Predicting Tissue Thermal Dynamics in Thermoregulatory Injuries such as Heat Stroke and Hypothermia

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Military & Medical Relevance

HEAT STROKE

Characterized by body core temperature **> 40 °C**

Without rapid cooling, it can progress to systemic inflammation and **death**

Background

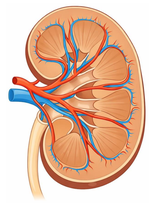
Research Question: What are the **limitations** of current bioheat transfer models in predicting body temperature changes during rapid cooling?

Most Used Model: Pennes Bioheat Equation (PBHE)

$$\rho c \frac{\partial T}{\partial t} = k\nabla^2 T + \rho_b c_b \omega (Ta - T) + q'''$$

This model assumes instantaneous thermal equilibrium between blood and tissue.

Objective: Assess the validity of Pennes' bioheat equilibrium assumption by measuring transient temperature gradients during *ex vivo* swine kidney perfusion.



Methods

Perfusion Protocol: N = Normothermic C = Cold

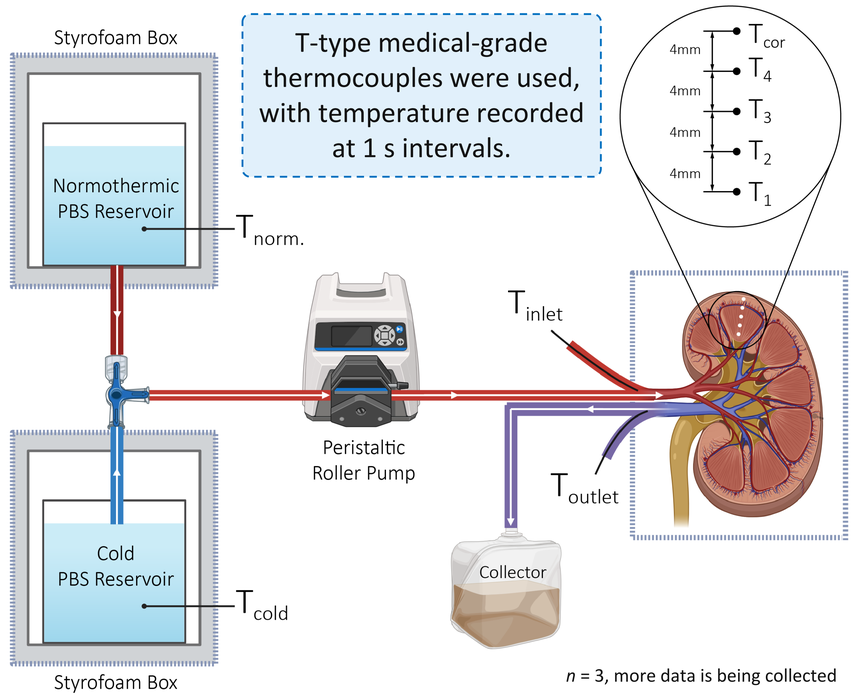
15 mL/min
Fixed time interval

N. PBS	C. PBS	N. PBS	C. PBS	N. PBS	C. PBS
20 min	20 min	20 min	20 min	20 min	20 min

20 mL/min
Time adjusted: every 0.5 °C change in T4

N. PBS	C. PBS	N. PBS	C. PBS	N. PBS	C. PBS
4-5 min	4-5 min	4-5 min	4-5 min	4-5 min	4-5 min

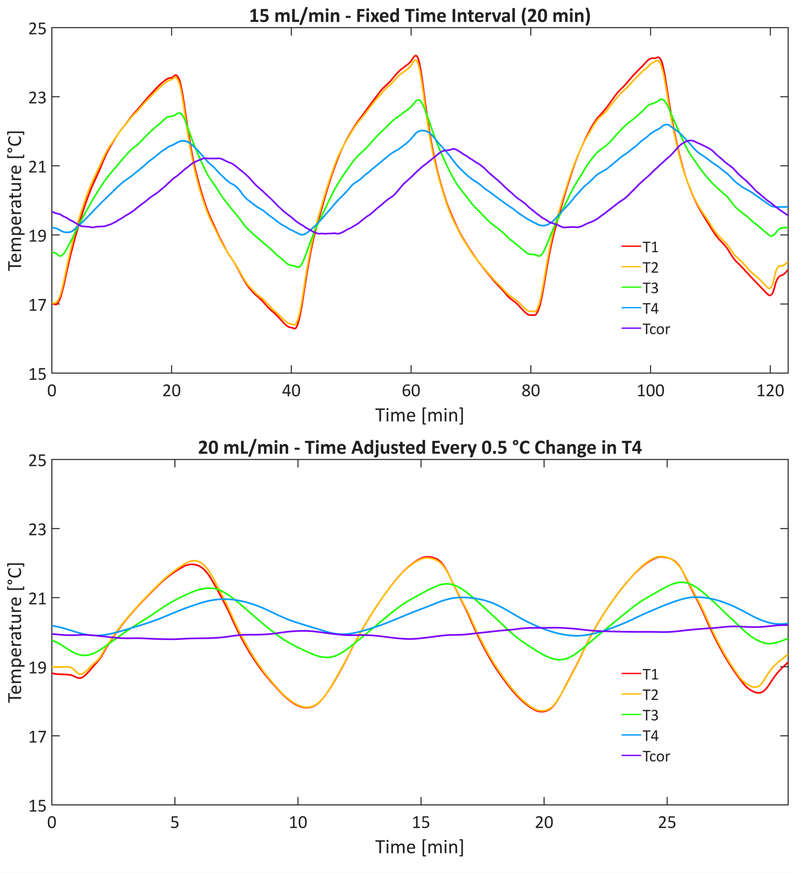
Methods



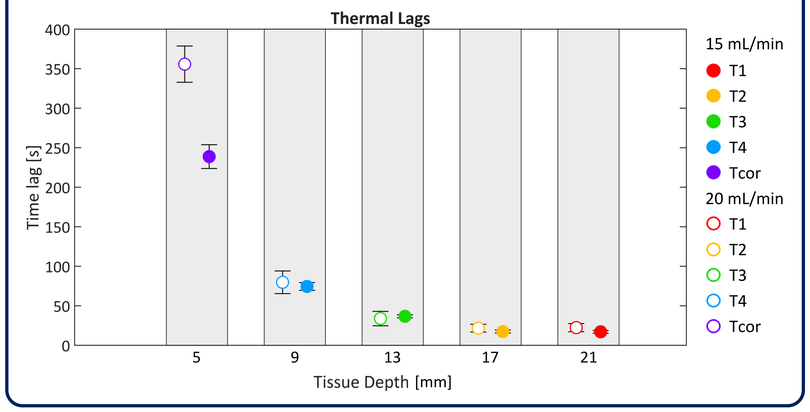
T-type medical-grade thermocouples were used, with temperature recorded at 1 s intervals.

n = 3, more data is being collected

Results



Results



Discussion

- Measured lags indicate **non-instantaneous perfusate–tissue thermal equilibration**
- **PBHE breaks down** when perfusate and tissue temperatures differ substantially
- Results reveal **depth-dependent thermal propagation**

Gap Revealed: Blood–tissue coupling or two-parameter models are needed to capture transient behavior.

Future Work

- Additional kidney perfusion experiments are ongoing
- **Development of a coupled blood–tissue thermal model is in progress**
- Improved temperature control in perfused tissues is relevant to hyperthermia, cryotherapy, and organ preservation, opening avenue for other applications
- **In heat stroke, this modeling approach may support whole-body simulations to evaluate and optimize cooling strategies**

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. EEC 1941543 and the NIH R01 on kidney cryopreservation No. DK117425.