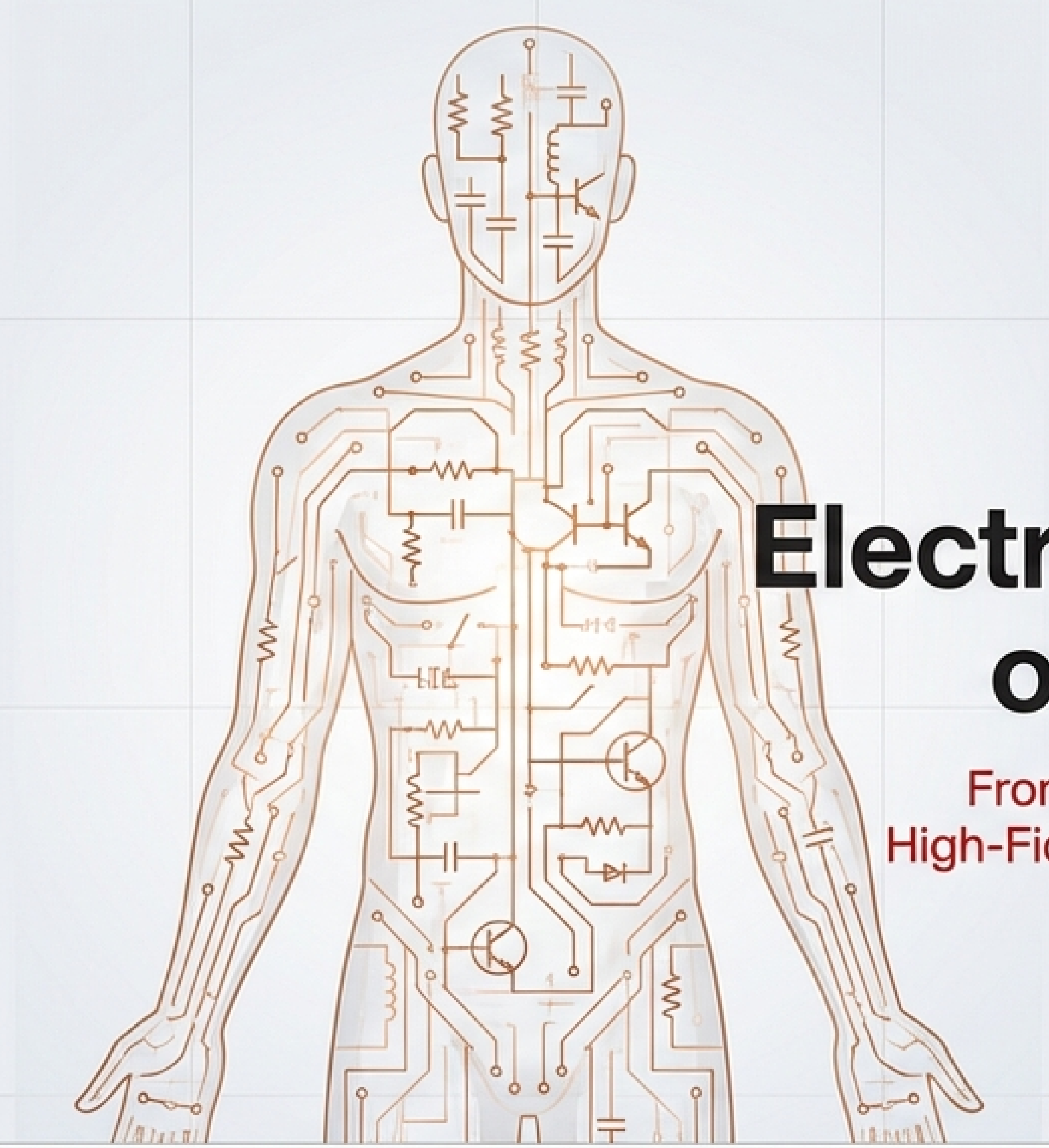


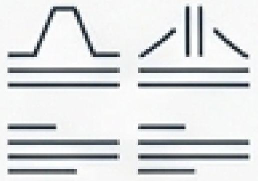
The Electrophysiology of Safety

From Skin Impedance to High-Fidelity Virtual Simulations

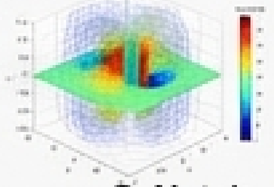
The Evolution

Biological Interface
Analyzing microscopic lipid layers.

Standardized Models
IEC safety zones derived from physical testing.



Computational Future
3D electromagnetic solvers and virtual humans.



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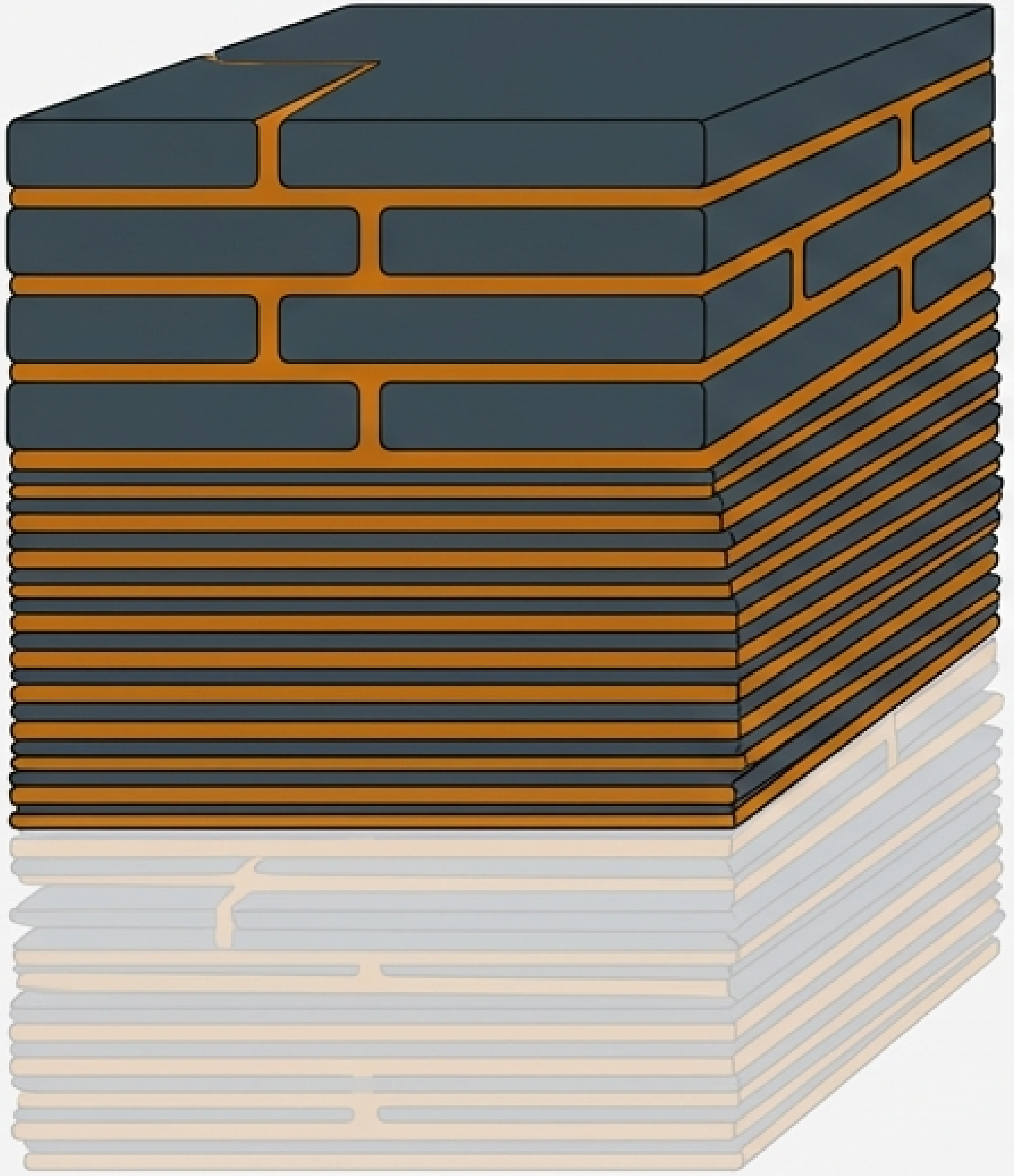
The First Barrier: Human Skin Mechanics

Stratum Corneum

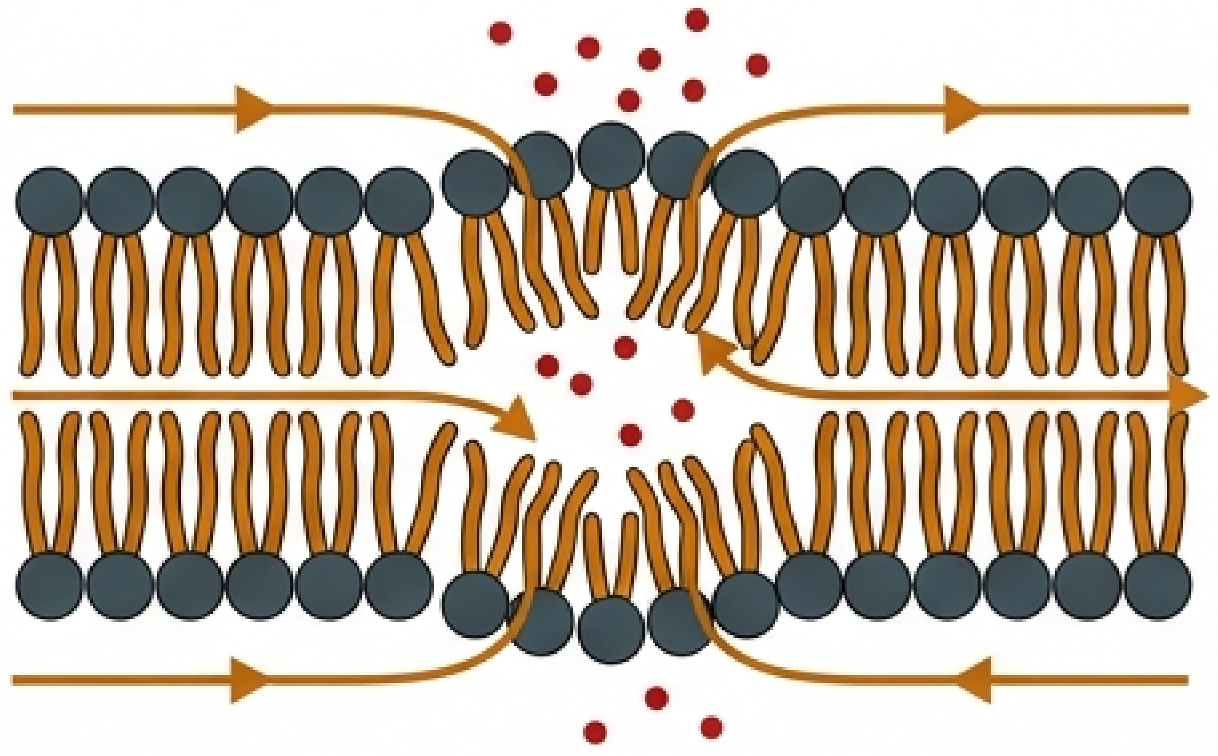


The Lochner Hypothesis

Effective Barrier: 15 Lipid Bilayers in Series

Traditional Assumption: 70–100 Layers

Mechanism: Electroporation



Dissertation Finding: Experimental data on Voltage-Current characteristics suggests the effective barrier is only 15 layers deep. At 10–20 V, electroporation creates pores in these membranes, causing a rapid, non-linear collapse in resistance.

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Helvetica Now Display: Breakdown and Recovery

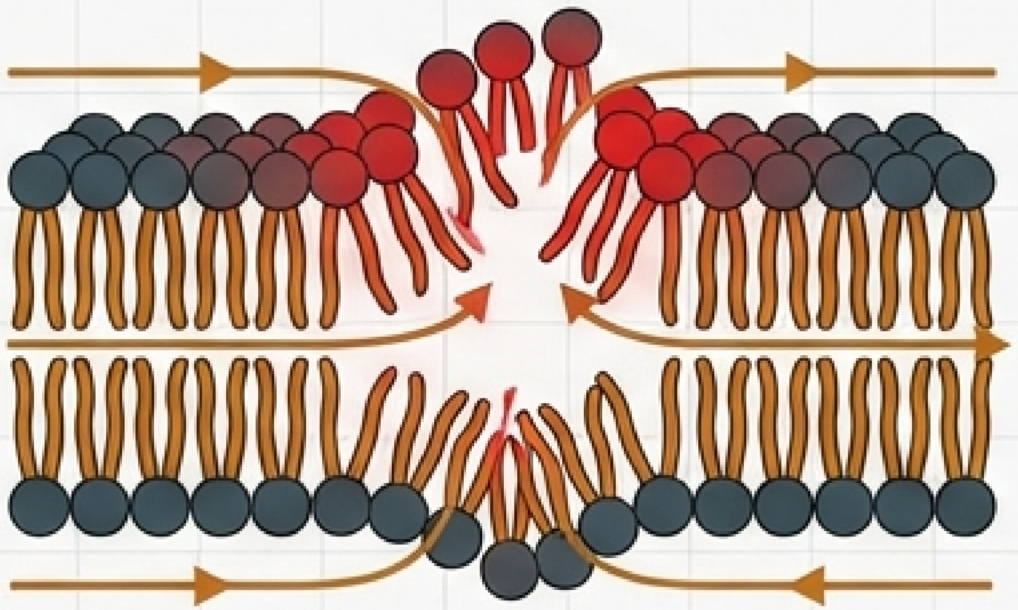
The Phenomenon

Partially Reversible Breakdown: Skin resistance drops rapidly under stimulatis but recovers when the stimulus is removed.

This dynamic behavior means safety models cann’t treat the body as a static resistor.

The Mechanics

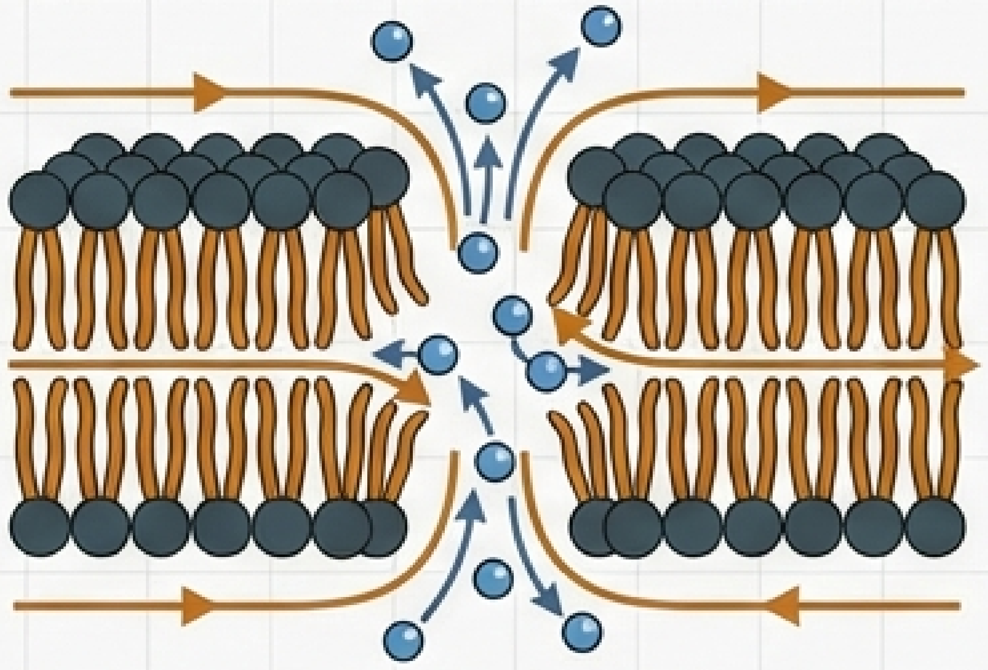
Dry Skin / Structural Rupture



Dry Skin / Structural Rupture

Rupture of lipid bilayer membranes.

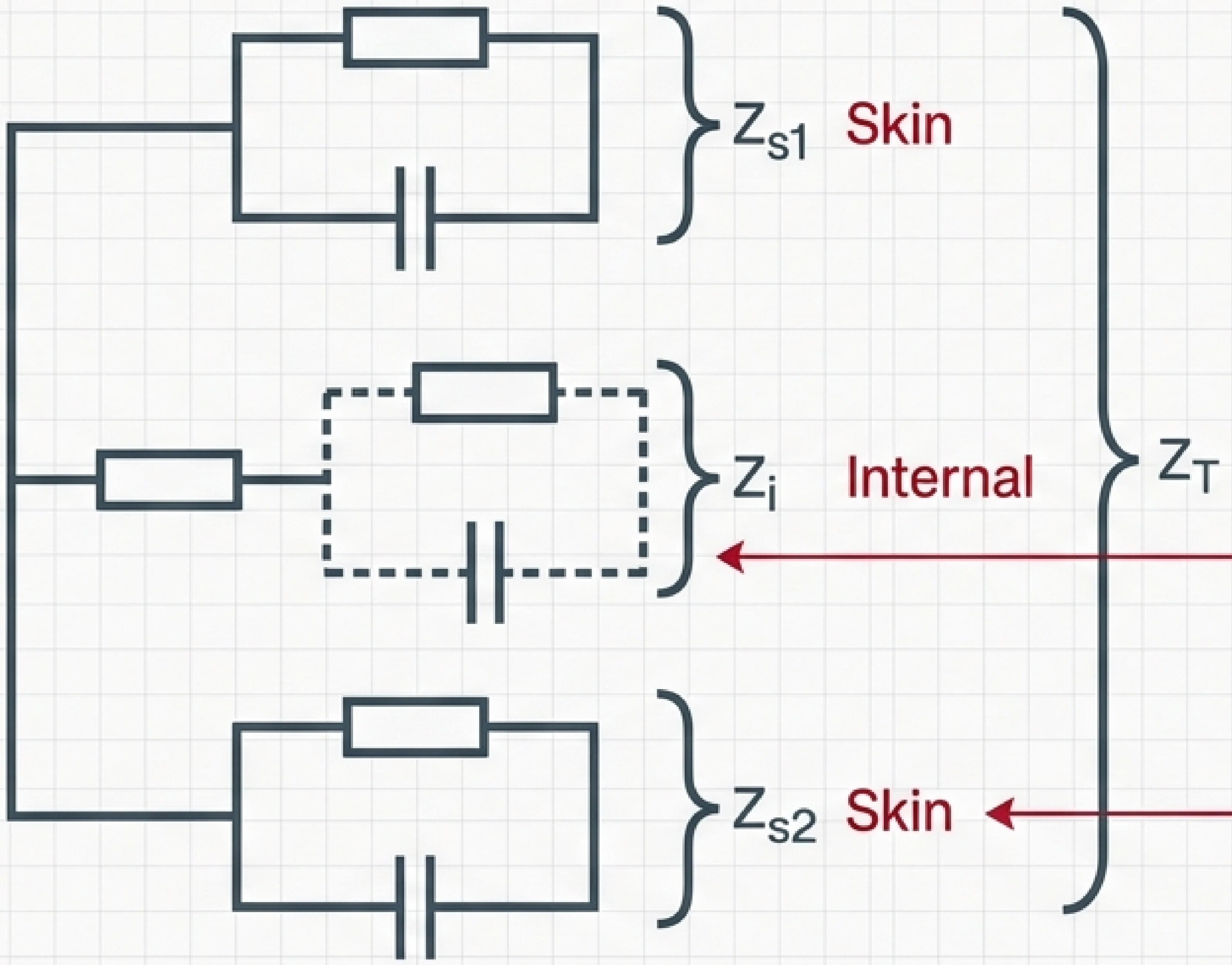
Wet Skin / Electro-osmosis



Wet Skin / Electro-osmosis

Asymmetric flow driven by electrical field.

Quantifying the Hazard: IEC 60479-1

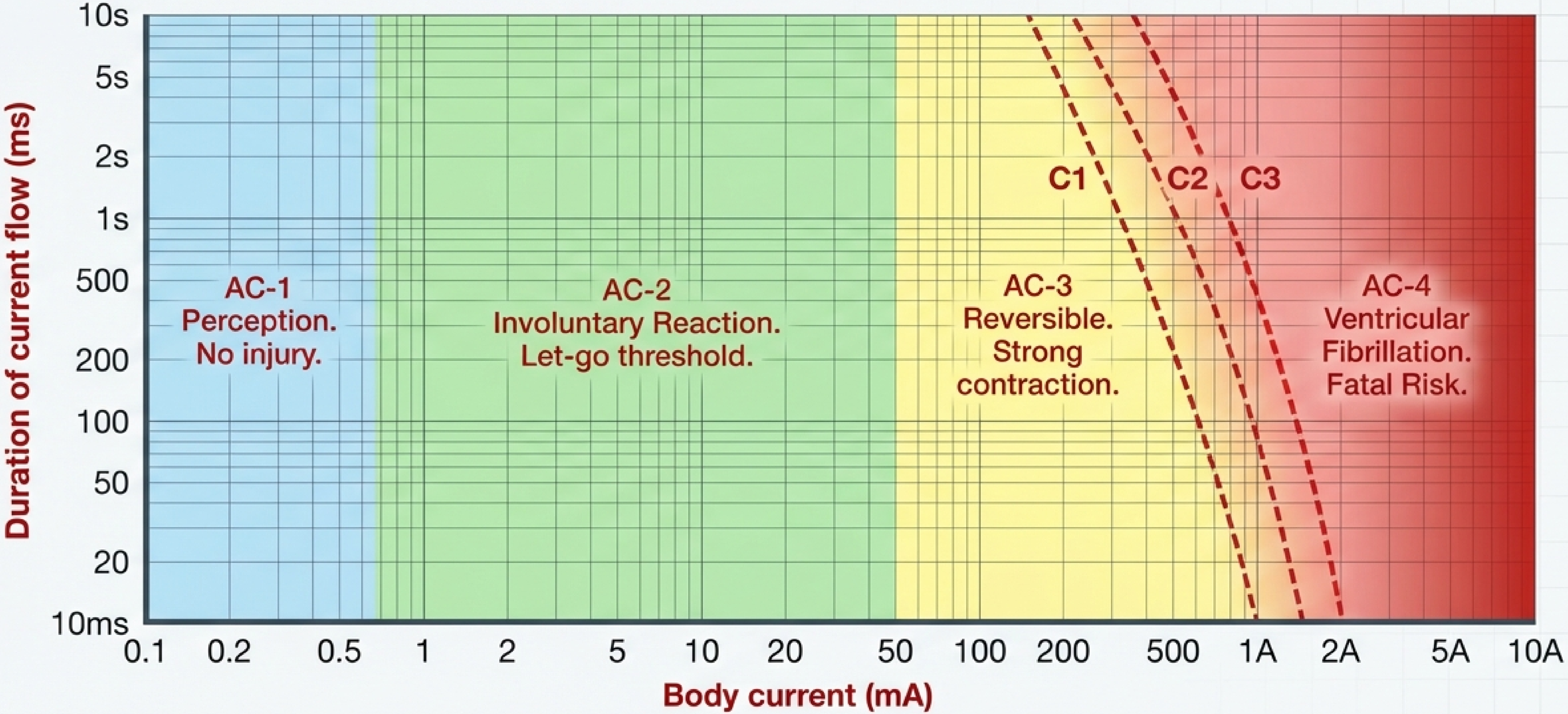


Total Impedance (Z_T)
= Skin (Z_s)
+ Internal (Z_i)
+ Internal (Z_i)
+ Skin (Z_s)

Internal Impedance. Primarily resistive. ~500 Ω.

Skin Impedance. Network of resistance and capacitance. Highly variable.

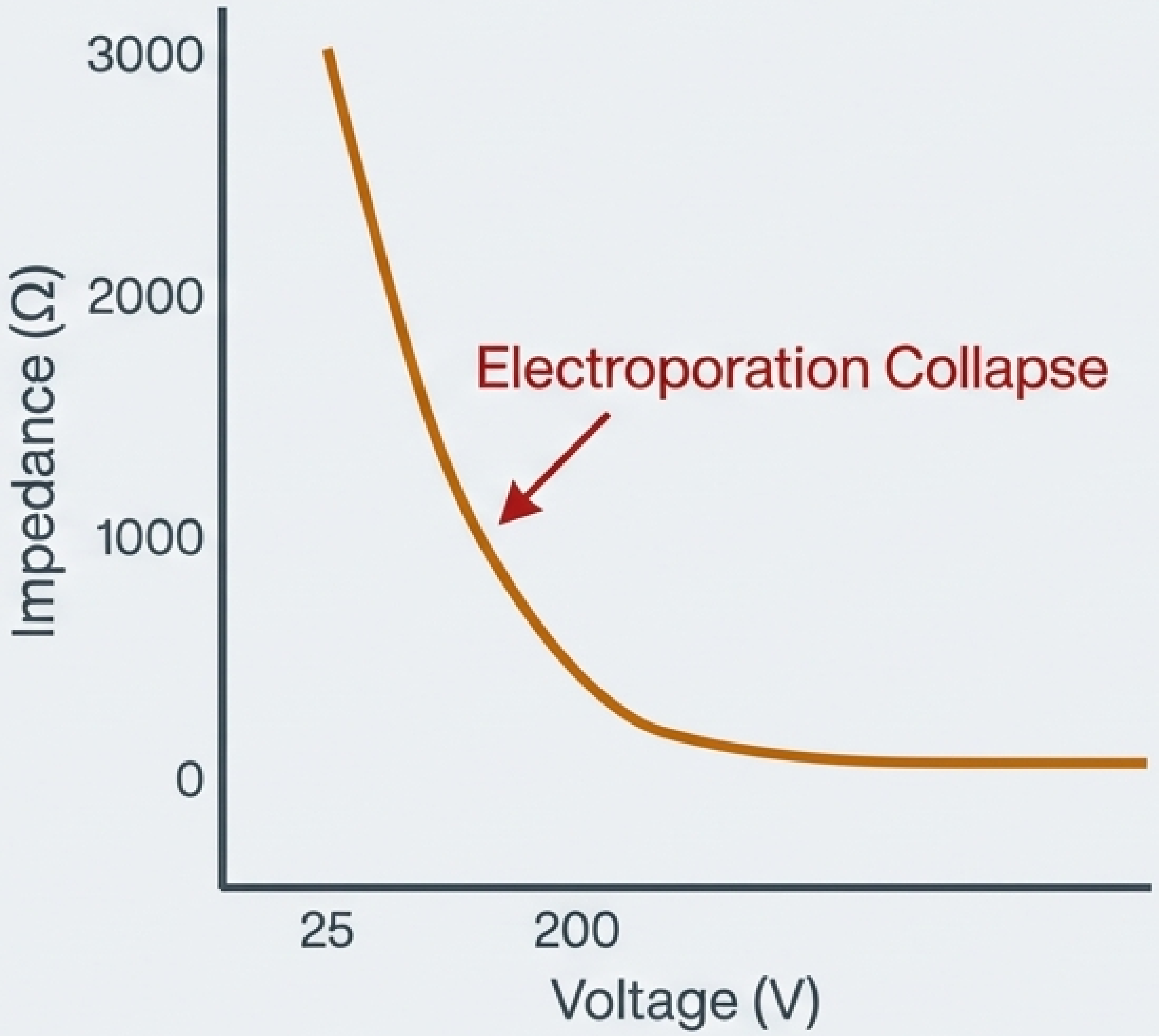
Time/Current Zones of Effects



Danger increases as exposure time (vertical) or current magnitude (horizontal) increases.

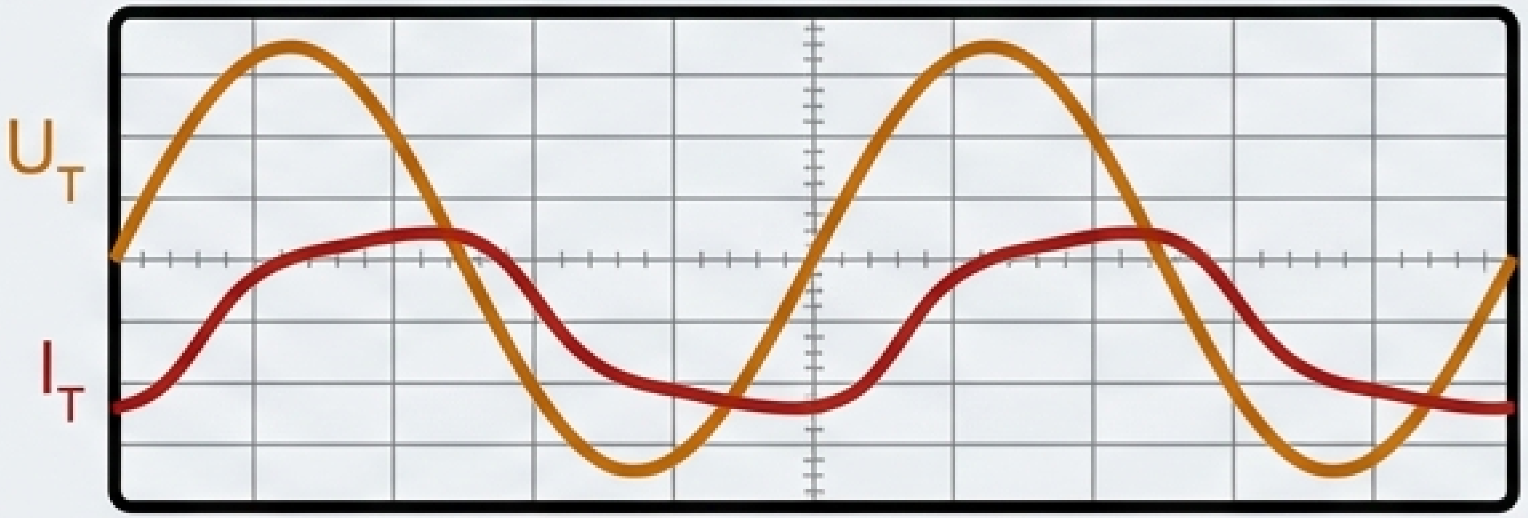
Variables of Impedance

Voltage Dependence



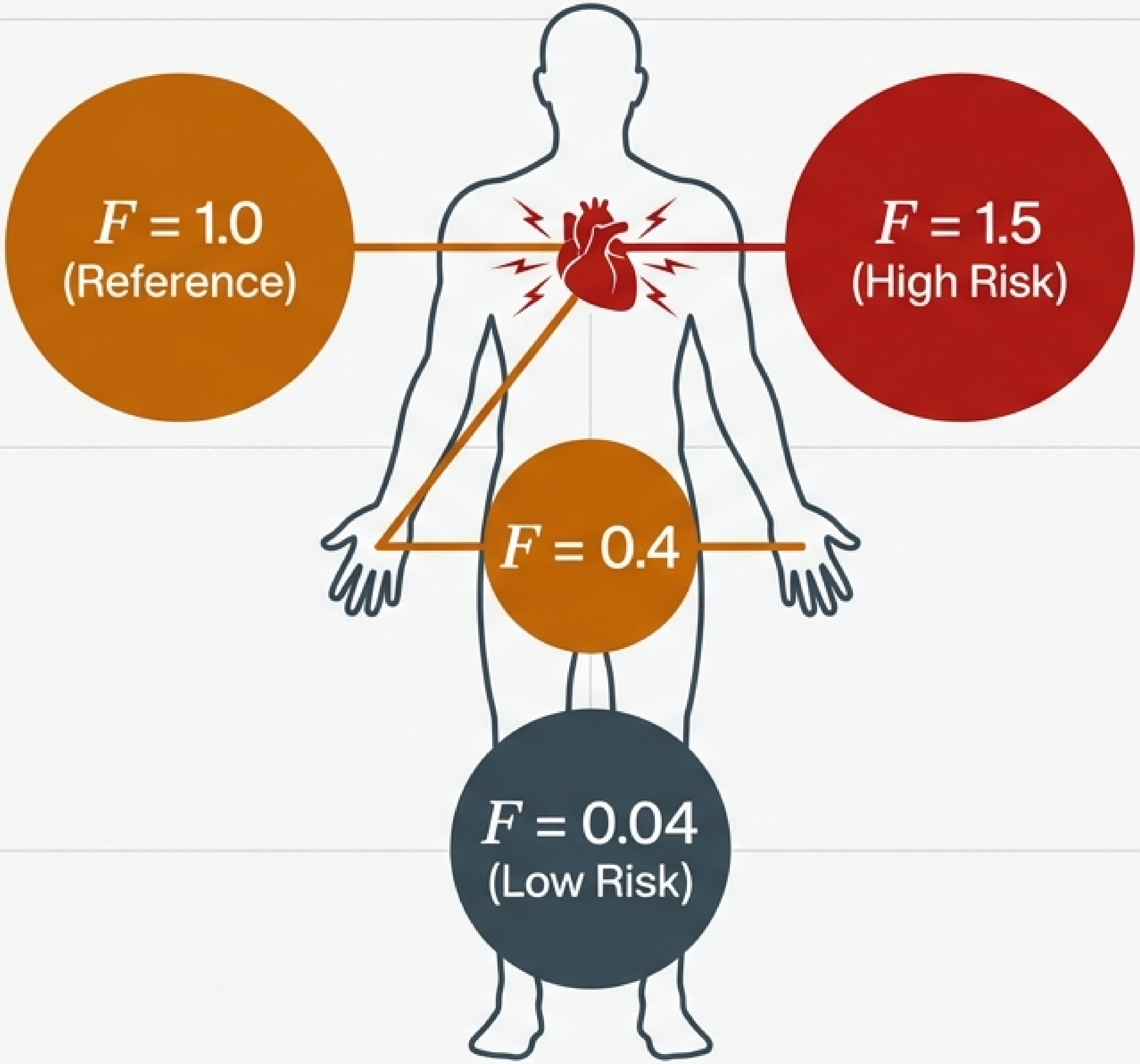
Moisture Factor

Oscillogram of Touch Voltage



At high voltages (>200V), skin impedance collapses effectively to zero, leaving only internal body resistance.

The Heart Current Factor (F)

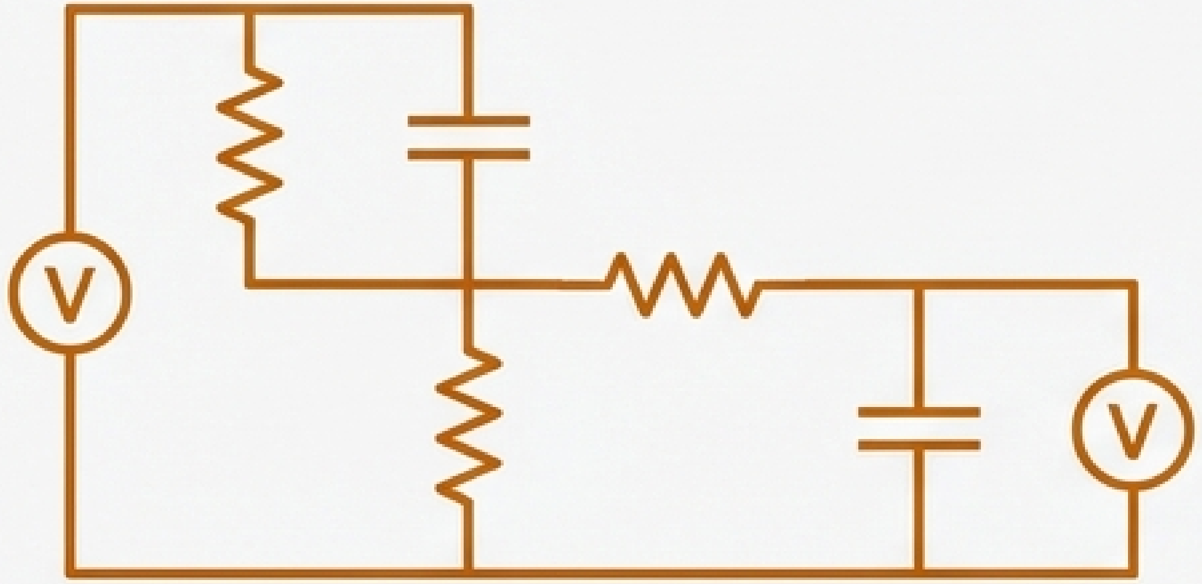


$$I_h = \frac{I_{ref}}{F}$$

Equivalent Danger Current = Reference Current divided by Heart Current Factor

The Limits of Physical Testing

The Past



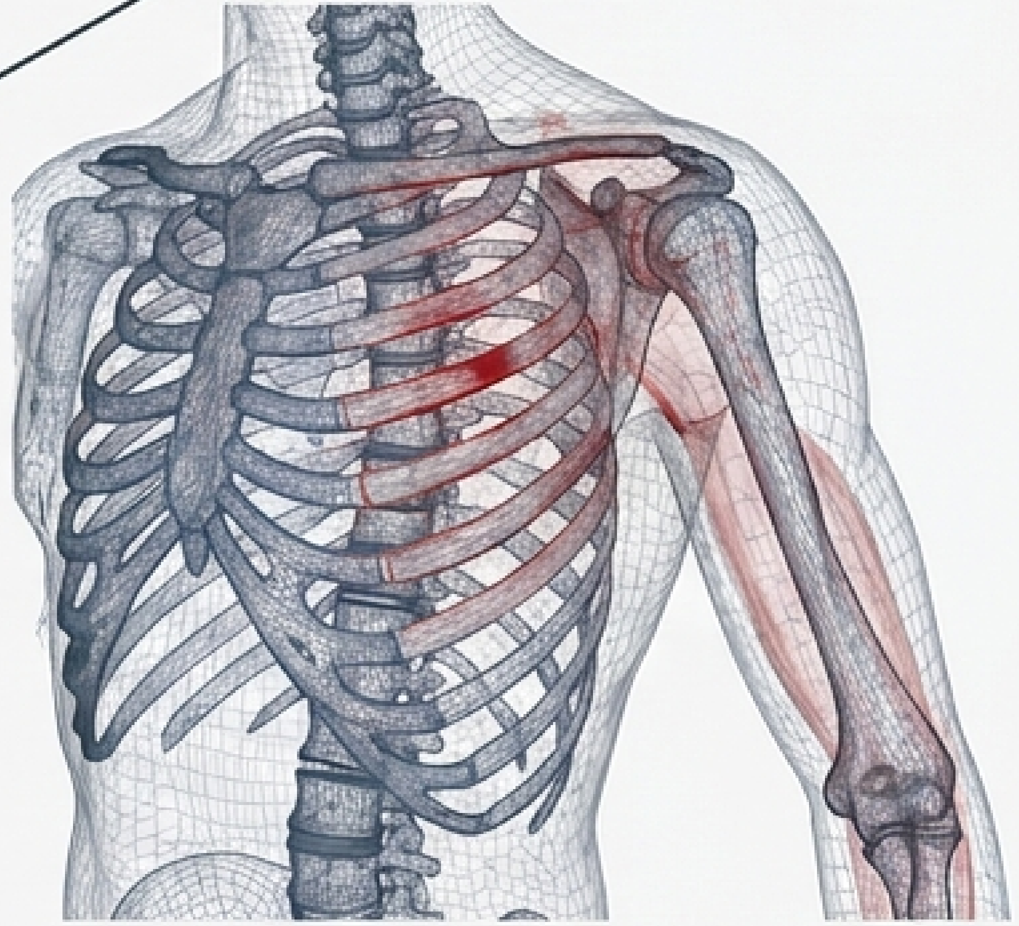
The Past

Lumped Parameter Model

Cannot account for organ geometry.
Derived from animal/corpse data.

We cannot shock live humans to death to test safety standards. We must rely on the transition from empirical estimation to **anatomical simulation**.

The Future

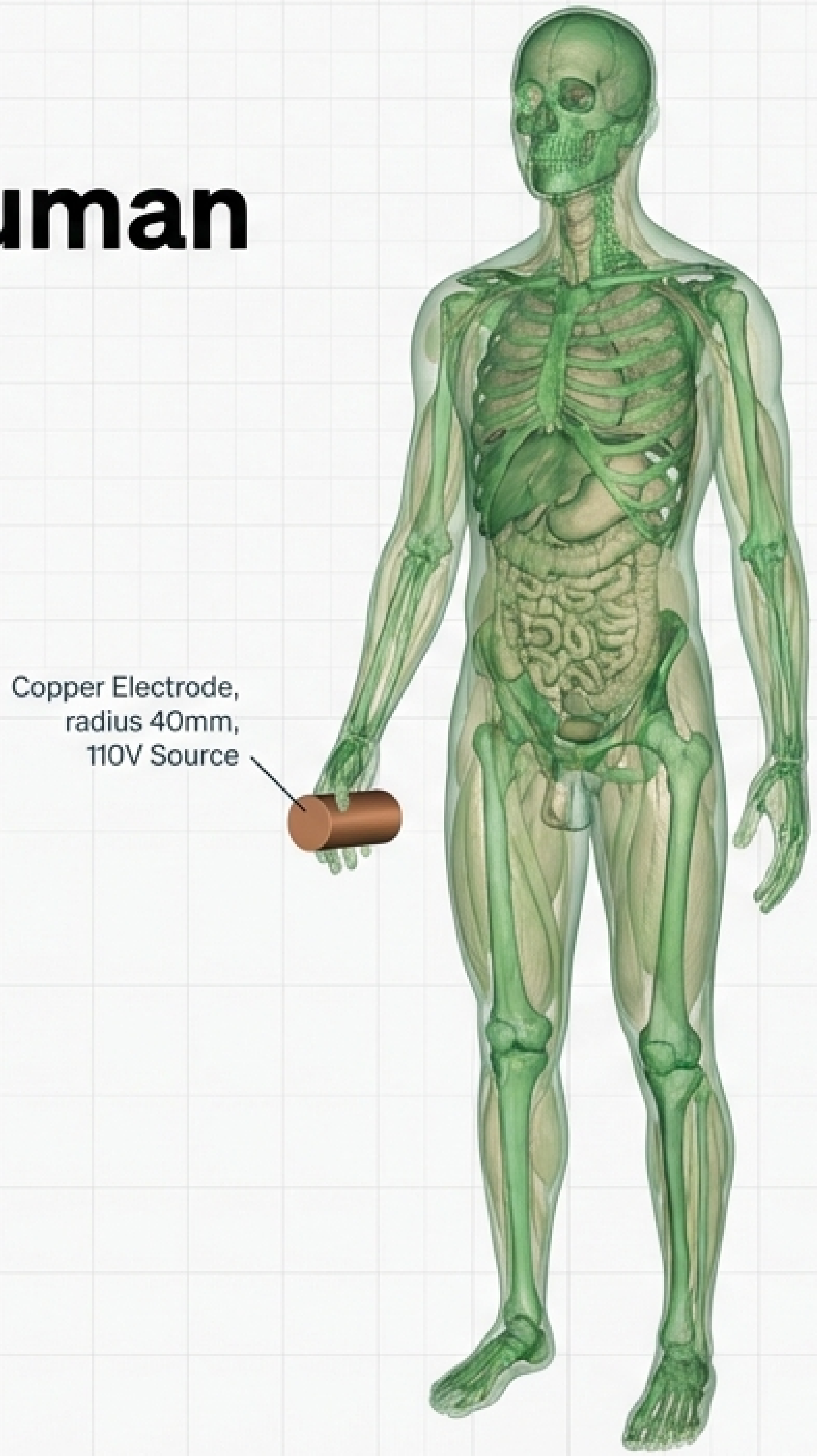


The Future

Computational Electro-pathology

3D Electromagnetic solving.
300+ tissue types.
0.5mm resolution.

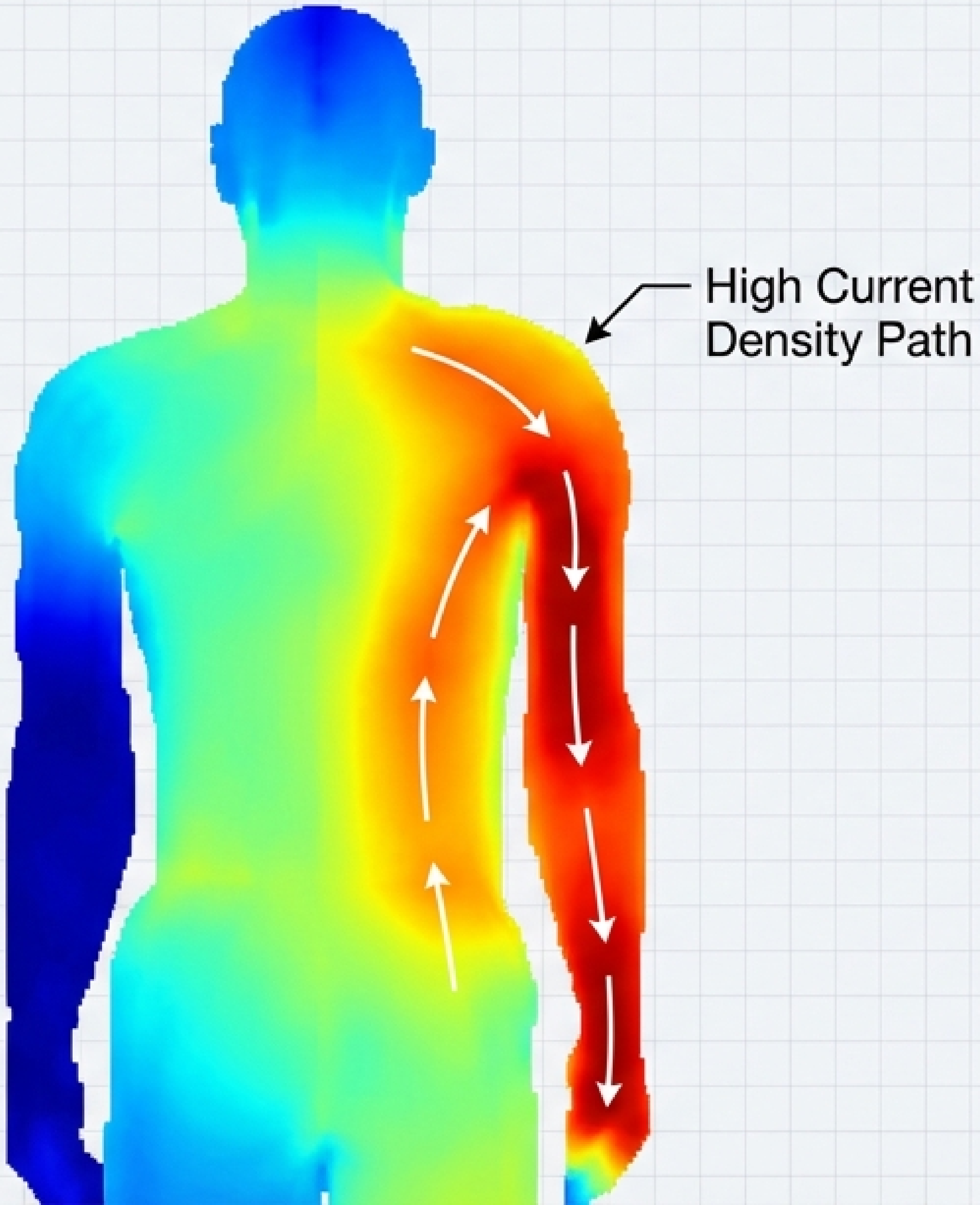
Meet ‘Duke’: The Virtual Human

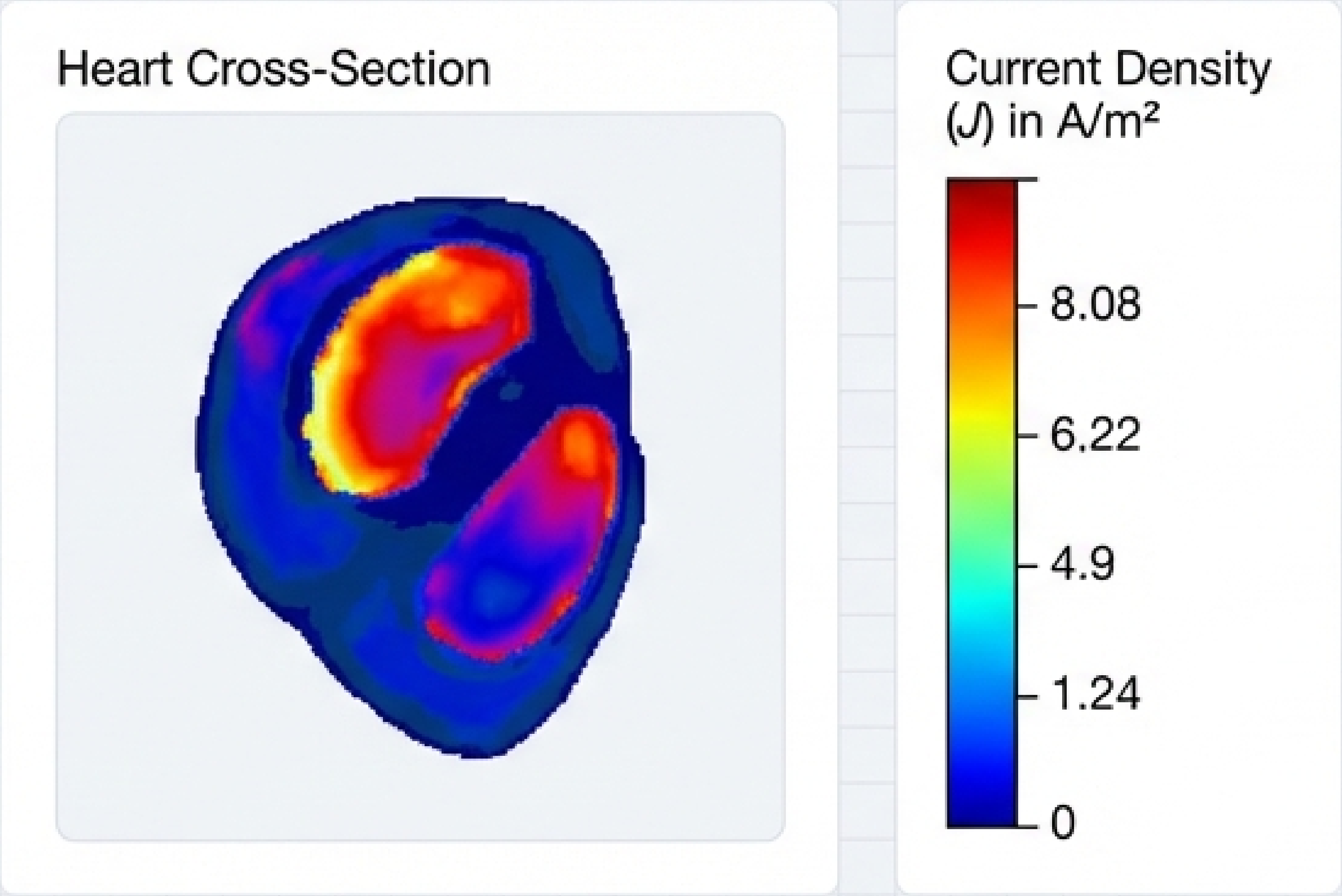


Spec Sheet

- Model: Duke (IT'IS Foundation)
- Resolution: 0.5 mm × 0.5 mm × 0.5 mm voxels.
- Anatomy: 300+ identified tissues and organs.
- Physics: Full 3D Maxwell’s Equations solver.
- Tissue Properties: Assignable conductivity and permittivity for muscle, fat, bone, and blood.

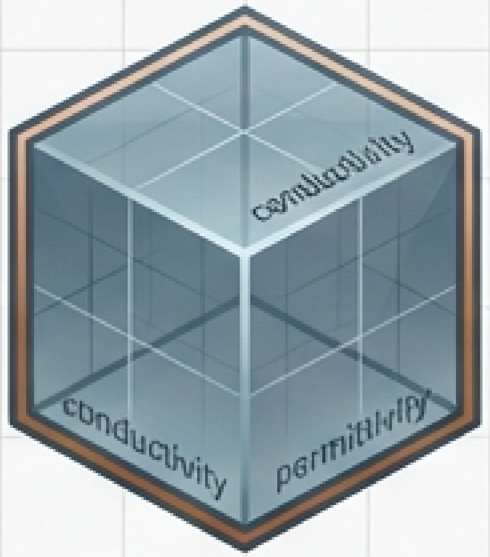
Visualizing the Invisible





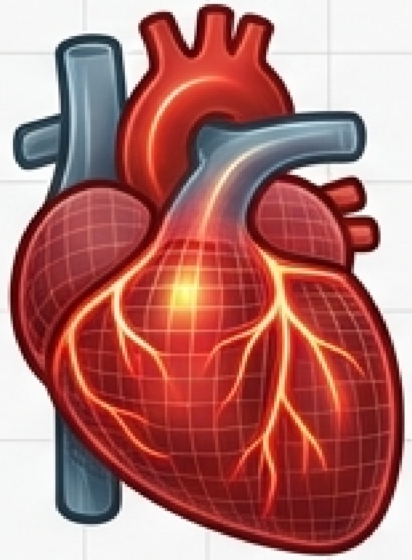
Current is not uniform. High density (J) concentrates along the path of least resistance through the arm and torso. At high frequencies, permittivity becomes a major factor alongside resistivity.

Calculating HCF via Simulation



Step 1
Assign Tissue Properties

Step 2
Apply 110V Source



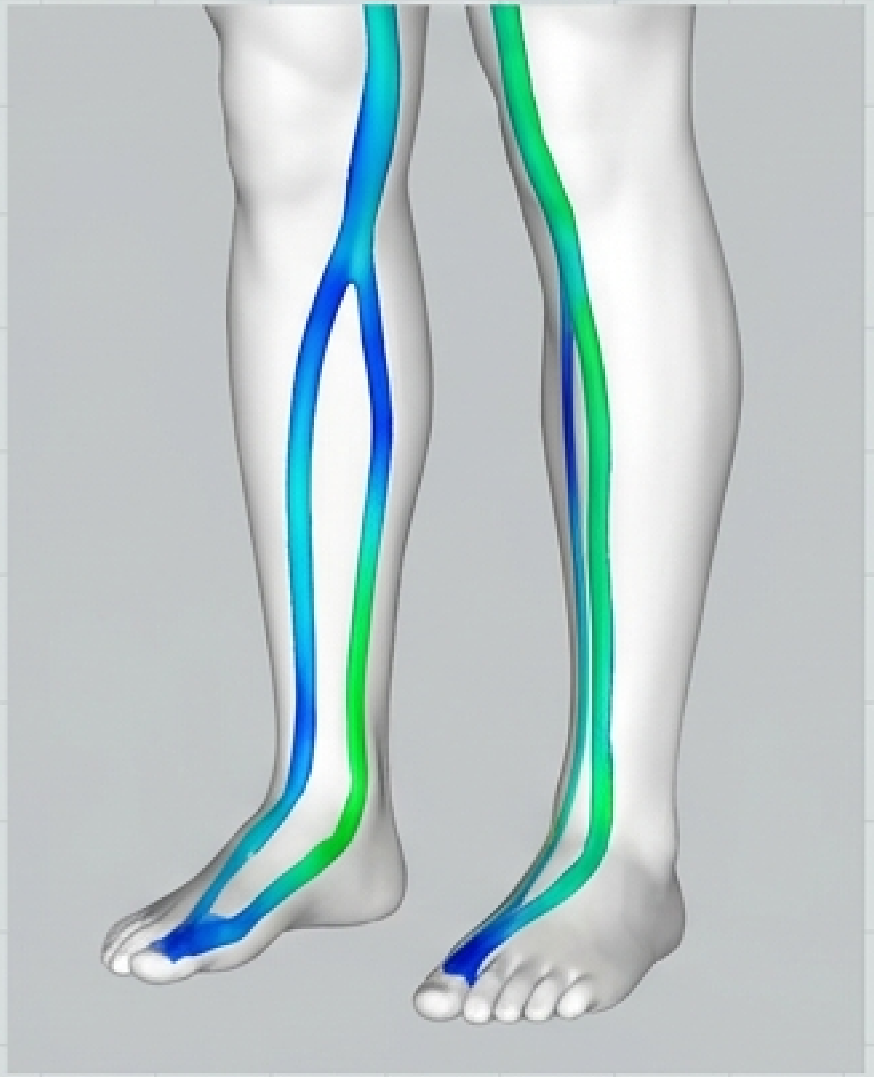
Step 3
Measure Max Current Density (J) on Heart

$$F = \frac{J_{\text{path}}}{J_{\text{ref}}} \times \text{Impedance Correction}$$

The Goal: Validate if the IEC standard numbers derived decades ago match the high-fidelity physics of modern simulation.

The Verdict: Where Models Align

	IEC	UL Simulation	
Left Hand to Feet (Reference)	1.0	1.0	✓
Left Foot to Right Foot	0.04	0.01	✓



The simulation confirms that foot-to-foot shocks are extremely low risk for ventricular fibrillation. Current bypasses the heart, aligning closely with established standards.

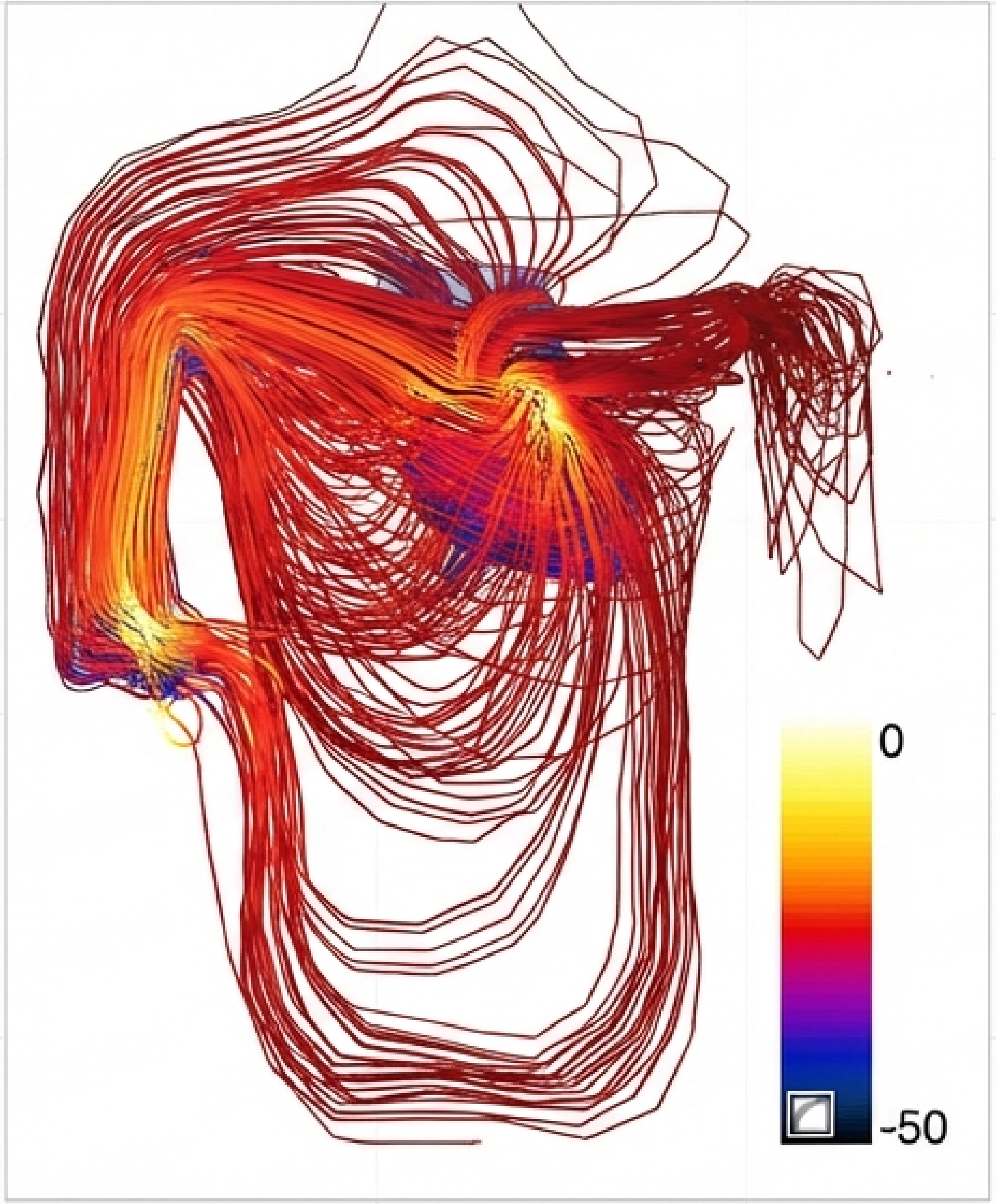
The Verdict: Significant Deviations

Passway	IEC	UL Simulation
Left Hand to Right Hand	0.4	1.0

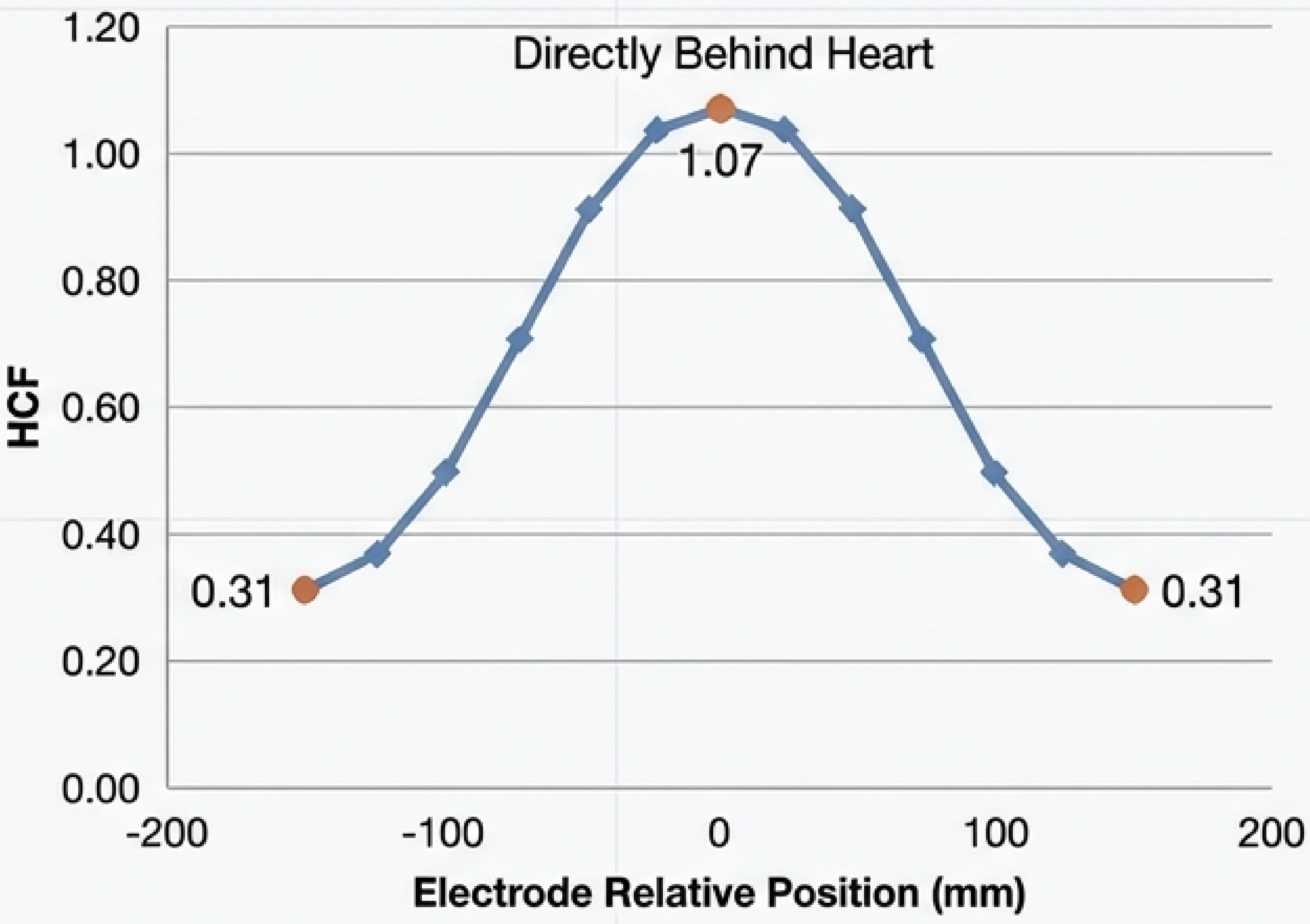
Simulation suggests equal risk to reference path.

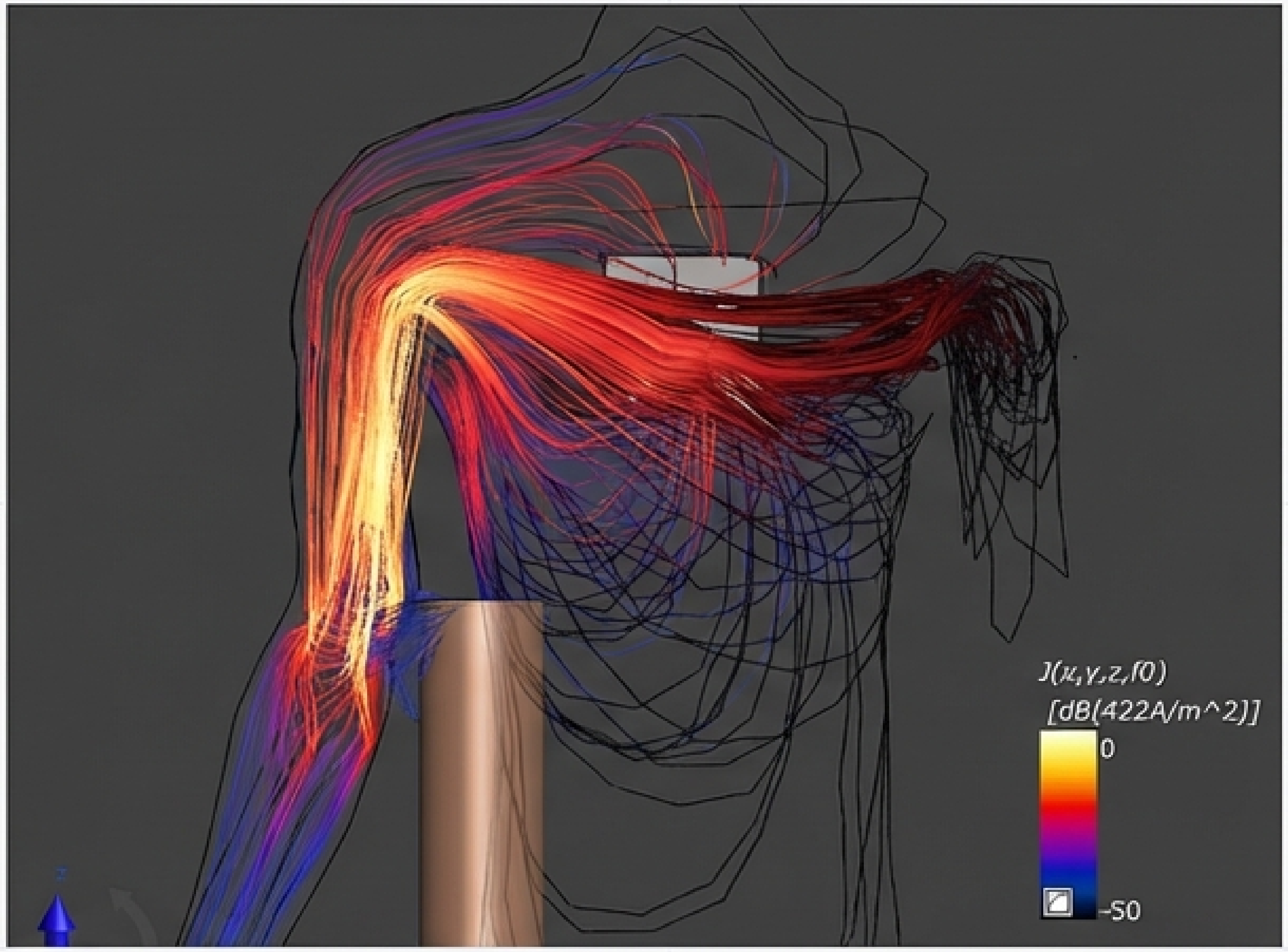
Chest to Left Hand Crimson Pro	1.5	2.0

Direct chest contact is more dangerous than predicted.



Sensitivity Analysis: The Geometry of Danger



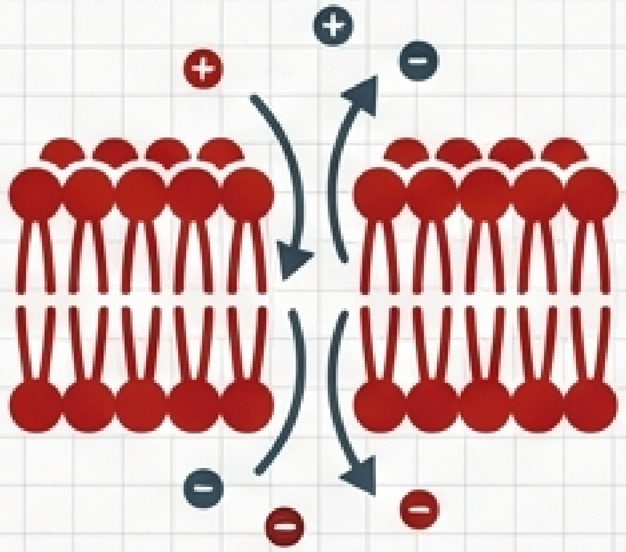


Moving the electrode by mere millimeters drastically changes the risk. The IEC standard (0.3) aligns with the 'best case' edge placement. Simulation reveals 'worst case' placement is 3x more dangerous (1.07).

Crimson Pro vieled allimetrer Paps White, #F9F9F9, Laboratory Grey

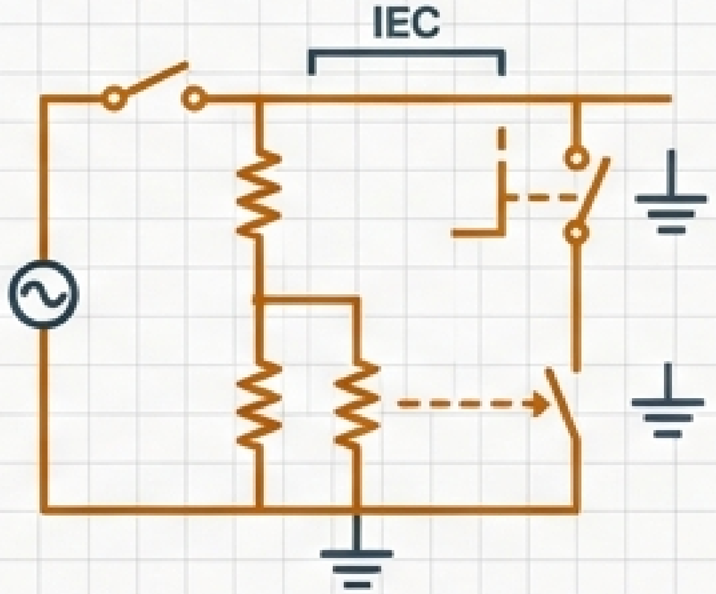
The Future of Electrical Safety

Micro



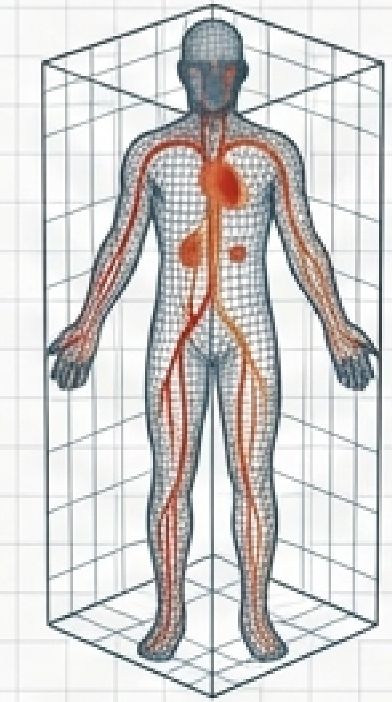
Understanding cell membrane electroporation

Macro



Robust, conservative industry standards

Virtual



High-fidelity simulation reveals hidden risks

The convergence of biological understanding and computational power allows us to visualize the invisible, making the invisible danger of electricity quantifiable and safer for everyone.