School of Engineering
ICP Institute of Computational Physics

THERMAL ANALYSIS OF NEW TRANSDERMAL DEVICES FOR POWER TRANSFER TO VENTRICULAR ASSIST DEVICES

ETH zürich

Christian Grossmann Aybar[1], Daniel Fehr[1,*], Fabrizio Spano[1], Andreas P. Kourouklis[2], Edoardo Mazza[2], Mathias Bonmarin[1]

[1] ZHAW Zurich University of Applied Sciences, School of Engineering, Institute of Computational Physics, Technikumstrasse 9, 8400 Winterthur, Switzerland

[2] Department of Mechanical and Process Engineering, Institute for Mechanical Systems, ETH Zurich, Leonhardstrasse 21, 8092, Zurich, Switzerland

**Corresponding author: fehd@zhaw.ch*

INTRODUCTION

The gold-standard approach of Ventricular Assist Devices (VADs) involves using insulated transcutaneous metallic drivelines to deliver power from the external battery through the abdominal wall to the pump in the upper abdomen. However, VAD drivelines can negatively affect wound healing, leading to driveline infections (DLI) in about 1 out of 5 patients within the first year of implantation [1], due to biofilm formation in the skin's upper layers (Fig. 1).

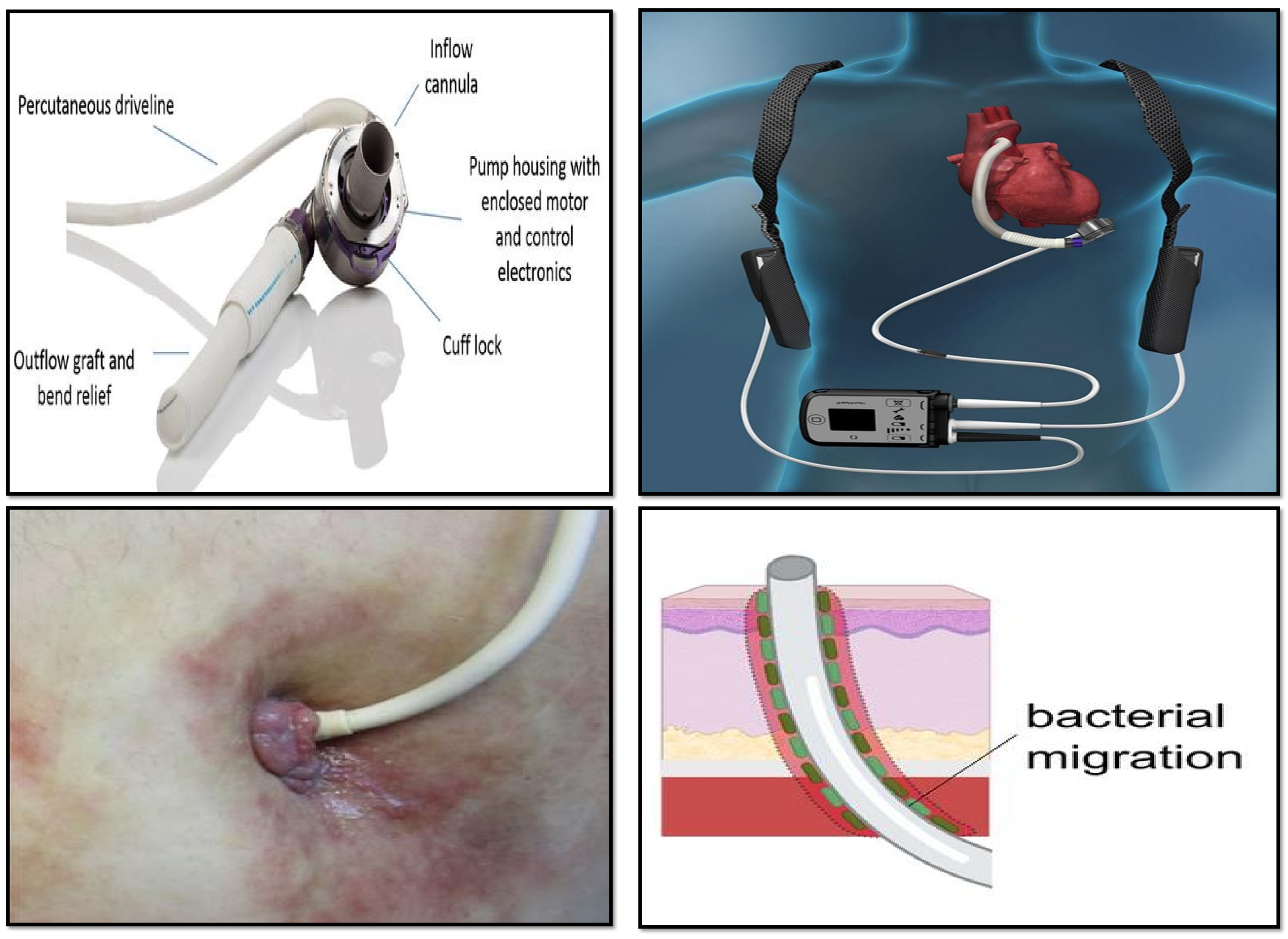

Fig. 1: Illustration of VAD and driveline infection. Adapted from [1], [2]

NEW TRANSDERMAL DEVICE FOR VADs

Current VAD drivelines

- Large-diameter (6-8 mm)
- Severe inflammatory reactions
- Frequent epidermal downgrowth

Transdermal wires

- 0.2 mm diameter
- Milder inflammatory responses
- Restricted epidermal downgrowth
- Improved mechanical adhesion
- Silicone and polyurethane coated wires

To promote healing of small wounds by minimizing wire impact on the skin interface and reduce DLI (Fig. 2), we propose a novel approach involving embedding a set of 0.2 mm diameter copper wires with polyurethane (PU) coating into a polymer-based material for VAD drivelines.

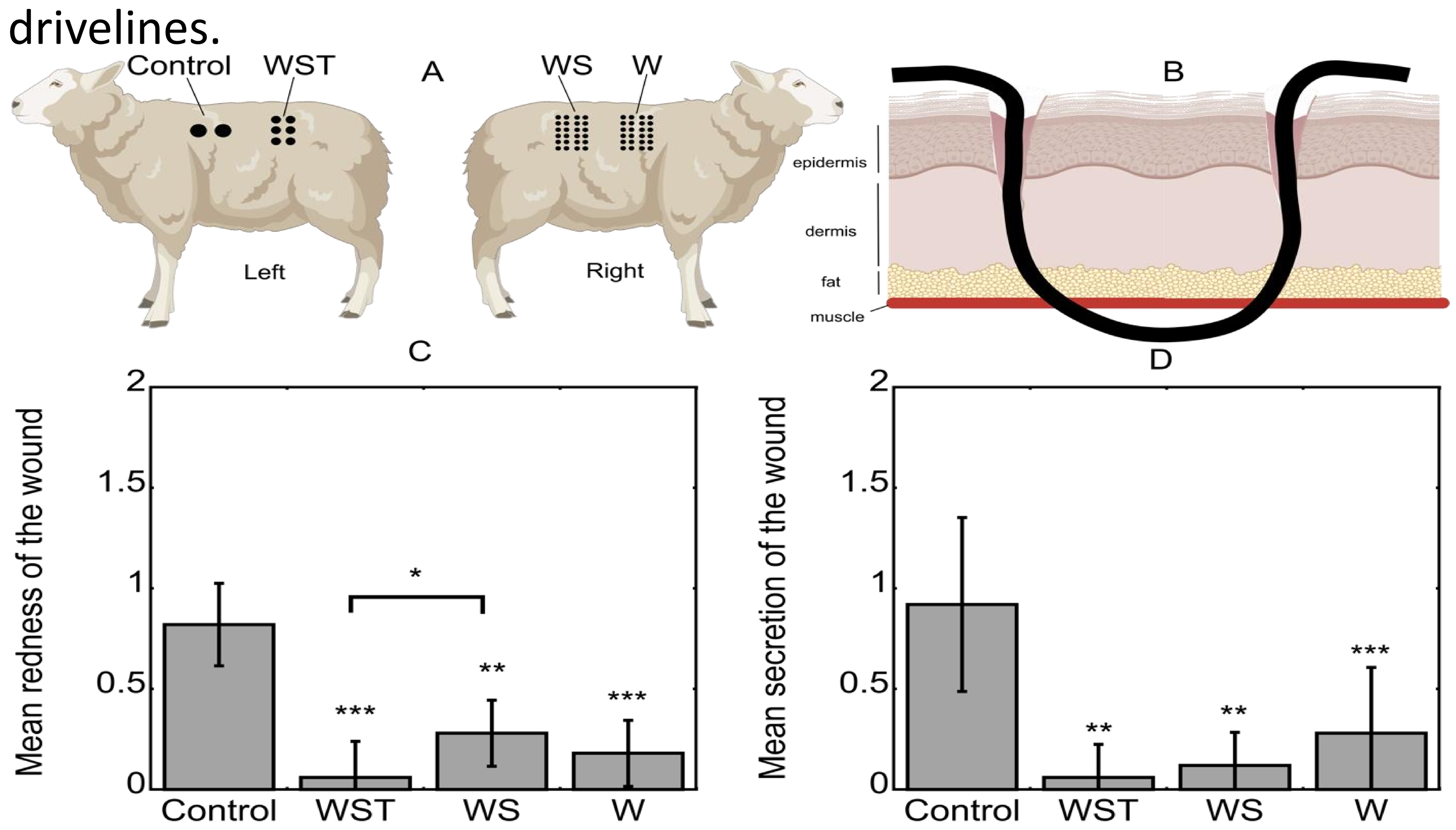

Fig. 2: In vivo evaluation of transdermal wires in a large animal model [3]

THERMAL ANALYSIS SIMULATIONS

We investigated the electrothermal implications of conductive wires on the human body through 3D COMSOL skin model simulations (Fig. 3) representing the epidermis, dermis, fat, and muscle [4]. Additionally, a PDMS layer was included in the model to represent the silicon-based material of the conductive skin. Various PU insulating coating thicknesses were tested on a 0.2 mm diameter copper wire.

- Increasing the insulation layer did not lead to a significant improvement in the skin model.
- The observed temperature difference in the model arose from the temperature skin gradient rather than the electric current (Fig. 4).
- The inrush current causes a temporary 0.42°C increase in the core temperature of the copper wires (Fig. 5).
- In the steady state, both wire core and PDMS temperatures remain elevated by around 0.08°C and 0.03°C, respectively

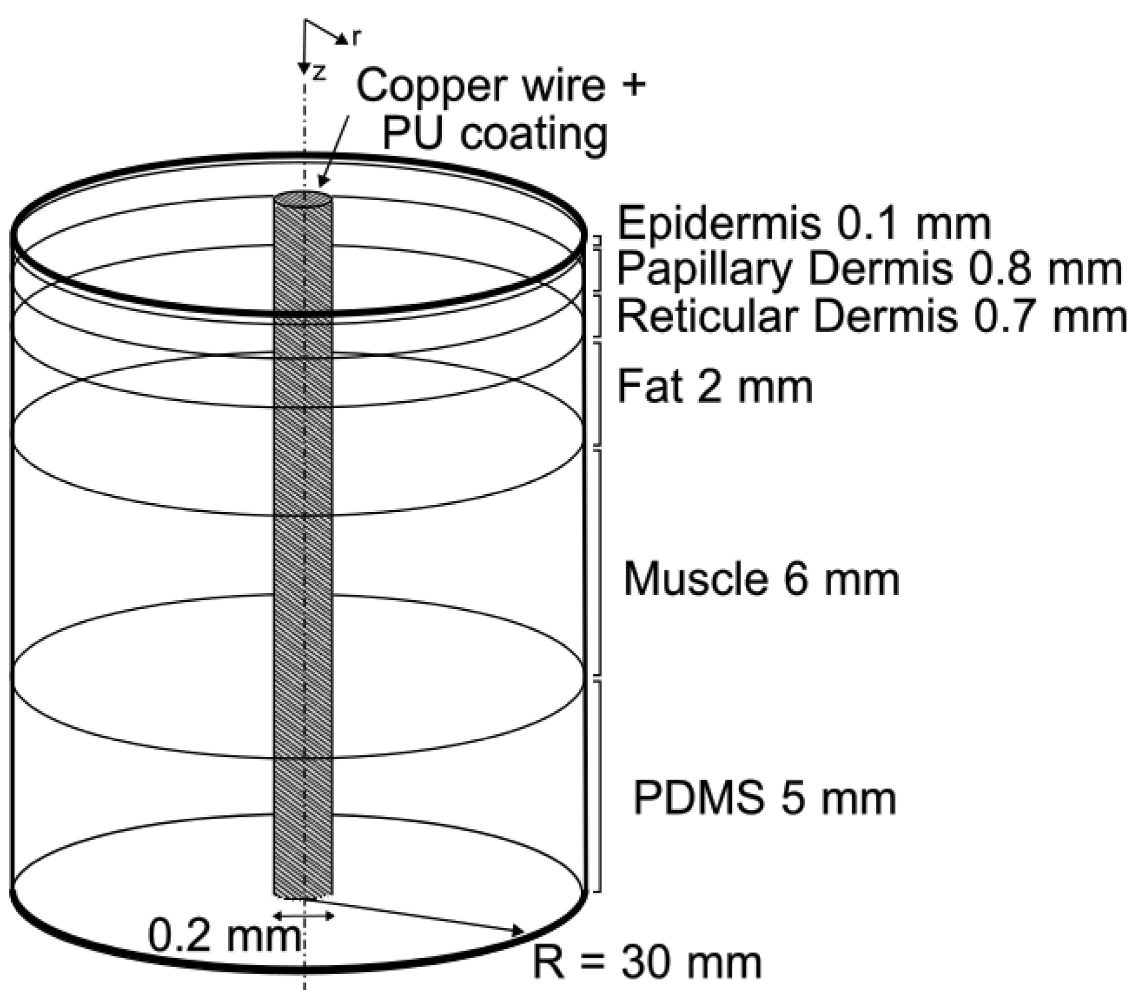

Fig. 3: Graphical representation of the 2D axisymmetric skin multilayered model [4]

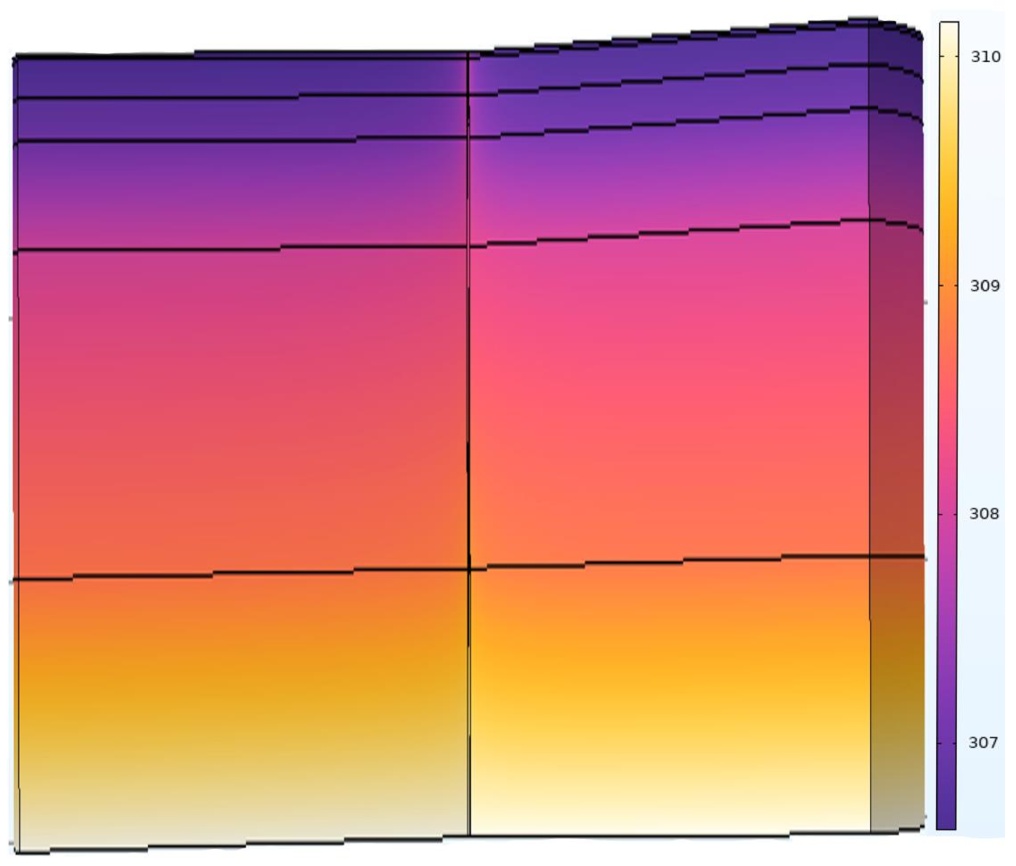

Fig. 4: Thermal distribution in COMSOL Multiphysics. Units: degrees Kelvin.

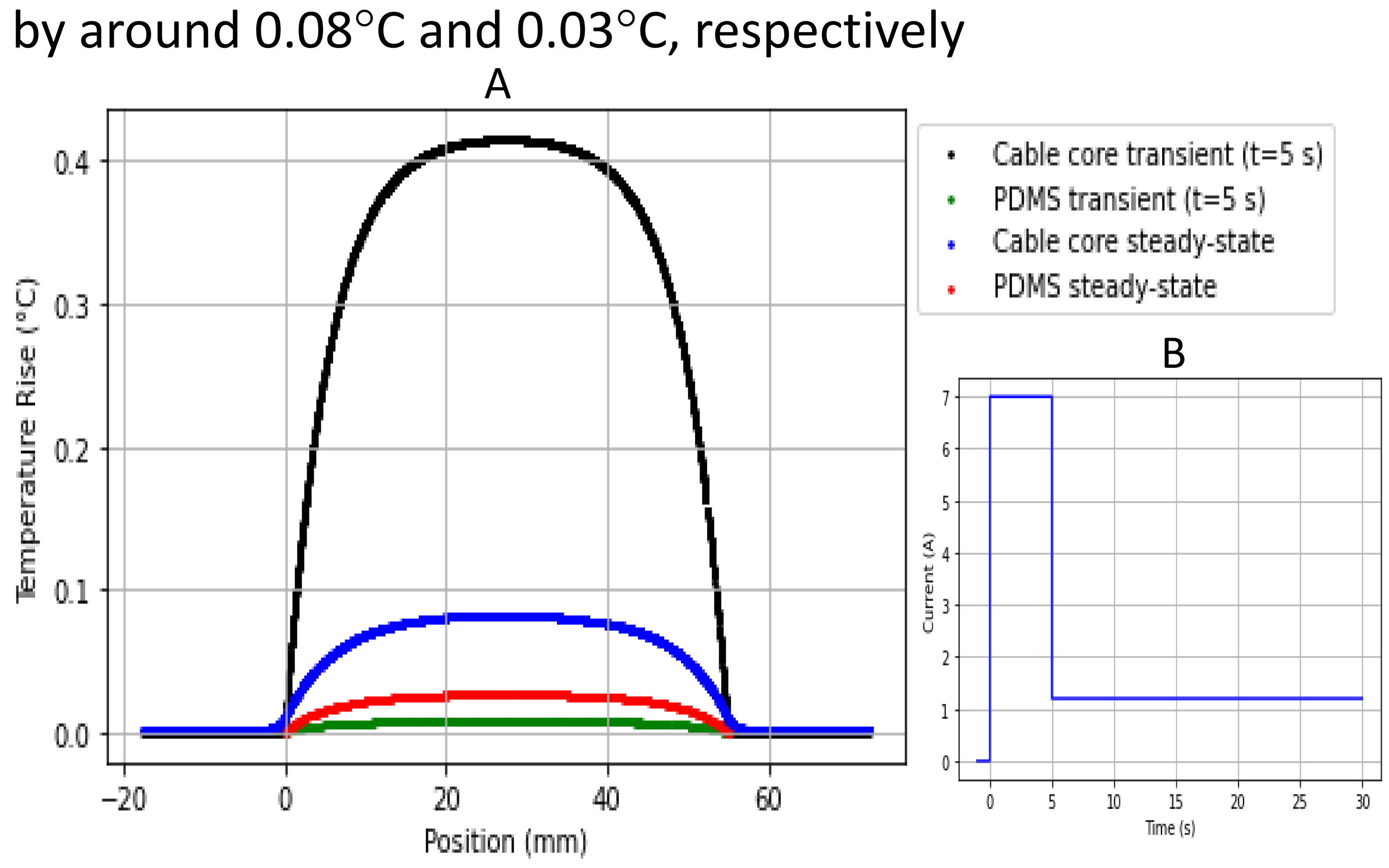

Fig. 5: A) Temperature rise in the core of the copper wire and in the PDMS due to inrush current and in the steady-state. B) Electrical conditions of the model.

CONCLUSIONS

This combination of experimental and computational findings will enable the design of new percutaneous medical devices to support therapies that require safe exchange of power, signal, and mass through the human body, without producing any significant risk for skin injury.

REFERENCES

1. A.P. Kourouklis, J. Kaemmel, X. Wu et al. “Systems of conductive skin for power transfer in clinical applications”, Eur Biophys., 51: 171–184, 2022.
2. K. Bourque et al. “Design Rationale and Preclinical Evaluation of the HeartMate 3 Left Ventricular Assist System for Hemocompatibility”, ASAIO J., 62:375-383, 2016
3. A.P. Kourouklis, V. Falk, E. Mazza et al., “Transdermal wires for Improved integration in vivo”, Biomaterials Advances, 2023
4. M. Bonmarin, F.A. Le Gal, “Lock-in thermal imaging for the early-stage detection of cutaneous melanoma: A feasibility study,” Comput. Biol. Med., 47:36–43, 2014.