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Leah S. Wilk and Maurice C. G. Aalders

AMSTERDAM CENTER FOR FORENSIC SCIENCE AND MEDICINE

The Colour and the Shape

Visible and thermal 3D imaging of human bodies for the reconstruction of the time since death

POLITIE

Amsterdam UMC
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fortechs

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Ministerie van Veiligheid en Justitie

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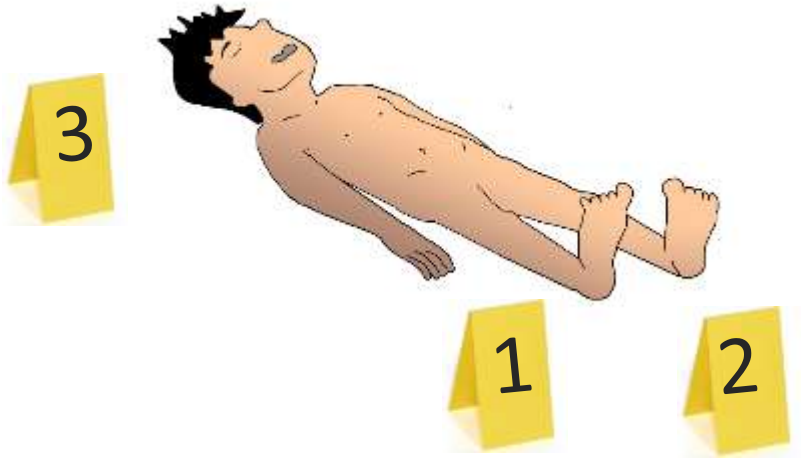
Disclaimer

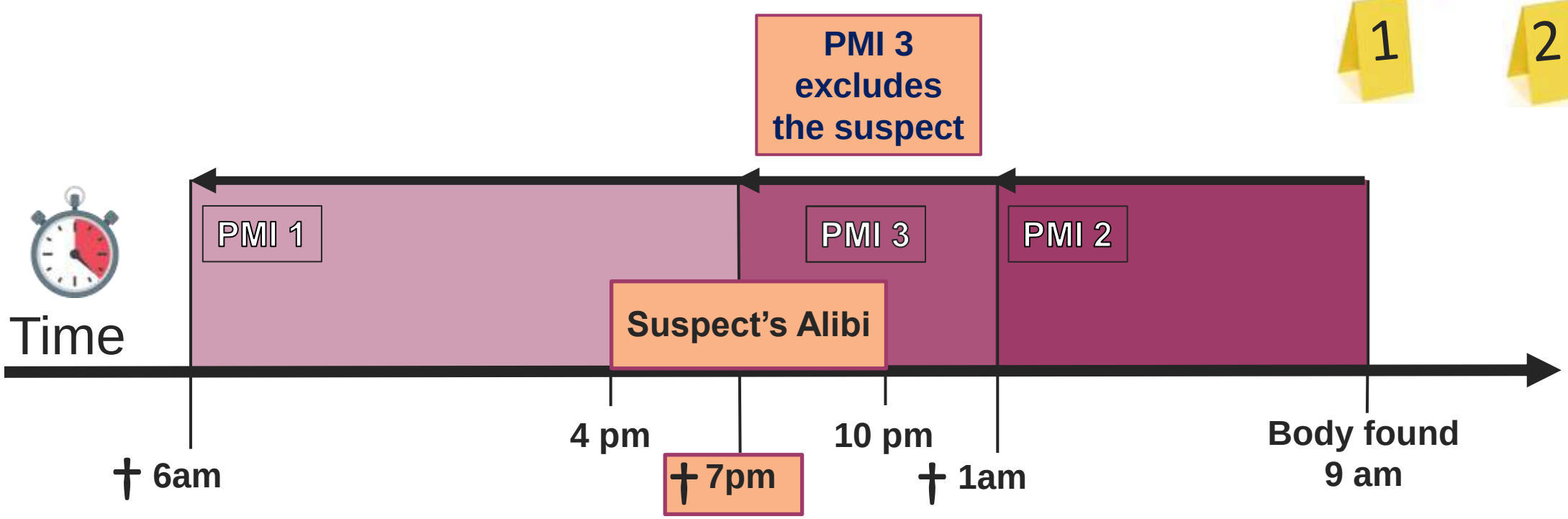
This presentation contains images of deceased human subjects.

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Relevance

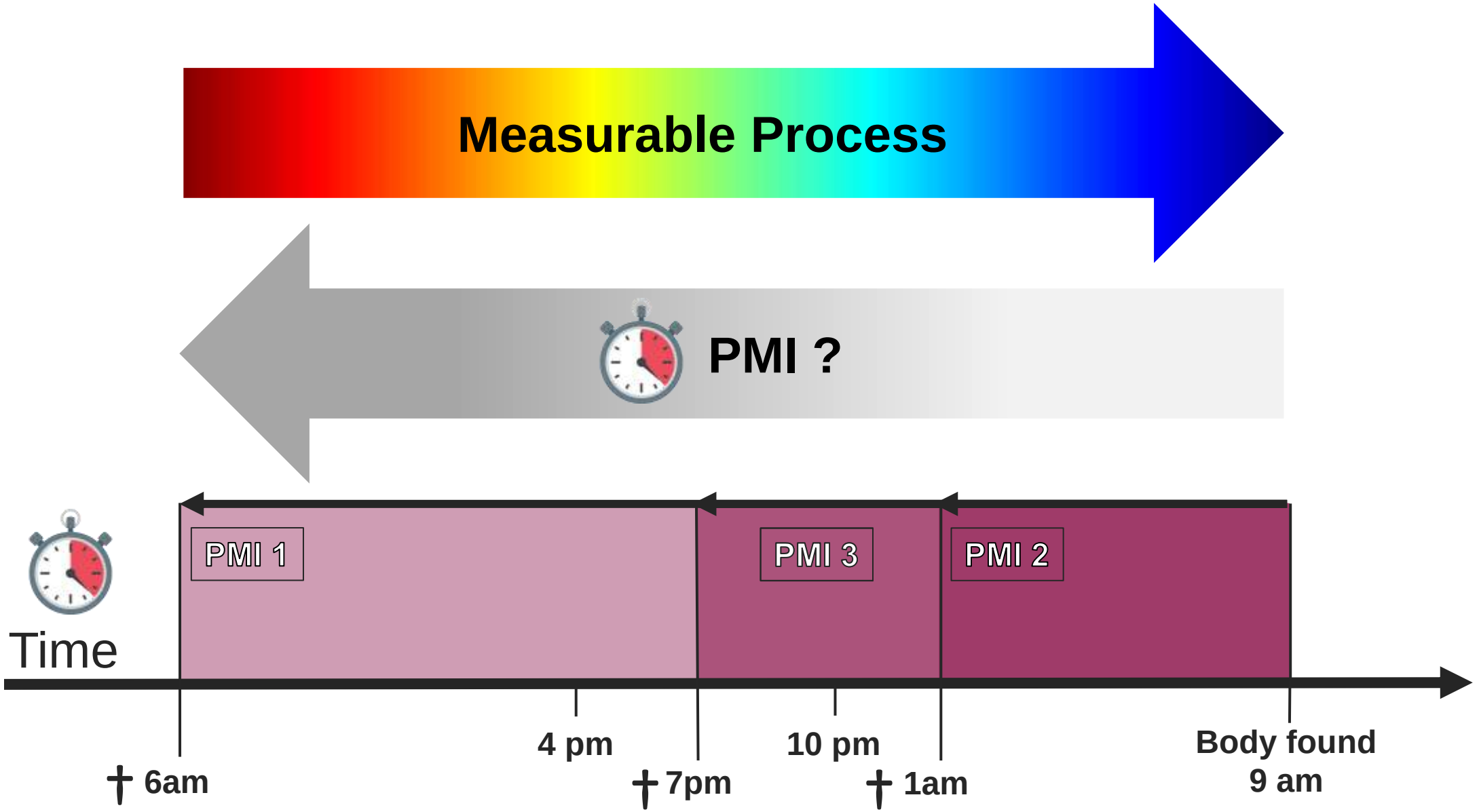
PMI = Post-mortem interval





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How



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What

Wet Chemistry DNA/RNA degradation, Ocular potassium levels…

Physics **Tissue**: Reflectance, Fluorescence, Stiffness, Temperature…

Biology Entomology, Botany, Palynology…

Time

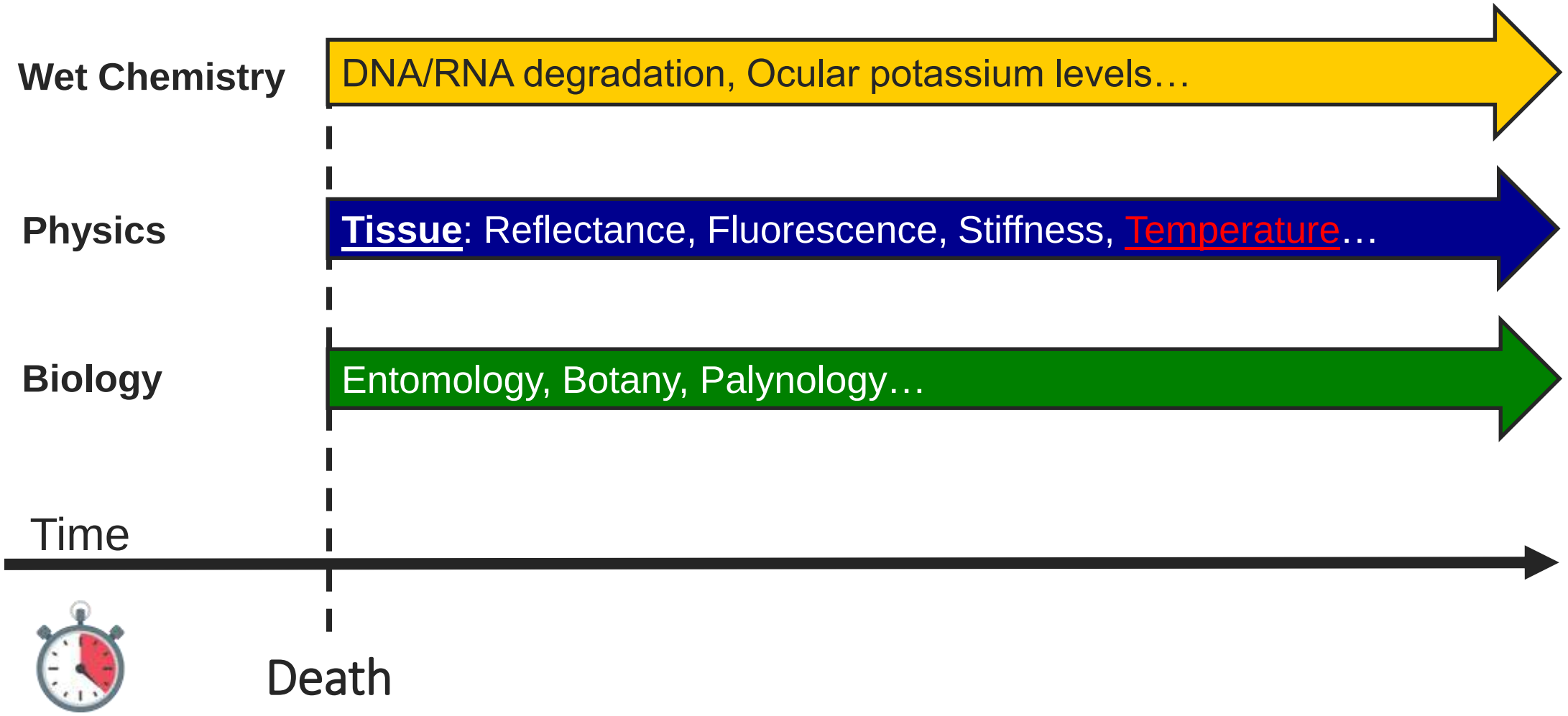


Death

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What

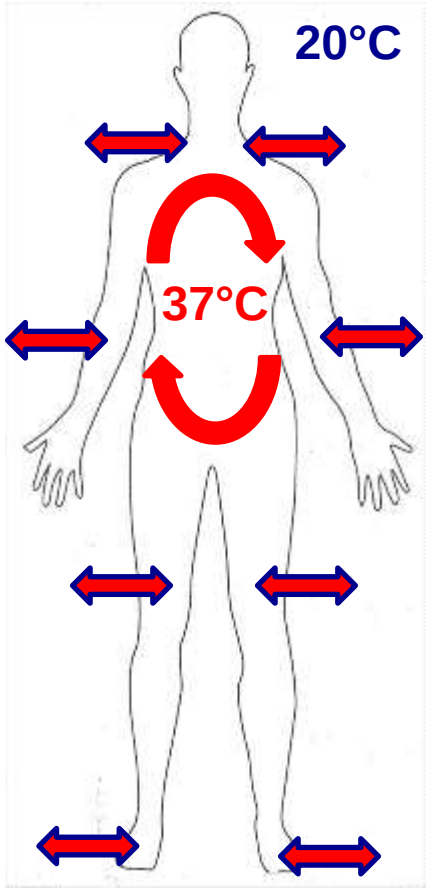


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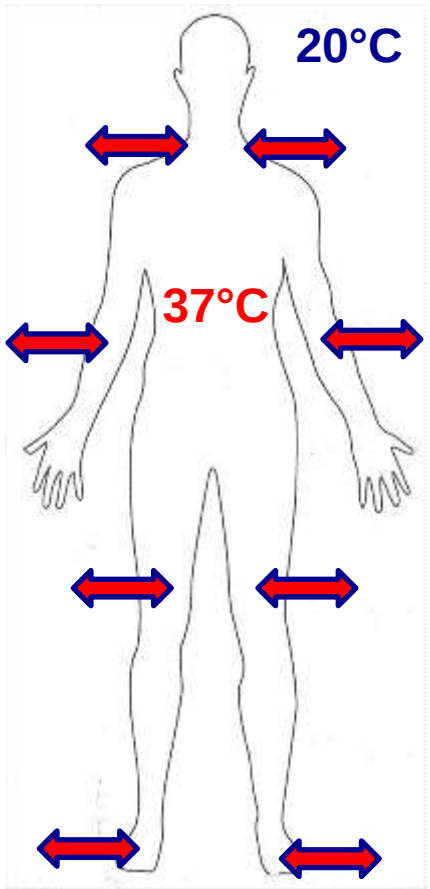
The physics

Heat Exchange + Thermoregulation



DEATH

Heat Exchange

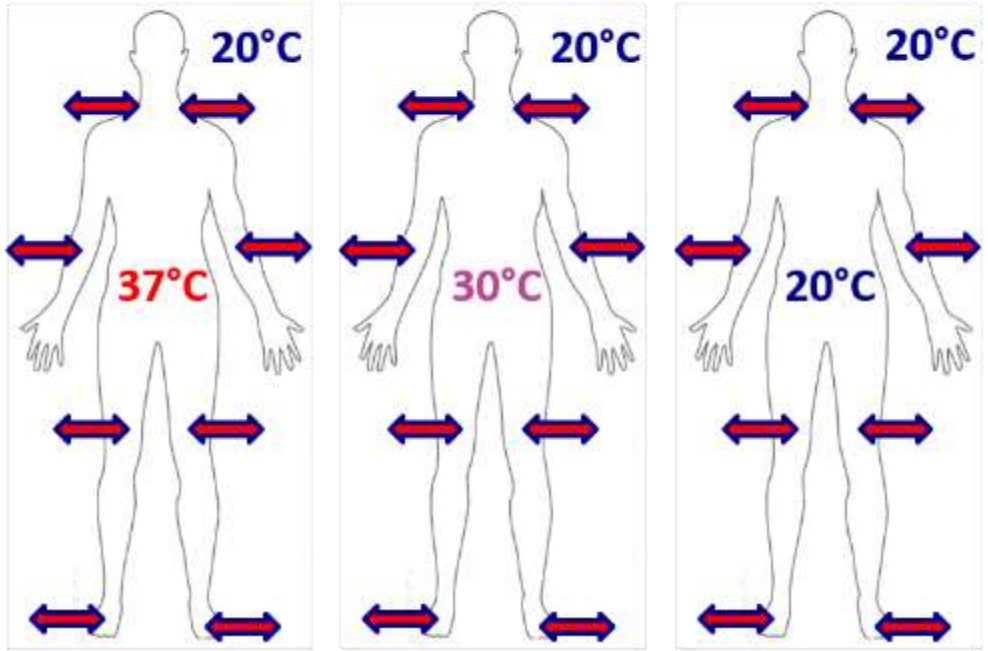


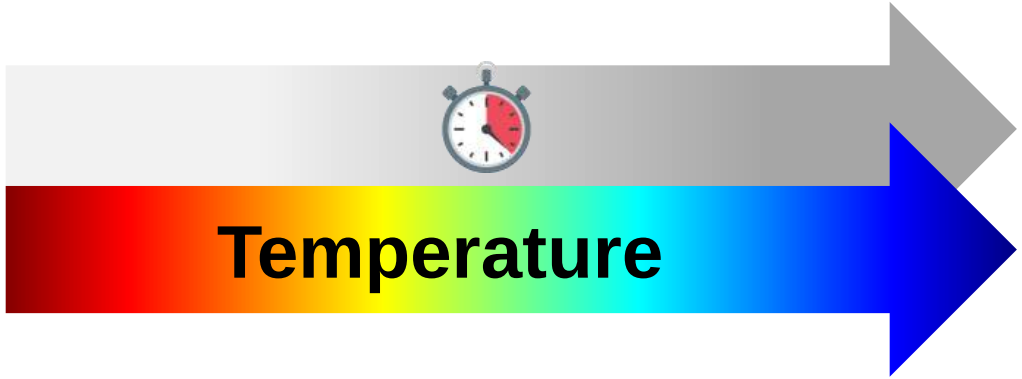
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The physics

Heat Exchange





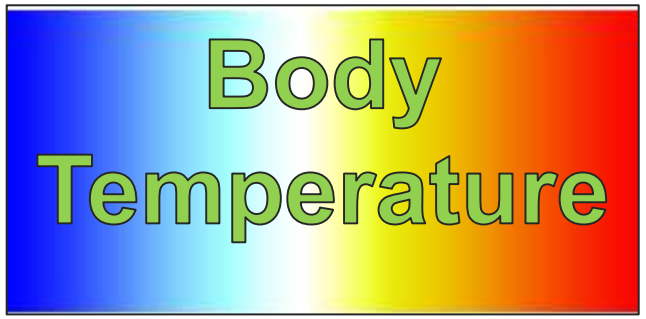
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How can we use this?

What we **need**:

What we **have**:



?

MODEL

What we **want**:



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Proposition I

All models are approximations.

Assumptions, whether implied or clearly stated, are never exactly true.

All models are wrong, but some models are useful.

So the question you need to ask is not "Is the model true?" (it never is) but "Is the model good enough for this particular application?"

Box, G. E. P. et al. (2009), Statistical Control By Monitoring and Adjustment, John Wiley & Sons.

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Modelling approaches

Heuristic

Establish a predictive relationship between post-mortem body temperature and PMI by experiment (**empirically**).

Gold Standard

Deductive

Conceptualise, model and describe the underlying heat exchange process in measurable quantities.

Our Approach

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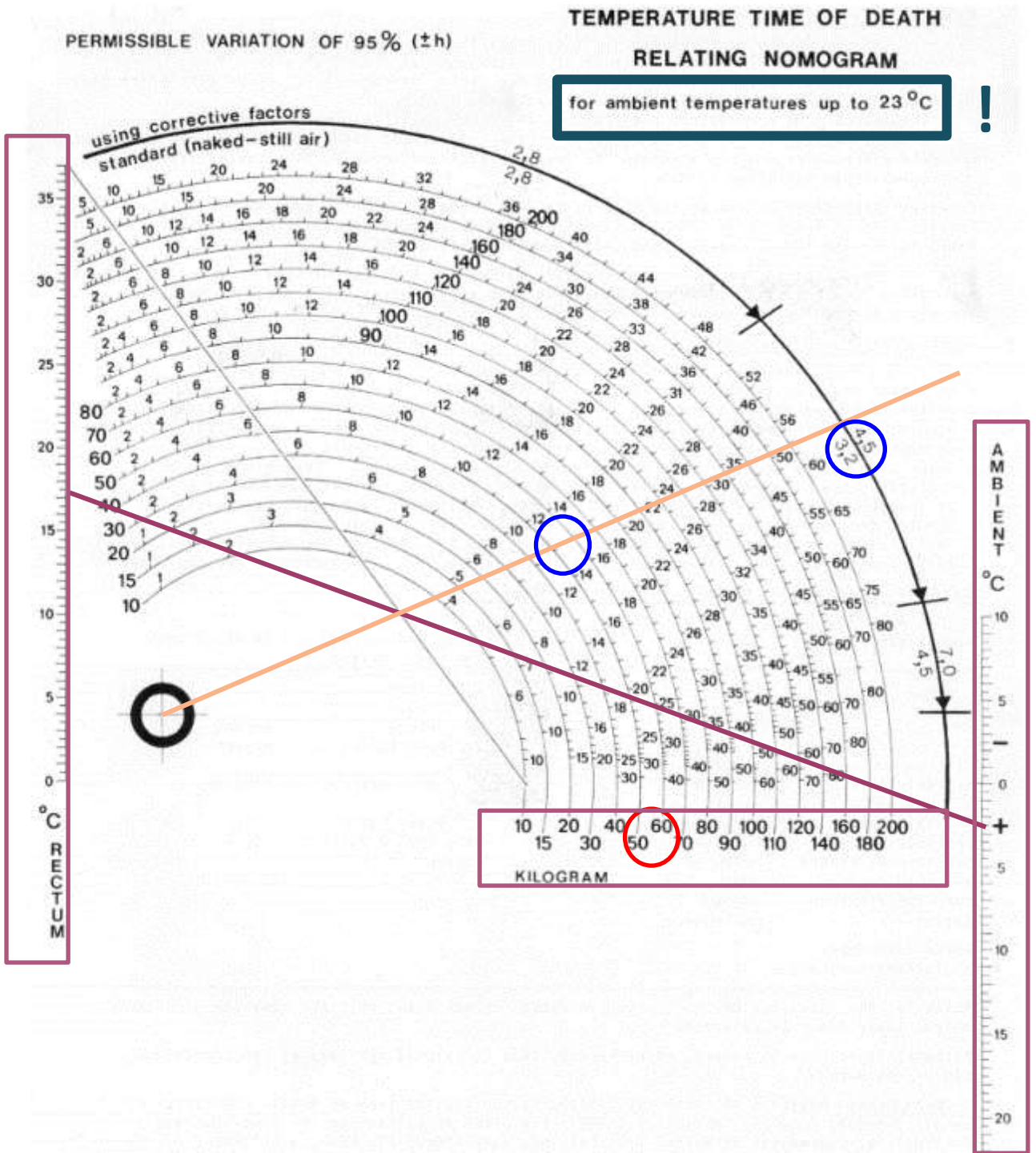
Gold standard

Henßge's nomogram

- Cooling model in the form of a look up table (created by experiment)
- Error margin ranges from 6h to 14h
- Almost always **weight correction factors**

- **Limited applicability (body shape and posture, coverage, ambient conditions, children…)**
- **Subjective**
- **Obscured error sources**

Is this model good enough for our application?



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Aims

- Develop a widely applicable (various scenarios) method for thermometric PMI reconstruction

- This method should be:

  i. Non-subjective
  ii. Improving on, or at least match, the error margins of the gold standard
  iii. Streamlined for forensic practice (fast, easy-to-use and ideally non-contact)

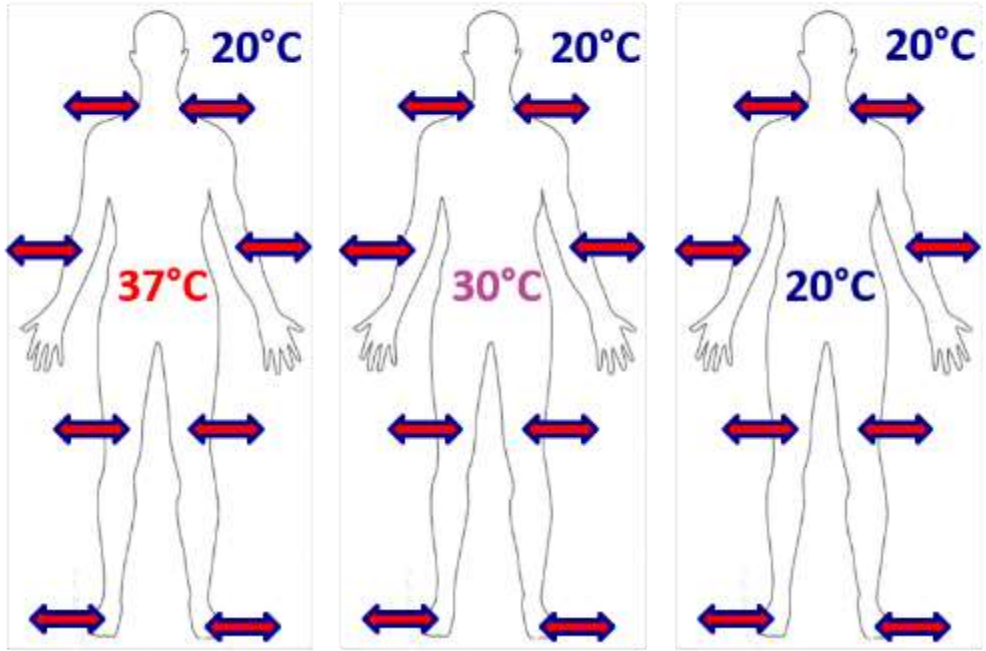
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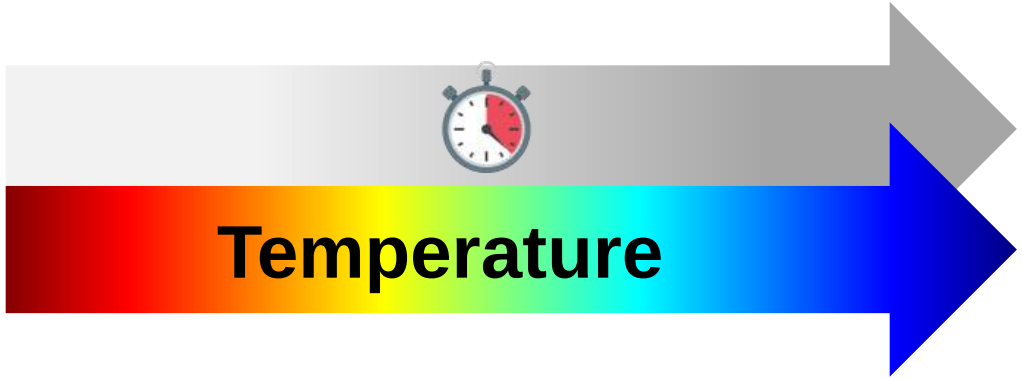
Non-subjective: Physics



Conceptualise and formalise the underlying heat exchange

Heat Exchange





Transient Heat Equation

$$\rho c_p \frac{\partial \boldsymbol{T}}{\partial \boldsymbol{t}} - \nabla \cdot (k \nabla \boldsymbol{T}) = Q$$

Temperature: T

Time: t

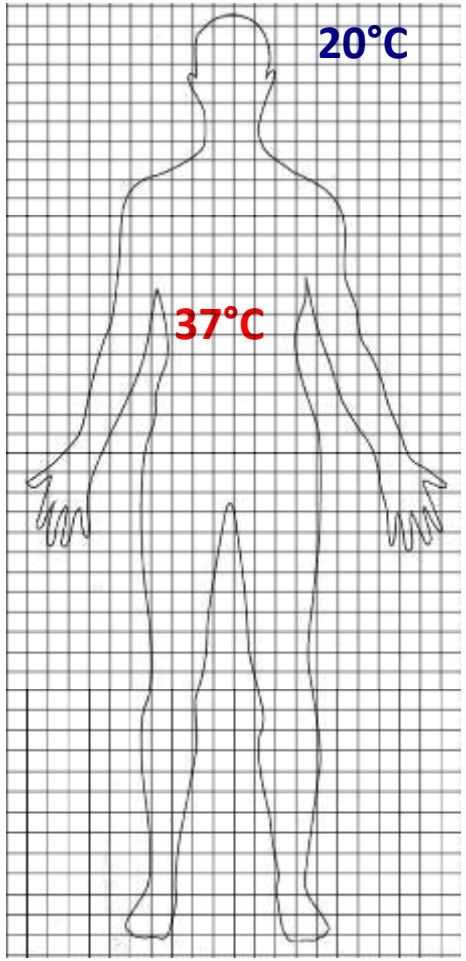
No analytical solutions for complex geometries…

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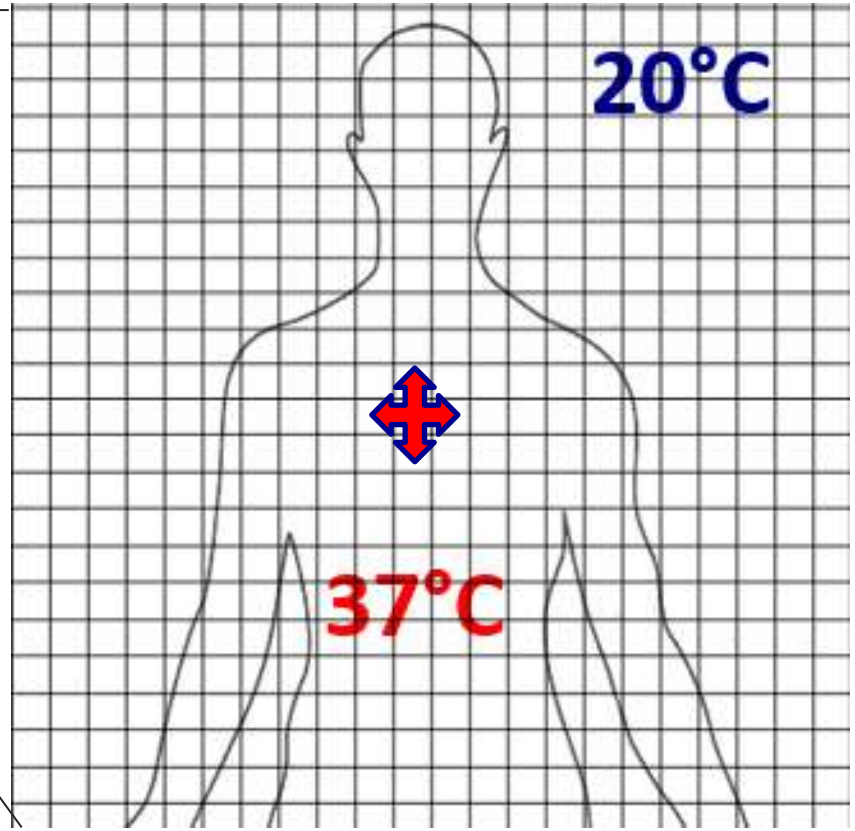


Our solution strategy

Discretize the problem…



…to compute the cube-wise heat exchange



L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders, Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

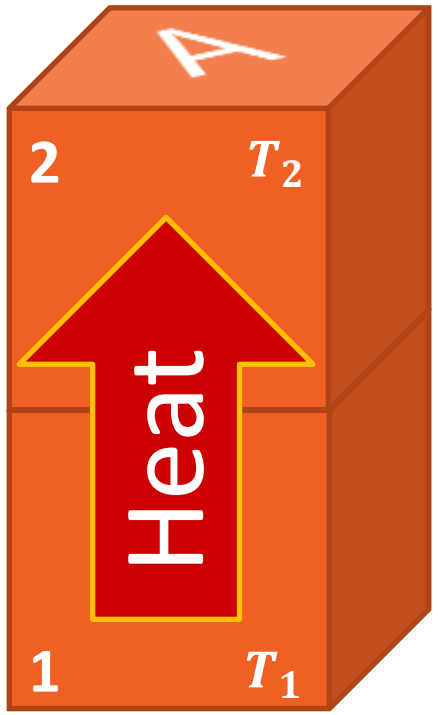
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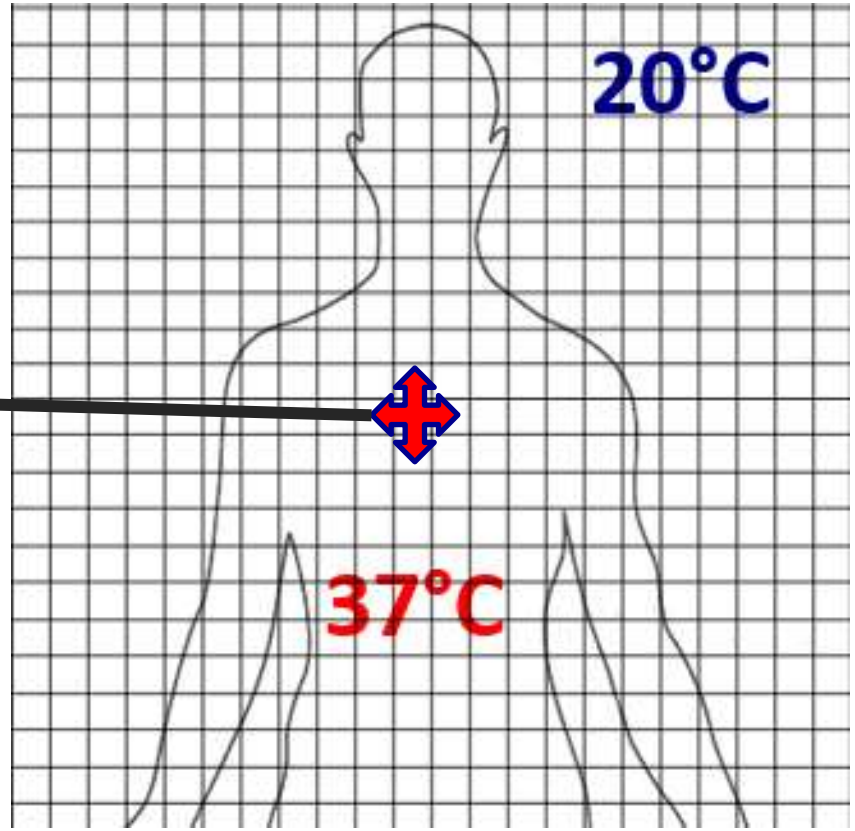
Heat transfer

$$\Delta E = h_{1,2} A \Delta T$$

$$\Delta T = T_2 - T_1$$



…to compute the cube-wise heat exchange



L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders, Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

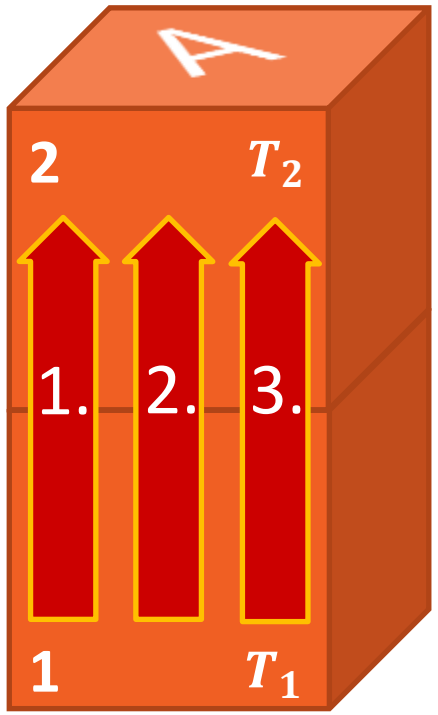
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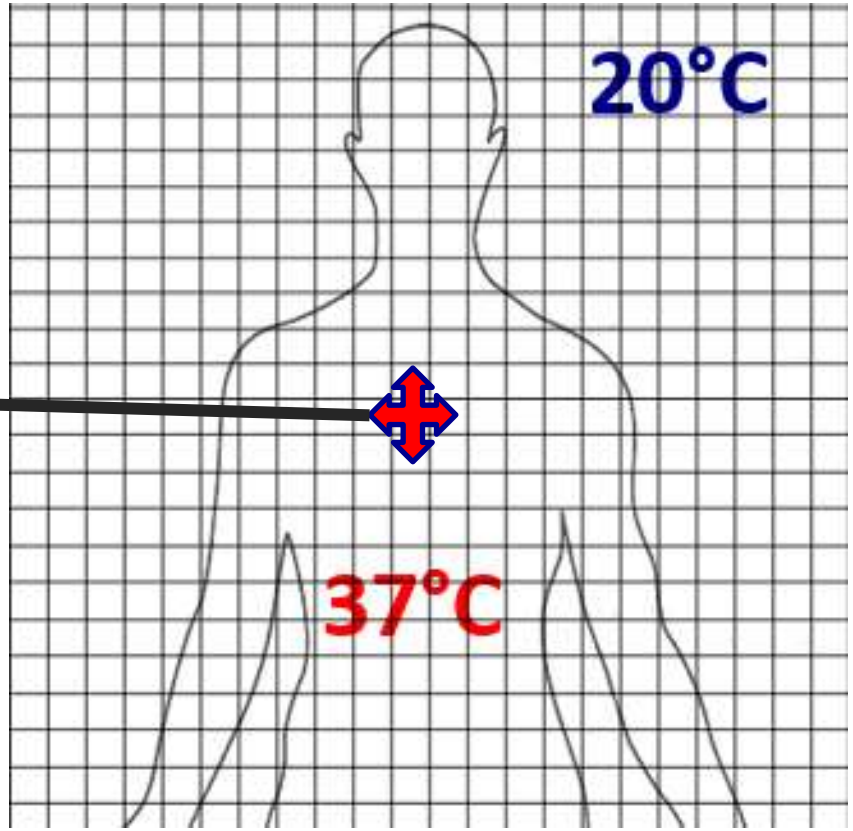
Heat transfer

Heat Exchange Pathways

1.Conduction | 2.Convection | 3.Radiation



…to compute the cube-wise heat exchange



L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders, Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

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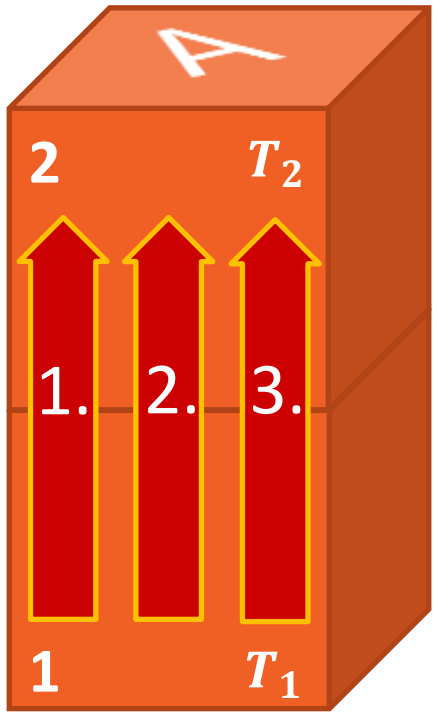


Heat transfer

Heat Exchange Pathways

1.Conduction | 2.Convection | 3.Radiation

Combining the heat transfer pathways: Energy Bookkeeping



(i) Conduction: $\Delta E_{cond} = h_{cond} A \Delta T \Delta t$

(ii) Convection: $\Delta E_{conv} = h_{conv} A \Delta T \Delta t$

(iii) Radiation: $\Delta E_{rad} = h_{rad} A \Delta T \Delta t$

$\Delta E = \boldsymbol{h_{1,2}} A \Delta T \Delta t$

Combine paths: $\longrightarrow \frac{1}{h_{cond}} + \frac{1}{h_{conv} + h_{rad}} = \frac{1}{\boldsymbol{h_{1,2}}}$

L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders, Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

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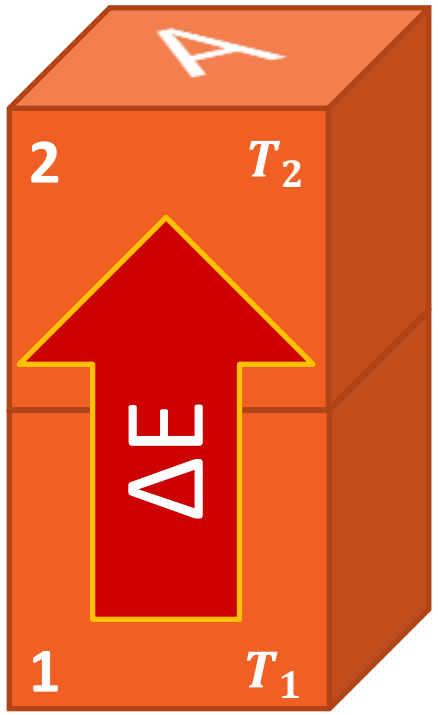


From heat to temperature

Heat Exchange Pathways

1.Conduction | 2.Convection | 3.Radiation

This strategy allows us to calculate the change in body temperature as a function of time!



ΔE

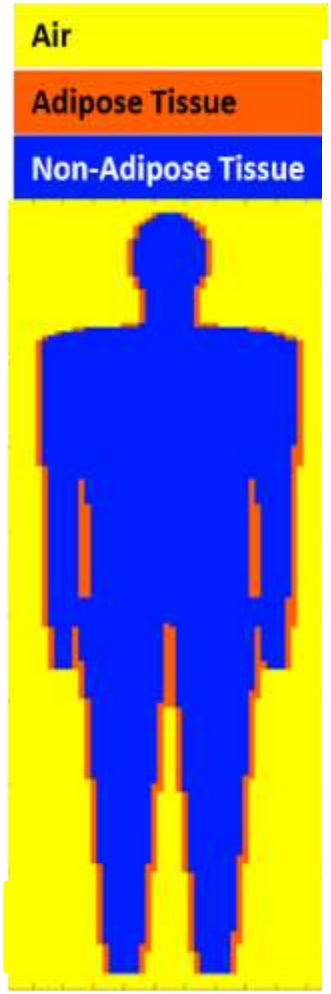
m_1:	Mass of cube 1
c_1:	Specific heat capacity of cube 1

L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders, Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

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The Shape 1.0



Experimental validation of our approach necessitates measurements on deceased human bodies:

- **Body Donation Programme** of the Amsterdam University Medical Centers, location AMC.

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Body Donation Programme

1. **Participants** have instated a codicil **donating their remains** to medical research

2. They further agreed to the use of their remains for **forensic and taphonomic research**

3. Following death, their remains are **immediately transported to the hospital morgue**

4. This enables several **unique forensic research** lines focussing on **human remains**

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Body Donation Programme

Prof. Roelof-Jan Oostra

Only European Taphonomic Research Facility (Test Site) for Human Remains

ARISTA

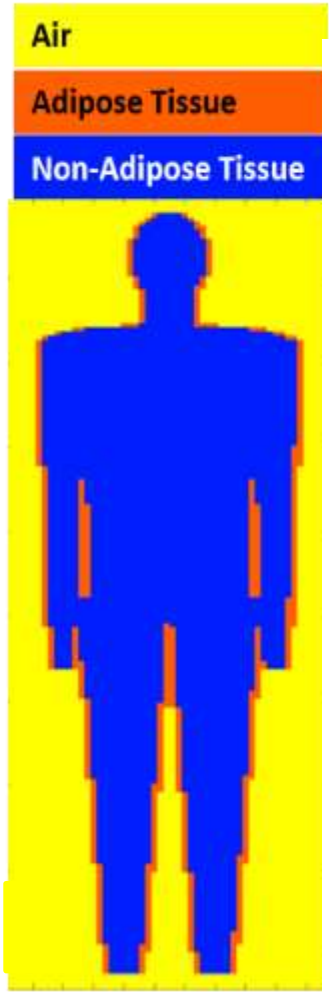
AMSTERDAM RESEARCH INITIATIVE FOR SUBSURFACE TAPHONOMY AND ANTHROPOLOGY

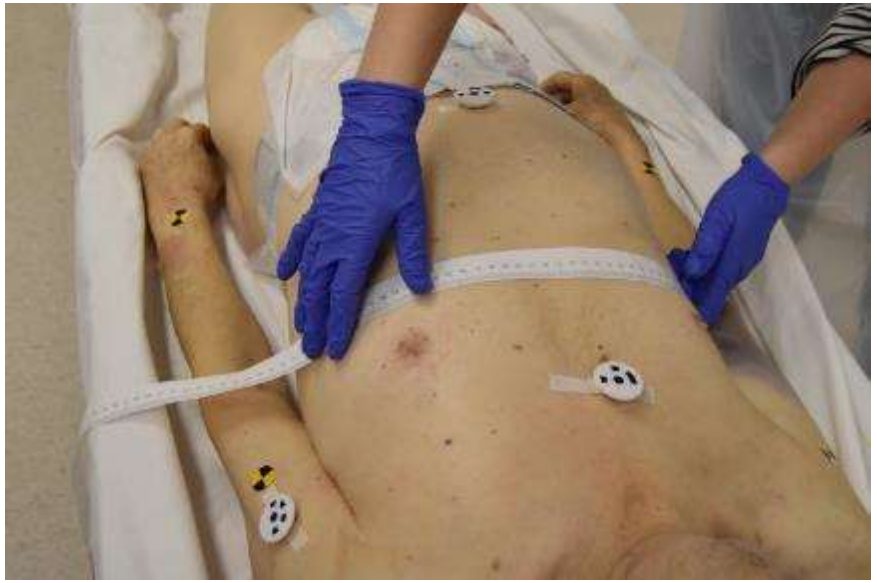


R. Oostra, T. Gelderman, W.J.M. Groen, H.G. Uiterdijk, E.L.H. Cammeraat, T. Krap, L.S. Wilk, M. Lüschen, W.E. Morriën, F. Wobben, W.L.J.M. Duijst, M.C.G. Aalders,
Amsterdam Research Initiative for Sub-surface Taphonomy and Anthropology (ARISTA) - A taphonomic research facility in the Netherlands for the study of human remains. Forensic Science International 317, 110483 (2020).

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The Shape 1.0







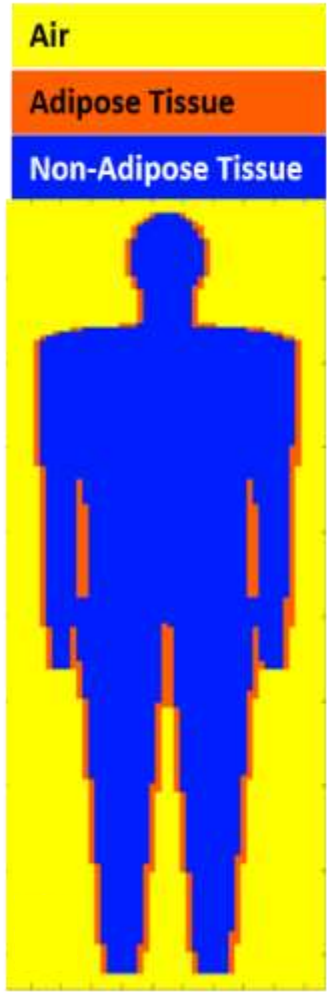
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Lengte hoofd:	23	Breedte hoofd:	16	Diepte hoofd:	20
Lengte nek:	7	Omtrek nek:	43	Hoogte borsten:	0
Breedte torso:	33	Omtrek torso:	96	Hoogte buik:	0
Lengte armen:	78	Omtrek schouder:	34	Omtrek pols:	18
Lengte benen:	96	Omtrek dijbeen:	49	Omtrek enkel:	21
				Omtrek heupen:	92

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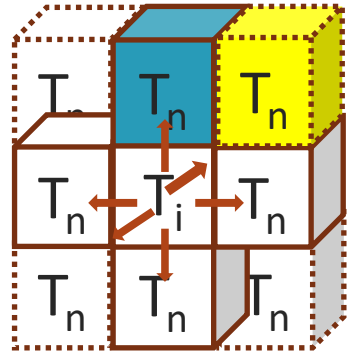


The Colour 1.0

Finally! Simulations!



…compute
cube-wise heat exchange
for consecutive time steps



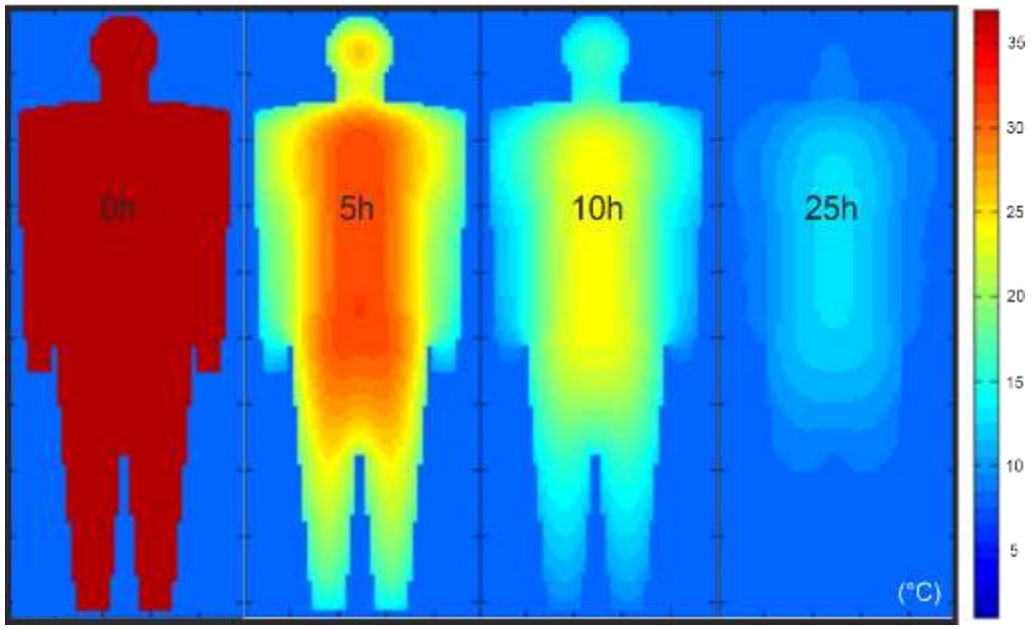
L. S. Wilk, R. J. M. Hoveling, G. J. Edelman, H. J. J. Hardy, S. van Schouwen, H. van Venrooij, M. C. G. Aalders,
Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

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How can we compare these with measurements?



The Colour 1.0

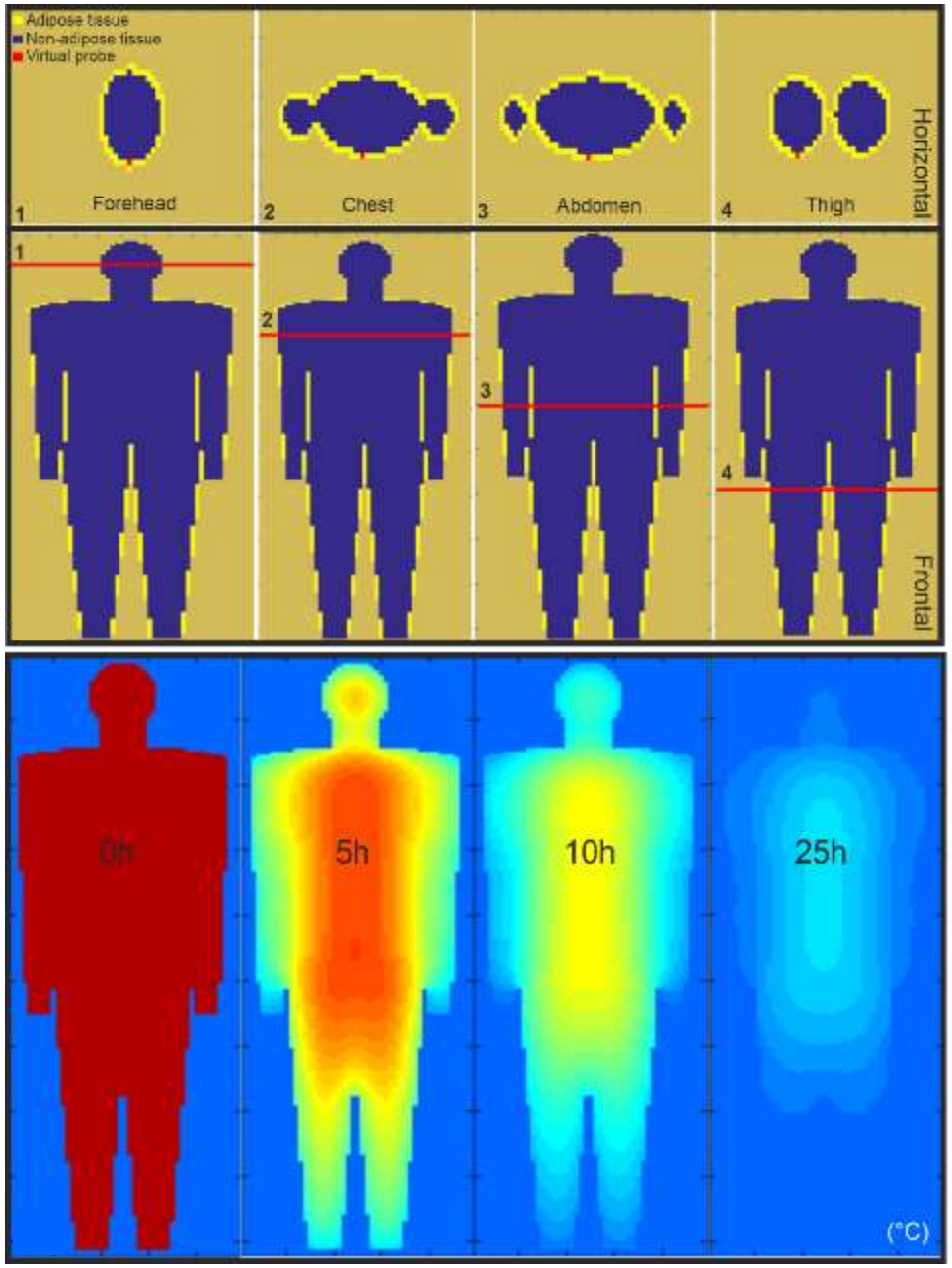


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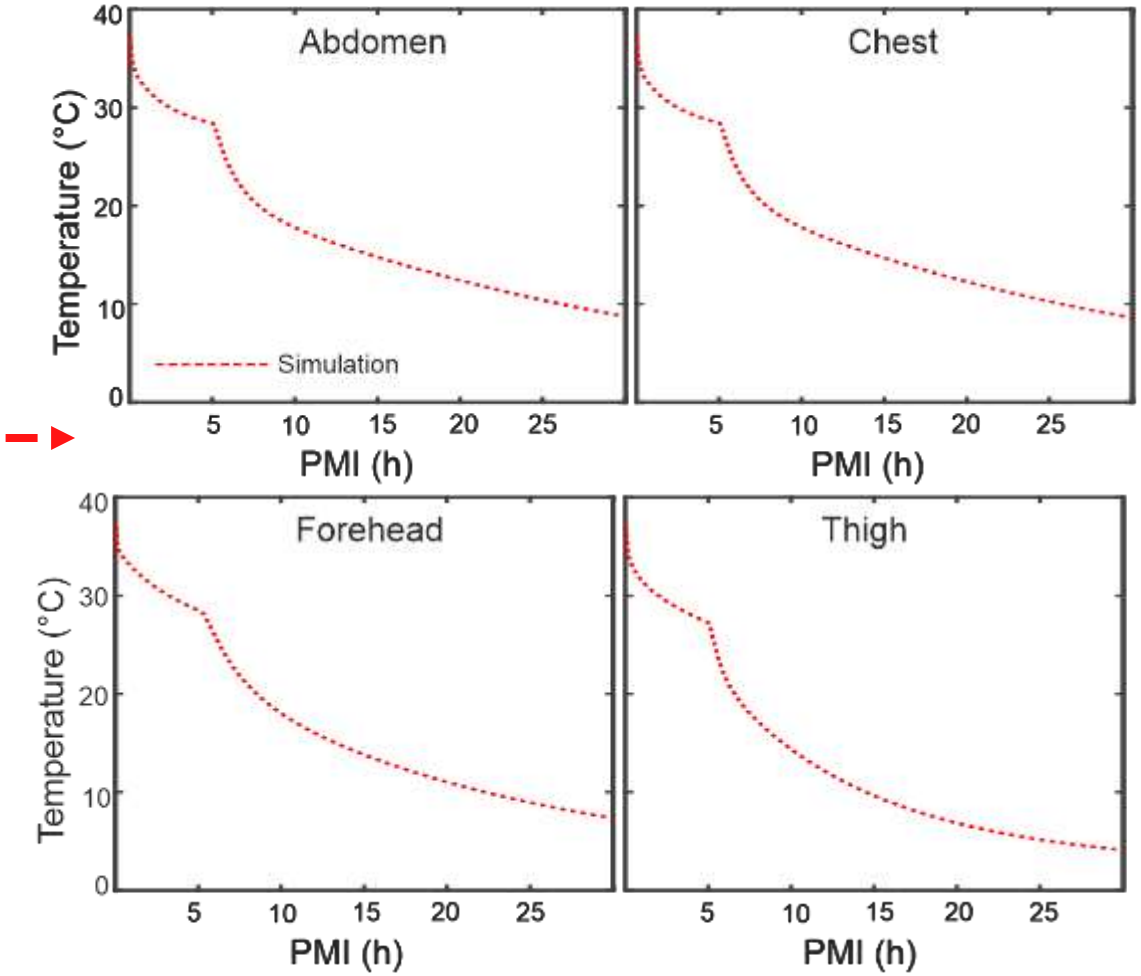


The Colour 1.0





Ø = 1.6cm

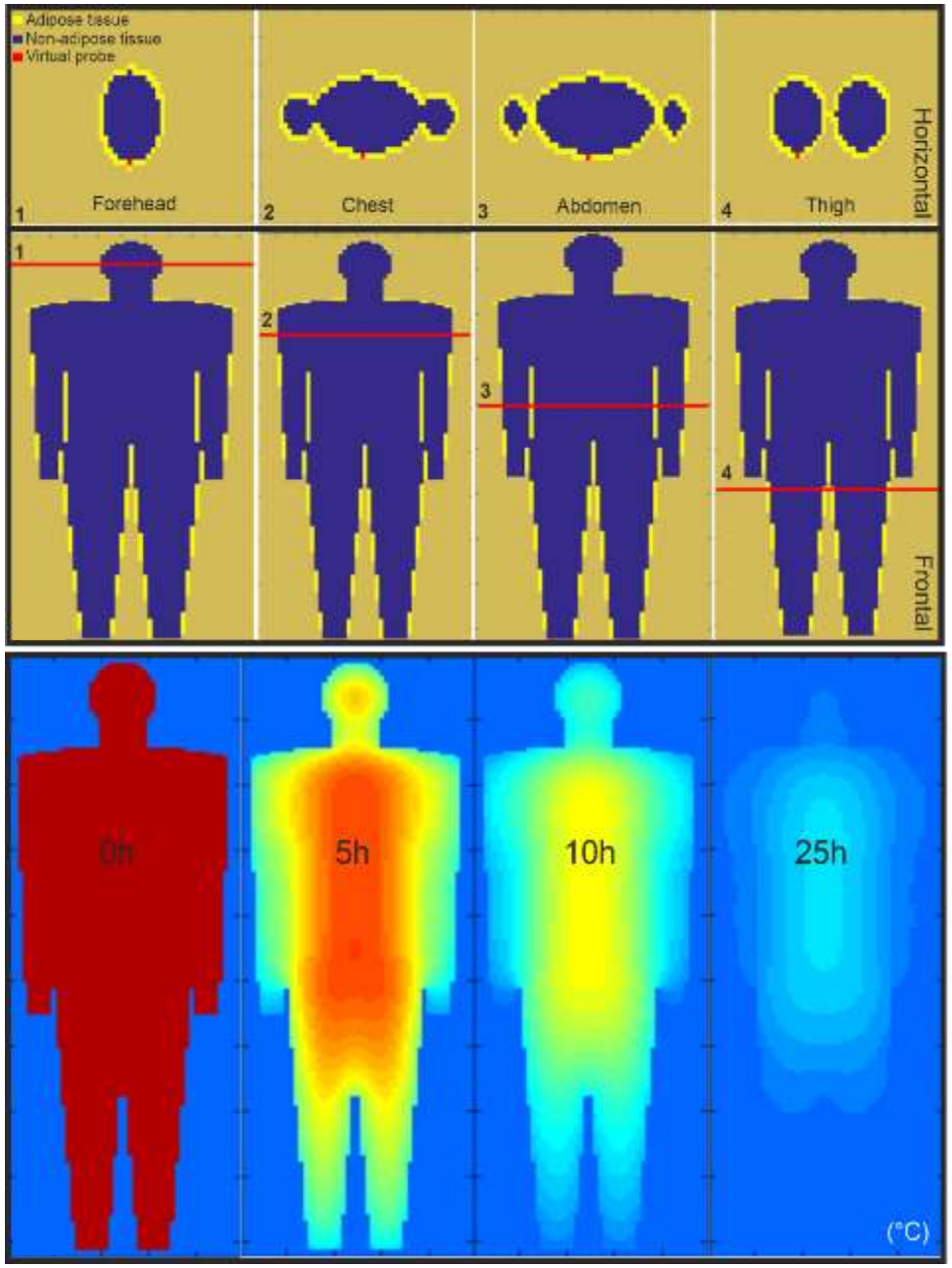


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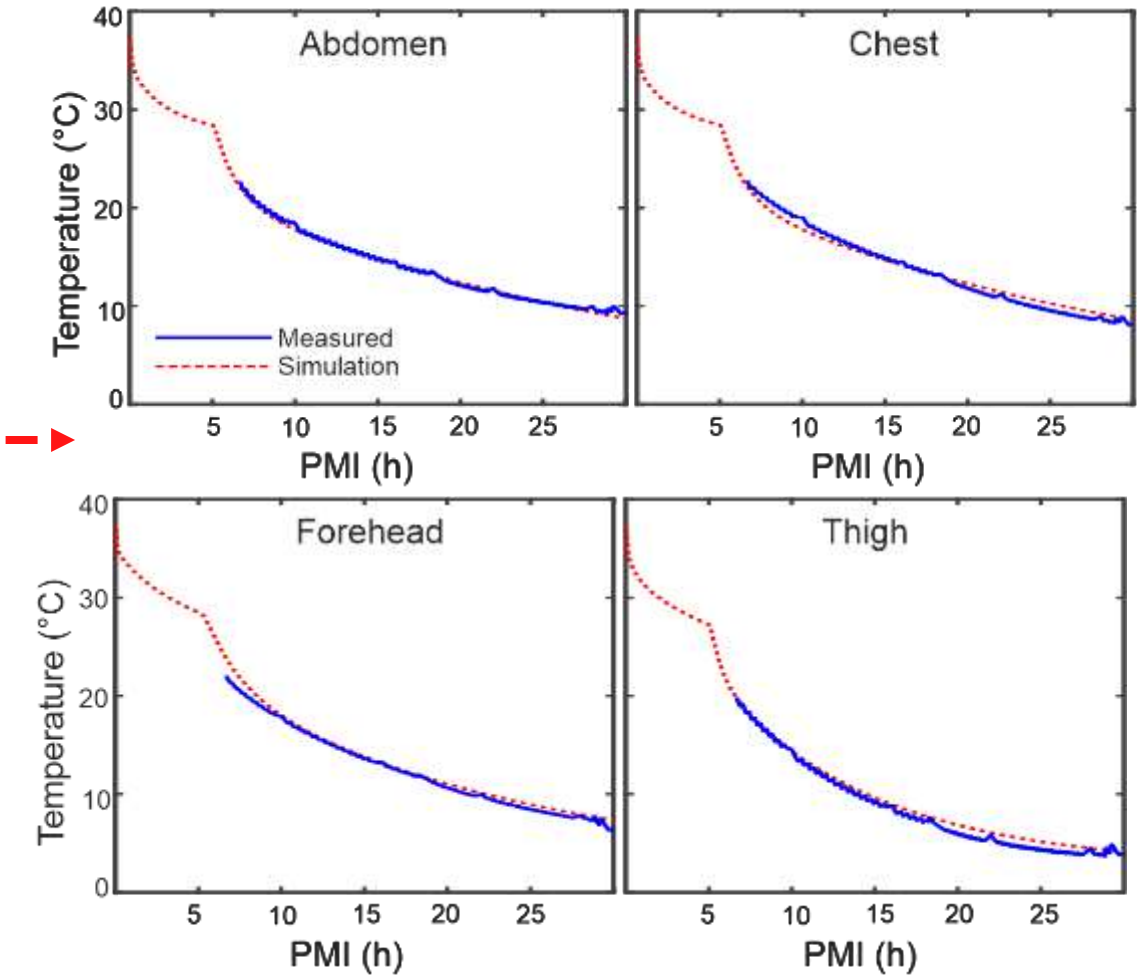


The Colour 1.0





Ø = 1.6cm



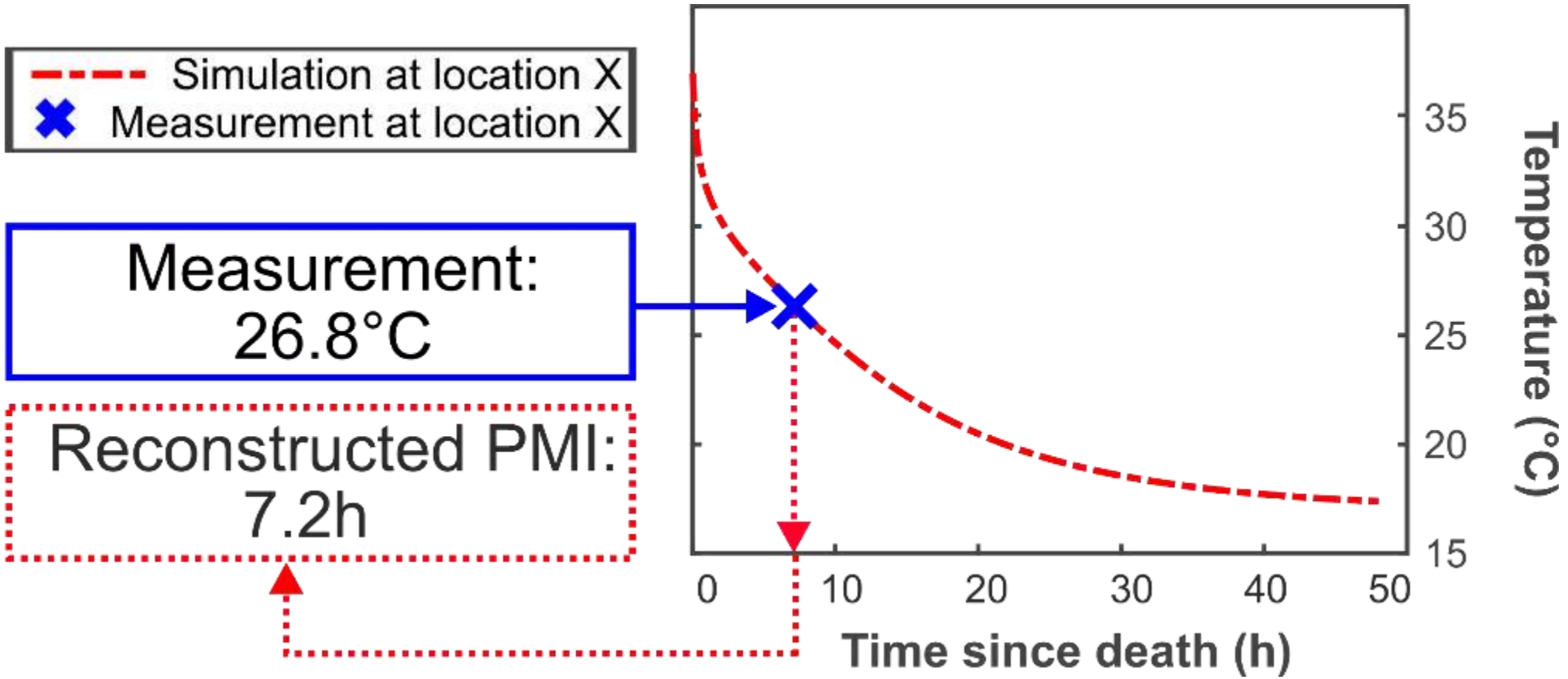
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Reconstructing the PMI



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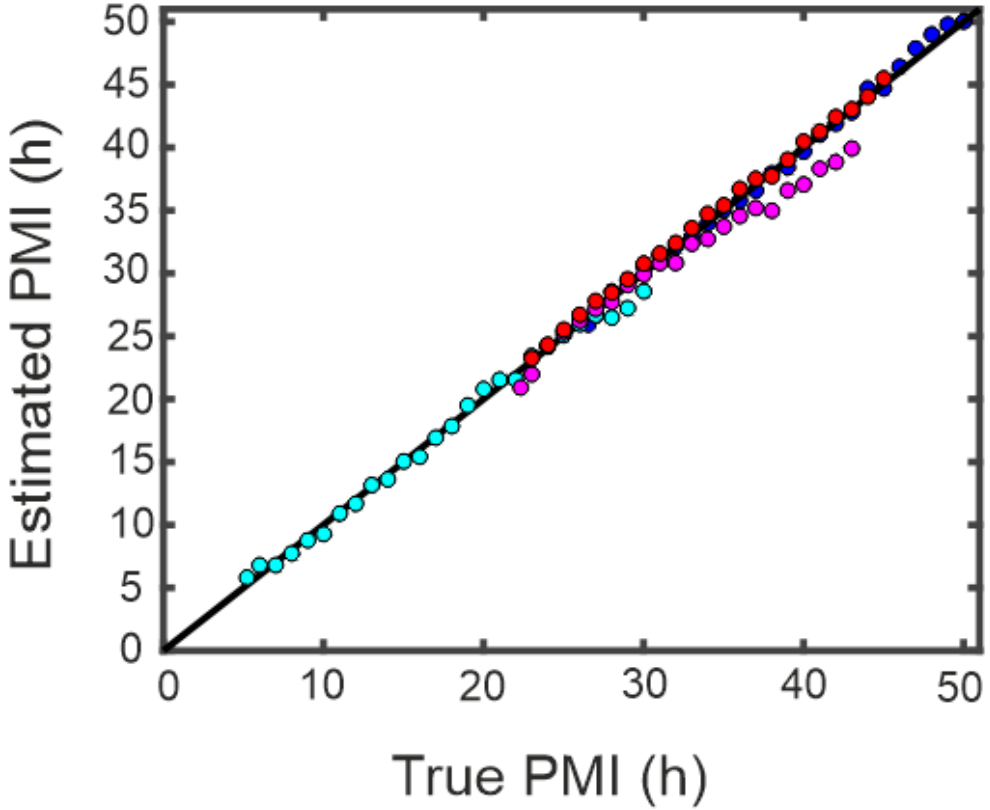
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First numerical approach to be validated on deceased humans

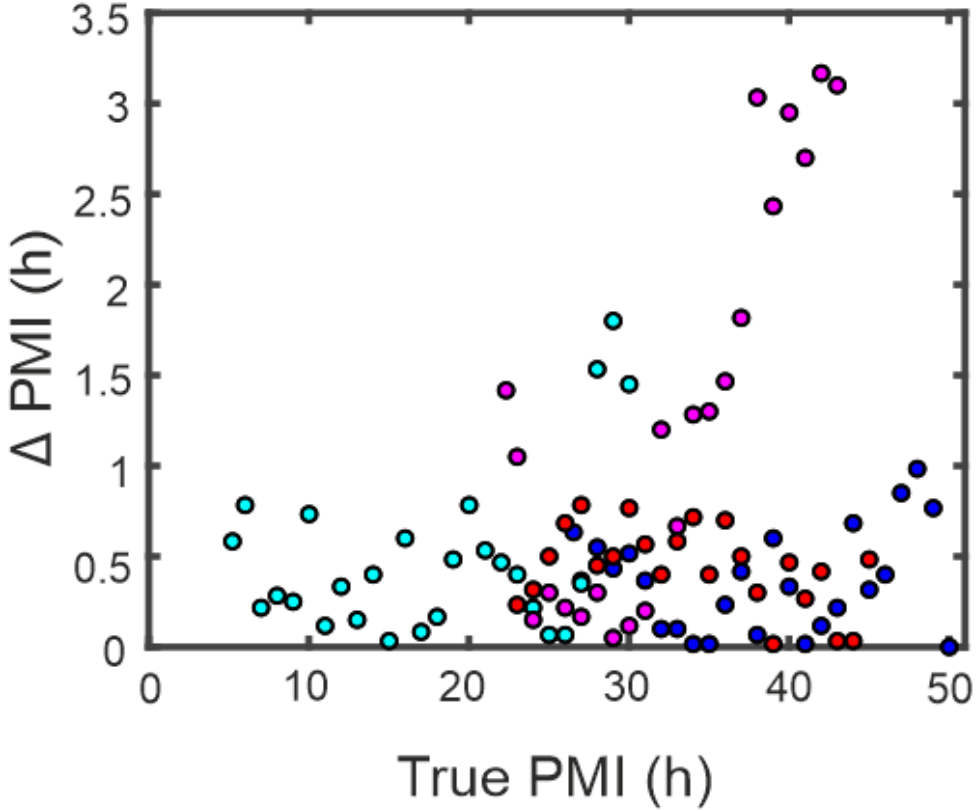


The Colour 1.0

Using abdominal temperatures



Mean Absolute Error = 38min
Maximum error of 3.2h for PMIs up to 50h!



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Reconstructing the time since death using noninvasive thermometry and numerical analysis. Sci. Adv. 6, eaba4243 (2020).

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- Students
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- Prof. Roelof-Jan Oostra
- Martin Roos
- Dr. Gerda J. Edelman
- Prof. Maurice C. G. Aalders

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