Transient Heat Transfer in Human Skin During Cryotherapy

Software: ANSYS Student (Fluent)

Due Date: Sunday 21st Dec. 2025

Group Task (4-5 members)

1. Introduction

Cryotherapy (e.g., ice packs, cooling pads) is widely used in clinical practice to reduce pain, inflammation, and swelling. The effectiveness of cooling depends on how deeply the temperature drop penetrates the skin and underlying tissues. Because biological tissues have layered structure and different thermal properties, heat transfer during cryotherapy cannot be accurately predicted without numerical simulation.

In this assignment, you will use **ANSYS Student**, or an equivalent numerical tool to model **transient heat conduction** in a simplified, multilayer skin system exposed to an external cooling source.

2. Objective

The primary goal of this assignment is to **simulate and analyze** the cooling response of human skin layers under cryotherapy, using the **1-D or 2-D transient heat conduction equation**.

3. Model Description

Geometry (choose one)

Option A: 1-D multilayer skin model

- Epidermis: 1 mm
- Dermis: 2 mm
- Subcutaneous fat: 10 mm
  Total thickness = **13 mm**

Option B: 2-D rectangular domain
Size: 40 mm × 20 mm to analyze lateral heat spreading.

Material Properties

Layer	k (W/m·K)	ρ (kg/m³)	c (J/kg·K)	Metabolic Heat q̇ (W/m³)
Epidermis	0.21	1200	3600	0
Dermis	0.45	1100	3300	4200
Fat	0.20	920	2500	1500

Governing Equation

Use the transient heat conduction equation (bioheat without perfusion):

$$\rho c \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + \dot{q}_{met}$$

Initial Condition

Assume the body is at uniform temperature:

$$T(x, 0) = 37°\text{C}$$

Boundary Conditions

Top surface (cold pack applied):

$$-k \frac{\partial T}{\partial x} = h(T_s - T_{ice})$$

Use:

- **Convective coefficient:** $h = 50$ W/m^{2}K
- **Cold pack temperature:** $T_{ice} = 0°$C

Bottom surface (body core):

$$T(L) = 37°\text{C}$$

4. Simulation Tasks

You are required to complete the following:

Task A — Build Numerical Model

- Create the 1-D (or 2-D) domain.
- Assign multilayer material properties.
- Apply boundary and initial conditions.
- Define a simulation time of at least **10 minutes** (600 s).
- Use an appropriate mesh for accuracy.

Task B — Solve Transient Heat Conduction

Run the simulation and obtain:

- Temperature distribution vs. depth
- Temperature distribution vs. time
- Cooling rate in each layer

Task C — Extract Key Quantities

For depths:

- 1 mm (base of epidermis)
- 3 mm (base of dermis)
- 10 mm (deep in fat)
  determine:

1. Minimum temperature reached
2. Time when the tissue temperature reaches **10°C**
3. Cooling penetration depth ("How deep does the temperature drop below 15°C?")

Task D — Sensitivity Analysis

Repeat the simulation for **two additional convective coefficients**:

- $h = 20$W/m²K *(light cooling)*
- $h = 100$W/m²K *(aggressive cooling)*

Analyze how the cooling rate and depth change.

5. Required Outputs

Your final submission must include:

Figures

- Temperature vs. depth at selected times (0, 60, 300, 600 s)
- Temperature vs. time at 1, 3, and 10 mm depths
- 2-D temperature contour plots (if applicable)

Tables

- Minimum temperature in each layer
- Time to reach 10°C and 15°C at each depth
- Comparison of different convective coefficients

Structured report (1–2 pages)

- Description of model setup
- Interpretation of results
- Also, Analyze the reason behind:
  - Why the epidermis cools rapidly but deeper tissues do not
  - Effect of fat as a thermal insulator