

Sample	Day 1 (g)	Day 2 (g)	Day 3 (g)	Day 4 (g)	% Change	Avg Weight (g)	Std Dev
Control-1	39.9	39.6	39.4	39.2	-1.8%	39.5	0.3
Control-2	39.5	39.3	39.0	38.8	-1.8%	39.2	0.3
Control-3	40.1	39.8	39.5	39.3	-2.0%	39.7	0.4
<b>Control Mean</b>	<b>39.8</b>	<b>39.6</b>	<b>39.3</b>	<b>39.1</b>	<b>-1.8%</b>	<b>39.5</b>	<b>0.3</b>
Passive-1	45.3	45.0	44.6	44.3	-2.2%	44.8	0.4
Passive-2	45.8	45.4	45.0	44.7	-2.4%	45.2	0.5
Passive-3	46.2	45.7	45.3	44.9	-2.8%	45.5	0.6
<b>Passive Mean</b>	<b>45.8</b>	<b>45.4</b>	<b>45.0</b>	<b>44.6</b>	<b>-2.5%</b>	<b>45.2</b>	<b>0.4</b>
Isothermal-1	57.8	54.4	52.2	49.3	-14.7%	53.4	3.6
Isothermal-2	56.6	55.6	52.4	49.2	-13.1%	53.5	3.4
Isothermal-3	55.6	53.7	52.0	50.6	-9.0%	53.0	2.2
<b>Isothermal Mean</b>	<b>56.7</b>	<b>54.6</b>	<b>52.2</b>	<b>49.7</b>	<b>-12.3%</b>	<b>53.3</b>	<b>0.3</b>

**Temperature-Moisture Trade-off:** The Isothermal device achieved strong wound closure, but the continuous heat resulted in 12.3% weight loss through moisture evaporation. This excessive dryness can stall cellular migration. I will need to create a moisture barrier in future device iterations.

## Multi-Metric Performance (Normalized 0-10 Scale)



Normalization: Wound Closure 0-25% → 0-10 | Temperature 20-40°C → 0-10 | Moisture Retained 80-100% → 0-10

# Iterative Design & Safety Verification

## Design Evolution

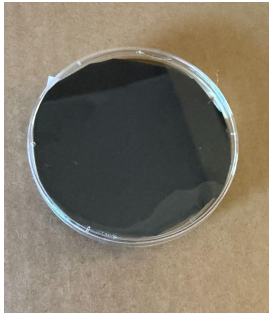
**Prototype v1.0: 4.2W Heater**  
Initial heater was too powerful. Tests showed it could reach 40°C+ quickly, which is unsafe for skin. **Rejected for safety.**



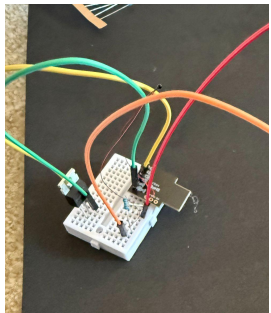
**Prototype v2.0: 1W Heater**  
Switched to a lower-power film heater. Battery last longer and kept the temperature in a safe range. **Validated for all trials.**



**Prototype v3.0: Foam to Reduce Hotspots**  
Heat not evenly distributed. Added a foam layer to spread heat and remove hot spots. **Added to final design.**



**Final System: Safety Mechanism Added**  
Created safety circuit to shut off power to heater at 40.0°C. **Added to device circuit.**



Photos by Ayan Arora

## Validation Methodology

**Thermal Mapping**  
**Method:** Used an Infrared (IR) thermometer to measure temperature.

**Moisture Loss**  
**Method:** Used a scale to measure weight of the hydrogel to track evaporation.

**Wound Closure**  
**Method:** Took photos and used ImageJ software to calculate wound closure.

**No Human Testing**  
All testing was done using hydrogel gelatin models that mimic human skin. No humans or animals were used at any stage of this project to ensure safety and ethical standards.

# Conclusion & Future Outlook

## What Was Demonstrated

ThermaAid proved that low-cost (under \$15 for all parts), and safe electronics can manage heat precisely. My prototype kept the temperature steady at 38.0°C and helped the wound model heal 3.5 times faster than a passive bandaid.



Photo of device, captured by Ayan Arora

## Future Research Directions

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### Testing on Real Tissue

The next step is to move from gelatin models to testing on real pig skin. Pig skin is the gold standard for research because it is very similar to human skin and will give us even better data.

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### Adding Wireless Sensors

I want to add sensors that track temperature and moisture. The data would be sent to a smartphone, allowing a doctor to check how a patient is healing from anywhere in the world.

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### Helping Real Patients

The ultimate goal is to get this device used in hospitals to help patients with diabetes heal their wounds faster and avoid serious infections or surgeries.

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