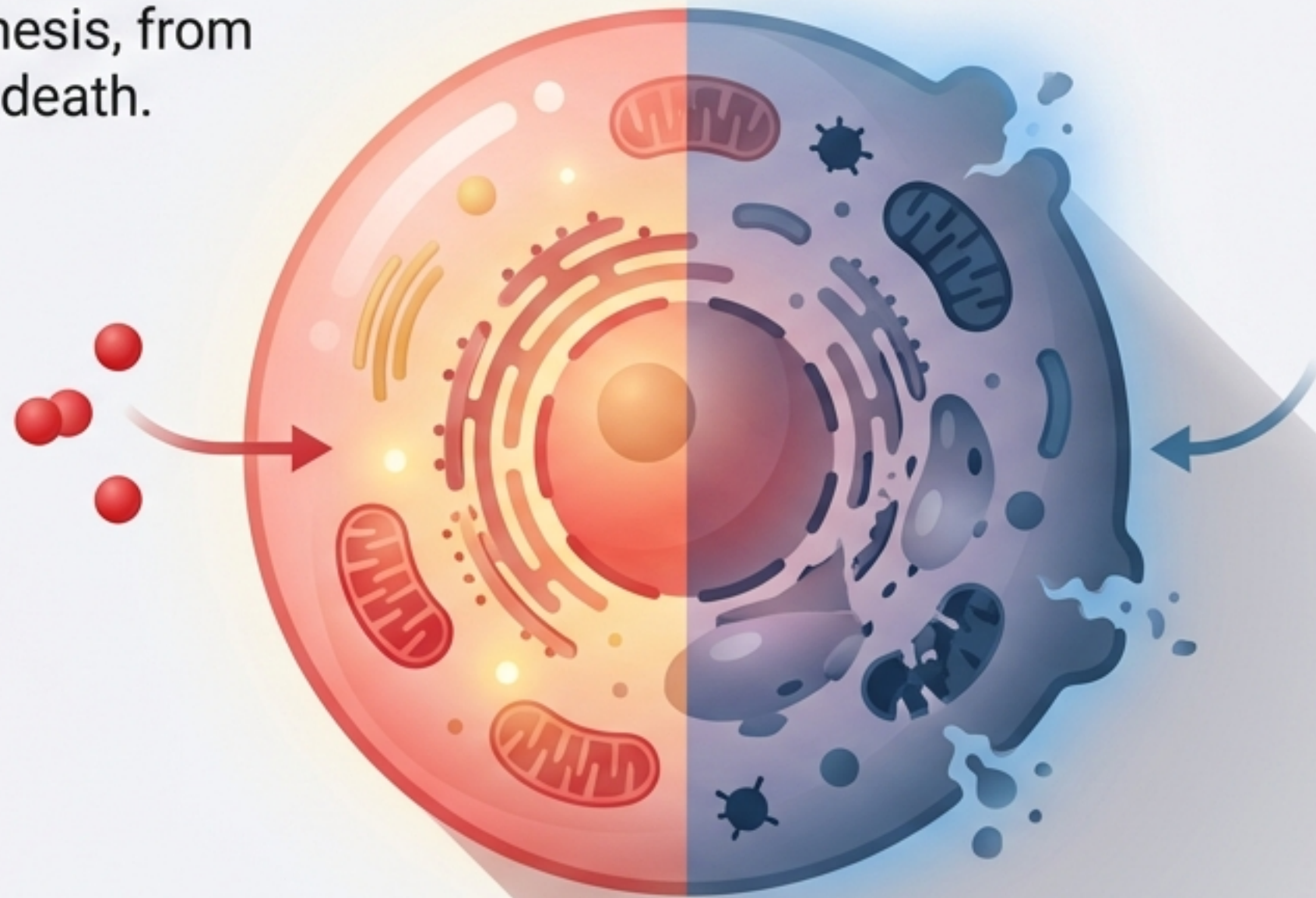


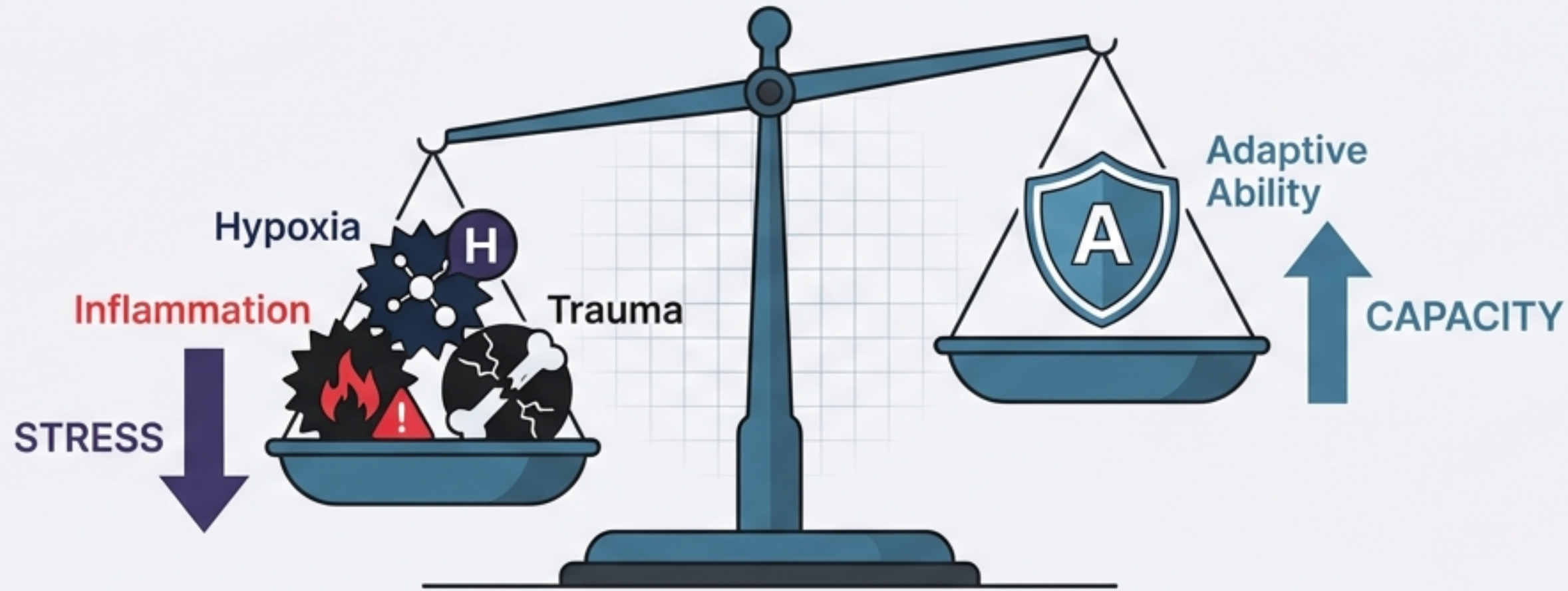
Cellular Injury & Hypoxia: The Siege of the Cell

A visual guide to pathogenesis, from oxygen deprivation to cell death.



Based on Fundamentals of Pathological Cellular Injury

Injury Occurs When Stress Exceeds Adaptation



Susceptibility



High Risk

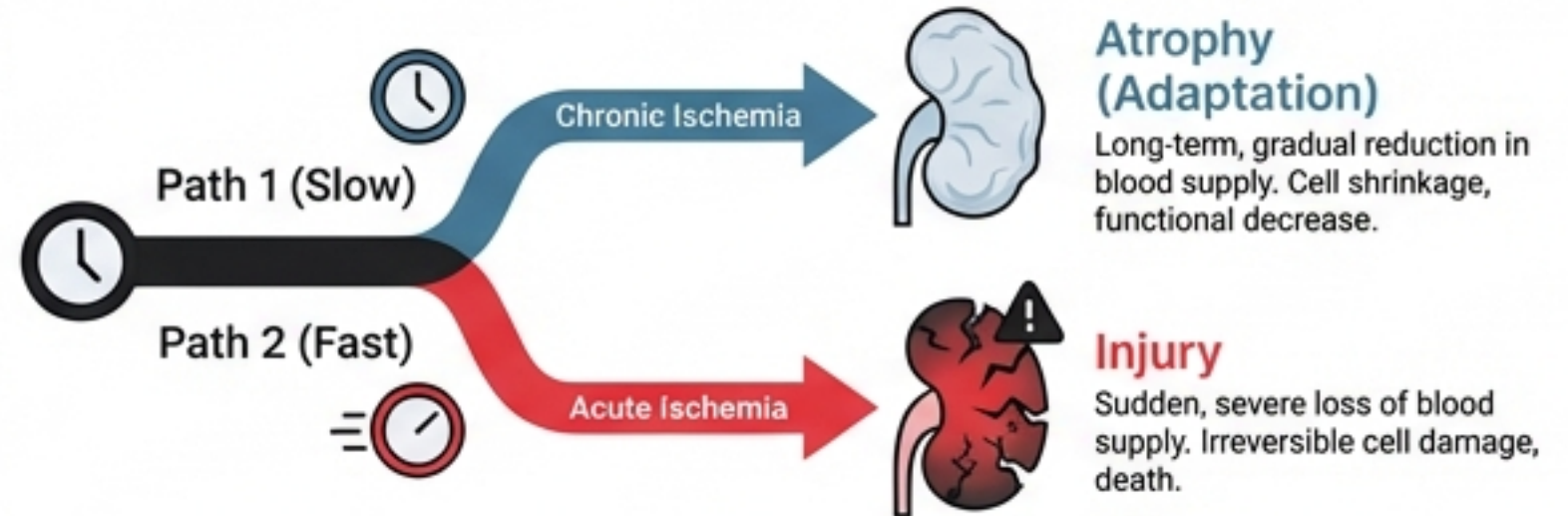
Neurons, cardiac muscle
(minimal regenerative capacity)



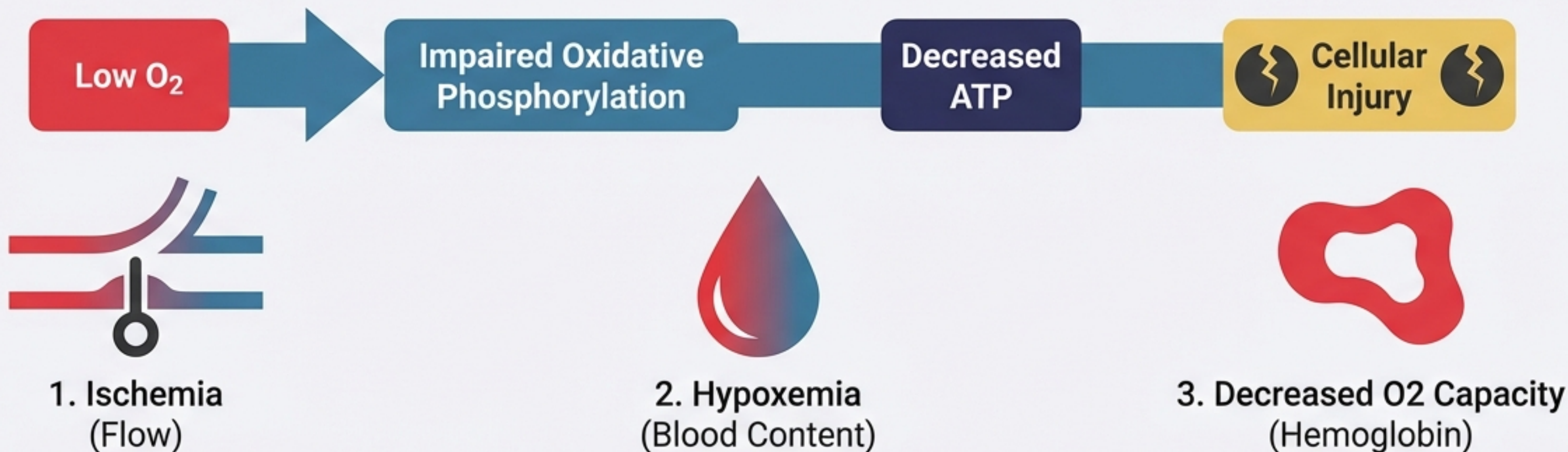
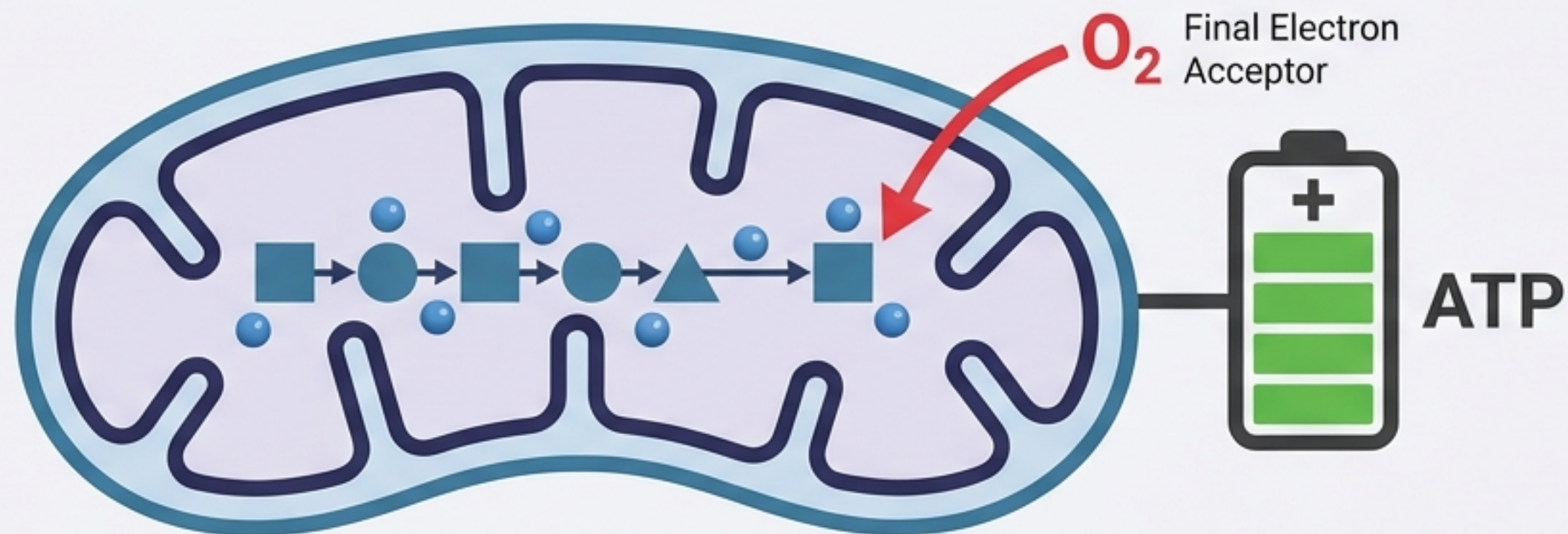
Resistant

Skeletal muscle, fibroblasts
(high regenerative capacity)

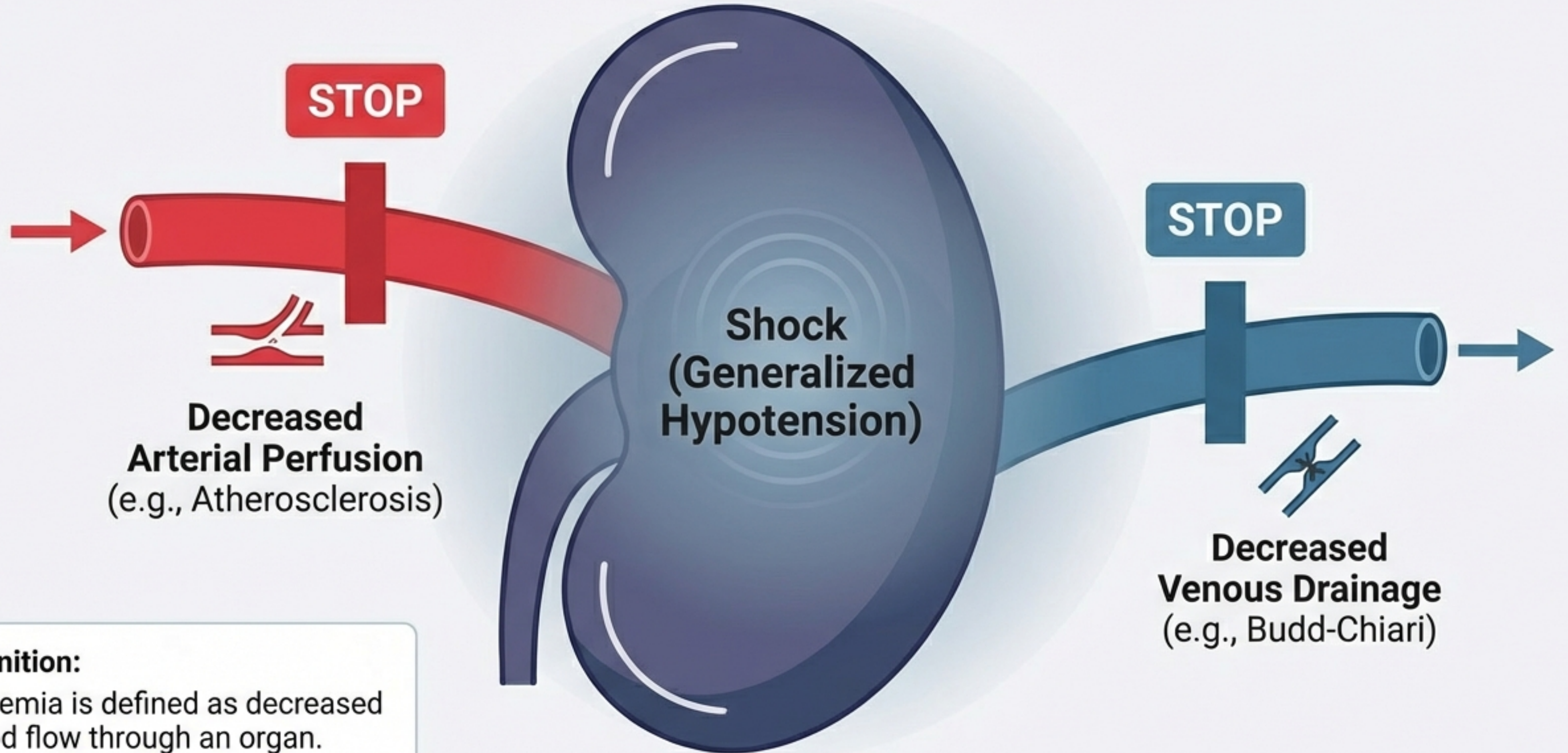
The Time Factor



Hypoxia Targets the Power Plant



Ischemia: A Failure of Perfusion



Definition:

Ischemia is defined as decreased blood flow through an organ.

Hypoxemia: Low Partial Pressure

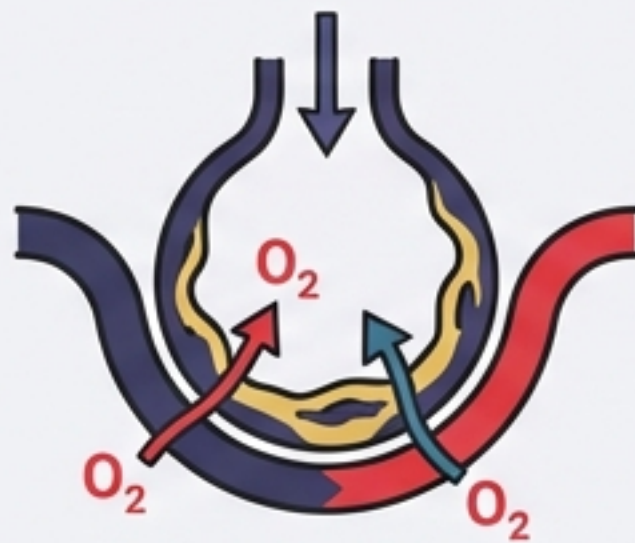
Defined as $PaO_2 < 60$ mm Hg and $SaO_2 < 90\%$



High Altitude (Low Barometric Pressure)



Hypoventilation (High CO_2 displaces O_2)

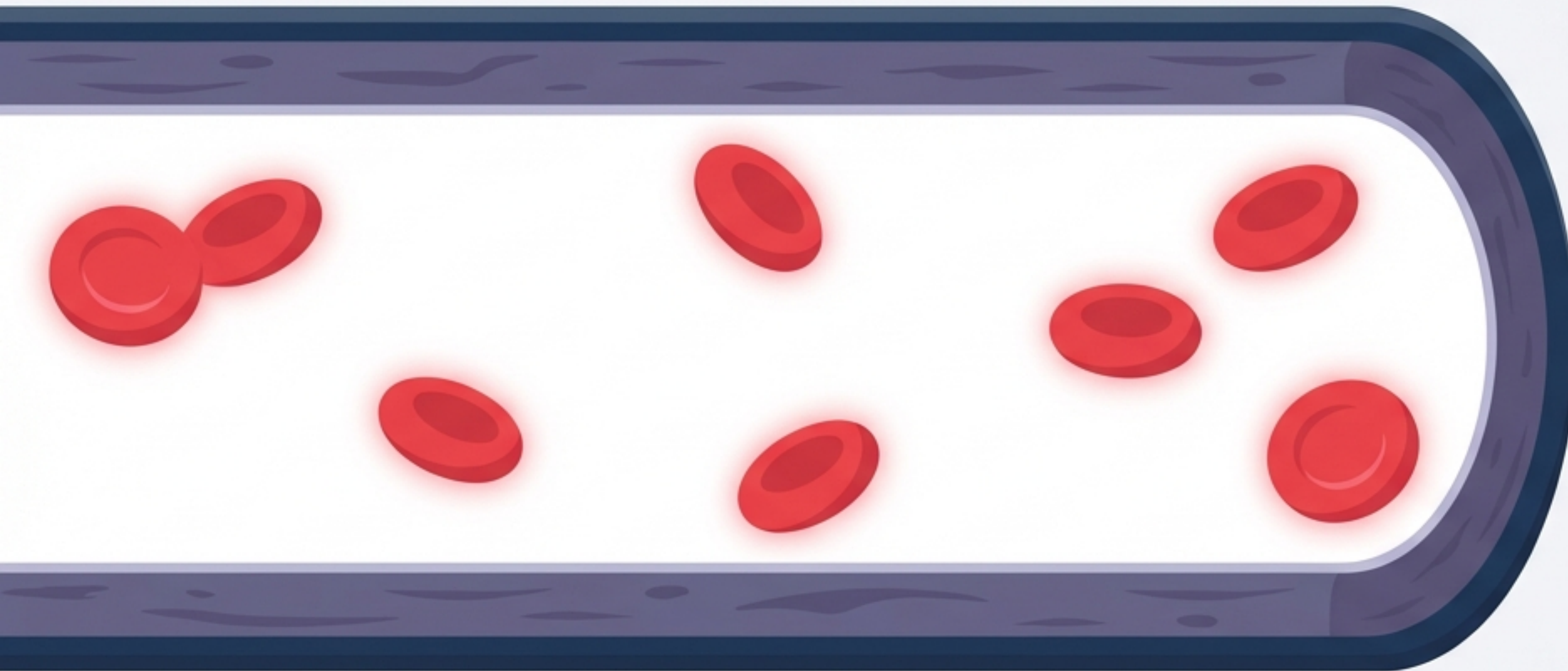


Diffusion Defect (Fibrosis blocks transfer)



V/Q Mismatch

Anemia: Reduced Carrying Capacity



Helvetica Now Display

**PaO₂:
Normal**

Roboto

**SaO₂:
Normal**

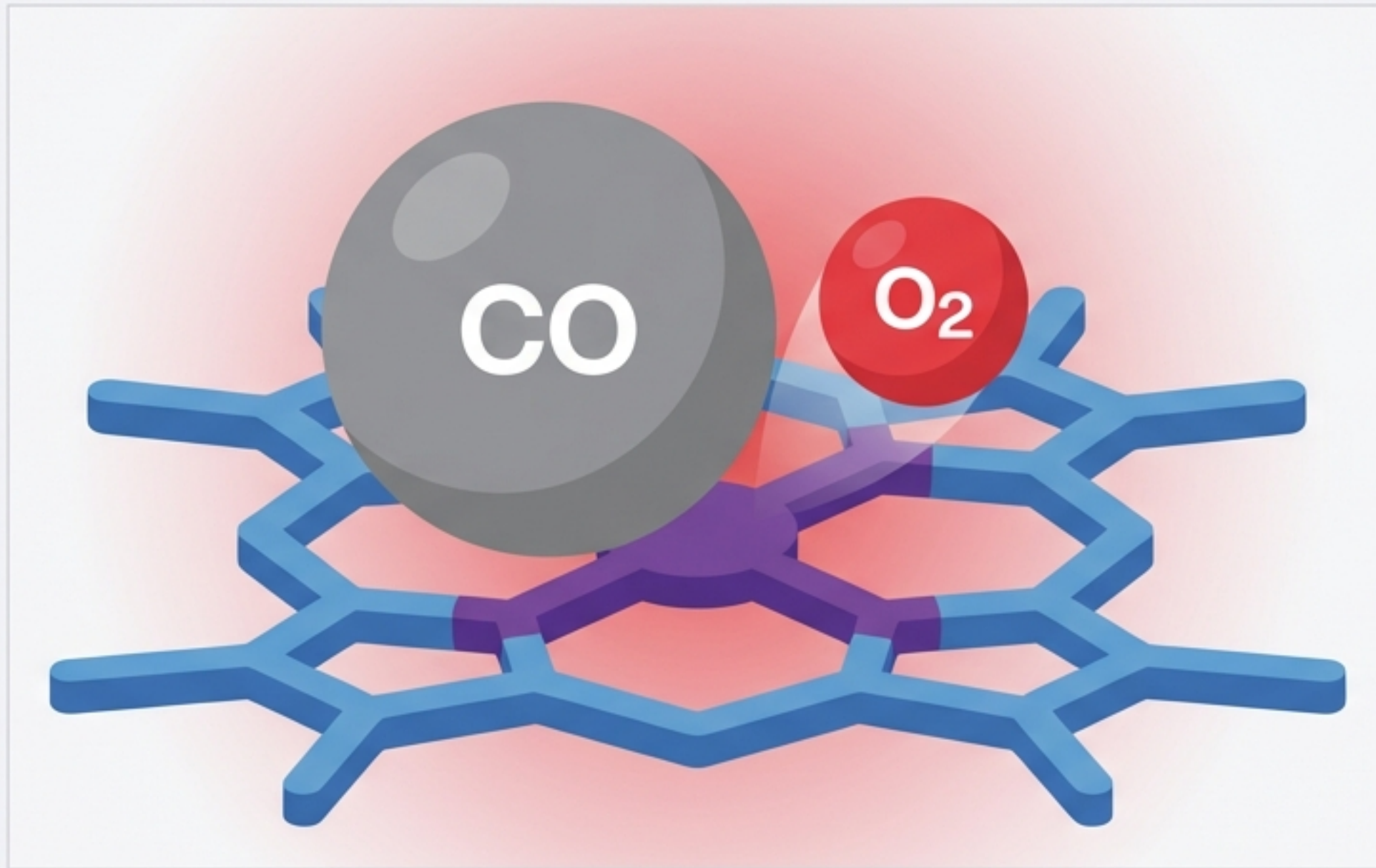
Roboto

Total O₂ Content:

LOW

Arterial Red (#E63946)

Carbon Monoxide: The Silent Competitor



PaO₂: Normal

SaO₂: DECREASED

(CO binds 200x stronger)

Clinical Notes

- **Sign:** Cherry-red skin
- **Symptoms:** Headache -> Coma
- **Source:** Smoke, Exhaust

Methemoglobinemia: The Iron Shift

Helvetica Now Display, Charcoal (#1D1D1F)



Normal Iron



Oxidized Iron



No O_2 Binding

Roboto, Arterial Red



Chocolate-colored Blood

PaO₂: Normal

Roboto

SaO₂: **DECREASED**

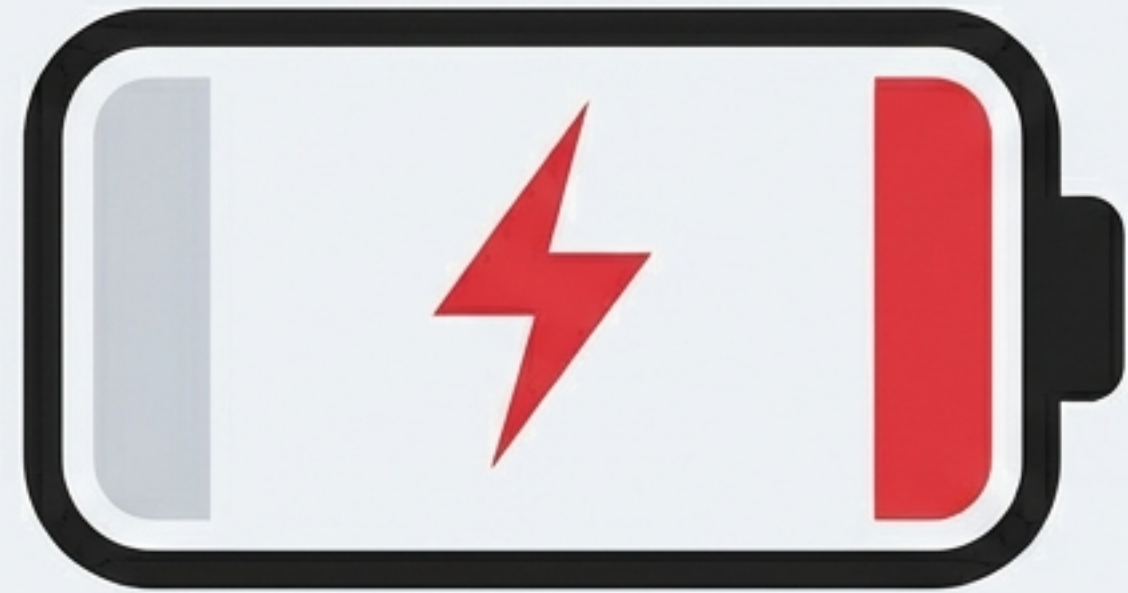
Clinical Notes

Helvetica Now Display

- **Sign:** Cyanosis with **Chocolate-colored blood**
- **Causes:** Sulfa/Nitrate drugs
- **Treatment:** IV **Methylene Blue** (Reduces Fe^{3+} back to Fe^{2+})

The Energy Crisis: ATP Depletion

Helvetica Now Display, Charcoal (#1D1D1F)



5% Charge

CRITICAL RED ZONE

Hypoxia



Oxidative Phosphorylation Fails



ATP Crash



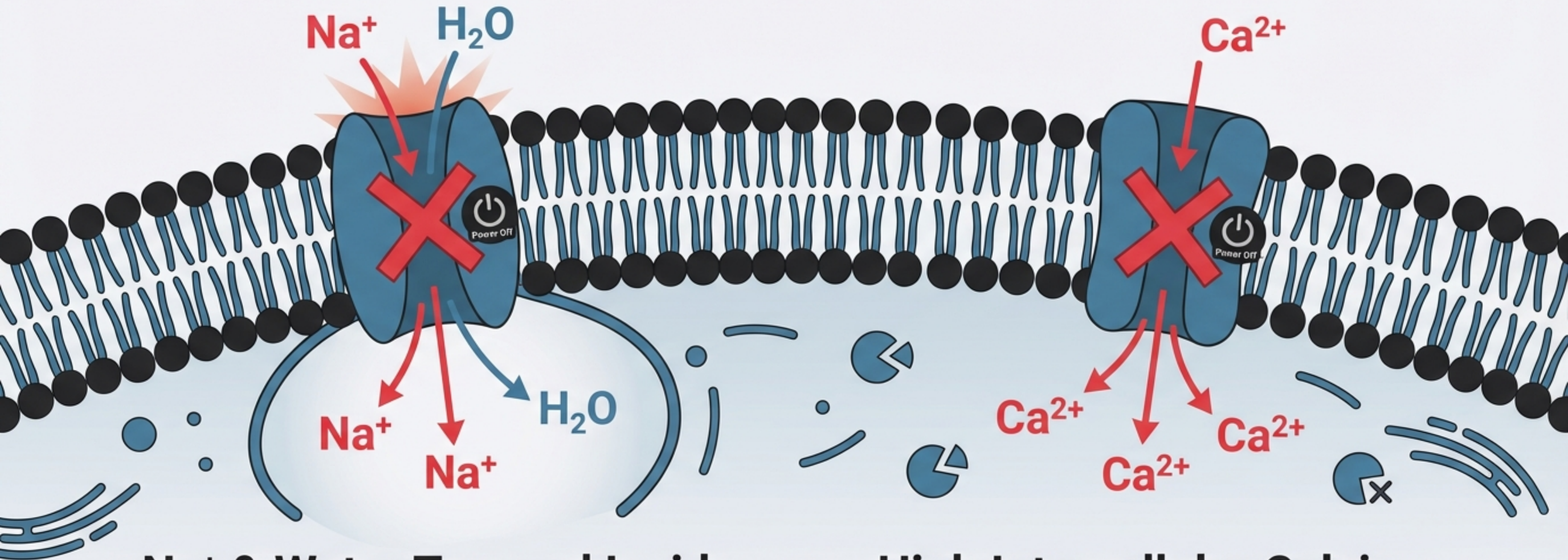
Switch to Anaerobic Glycolysis



**Lactic Acid Buildup
→ pH Drops**

Clumped/Precipitated DNA

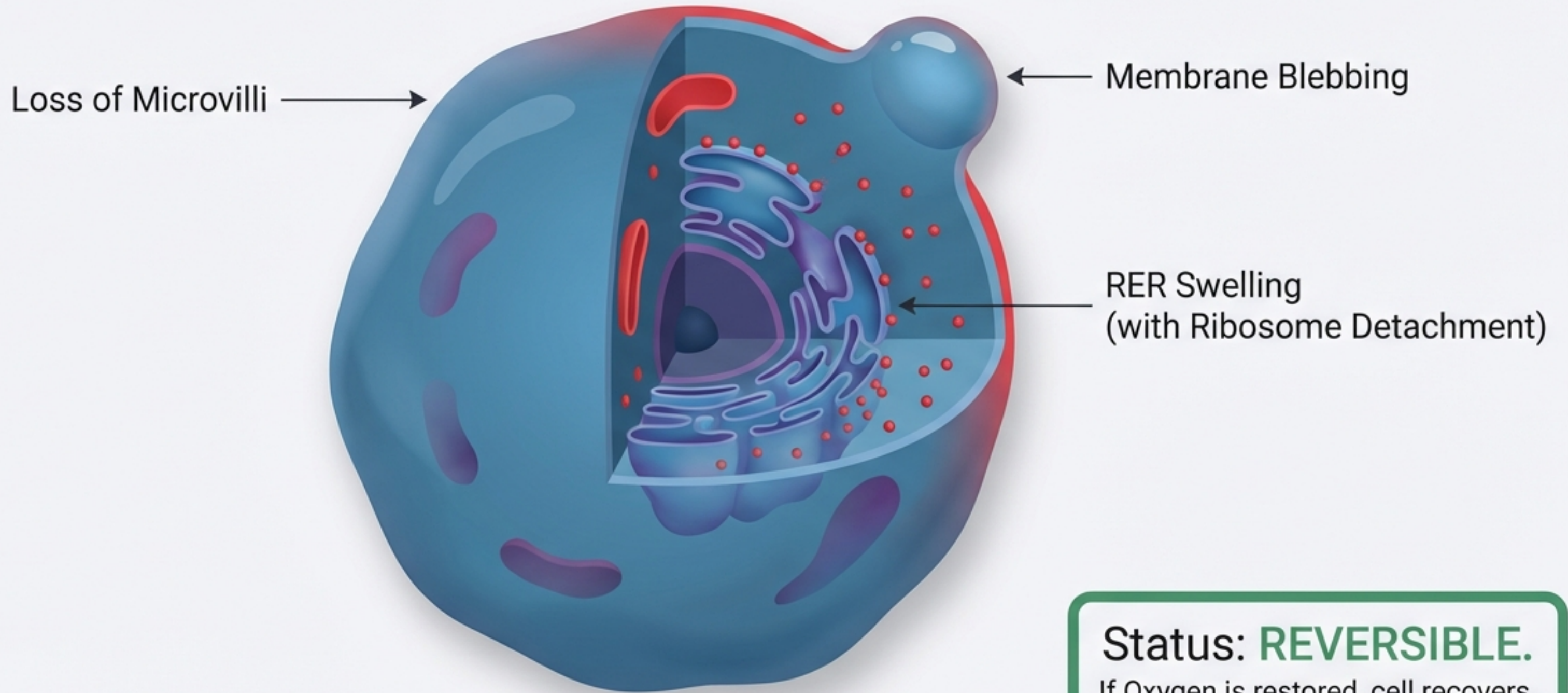
Systemic Failure: The Pumps Shut Down



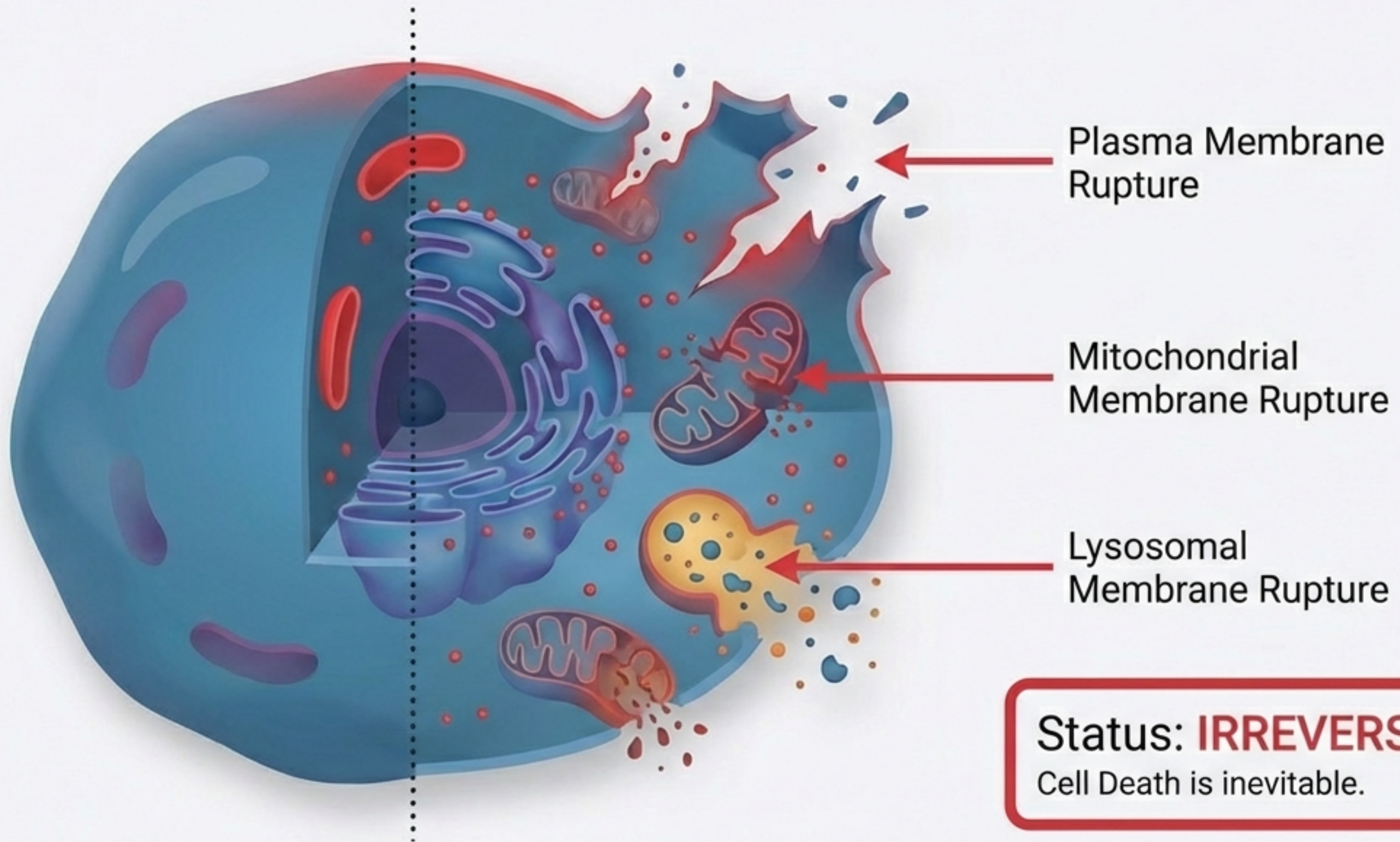
Na⁺ & Water Trapped Inside
→ **SWELLING**

High Intracellular Calcium
→ **ENZYME ACTIVATION**

Phase I Injury: Reversible Swelling

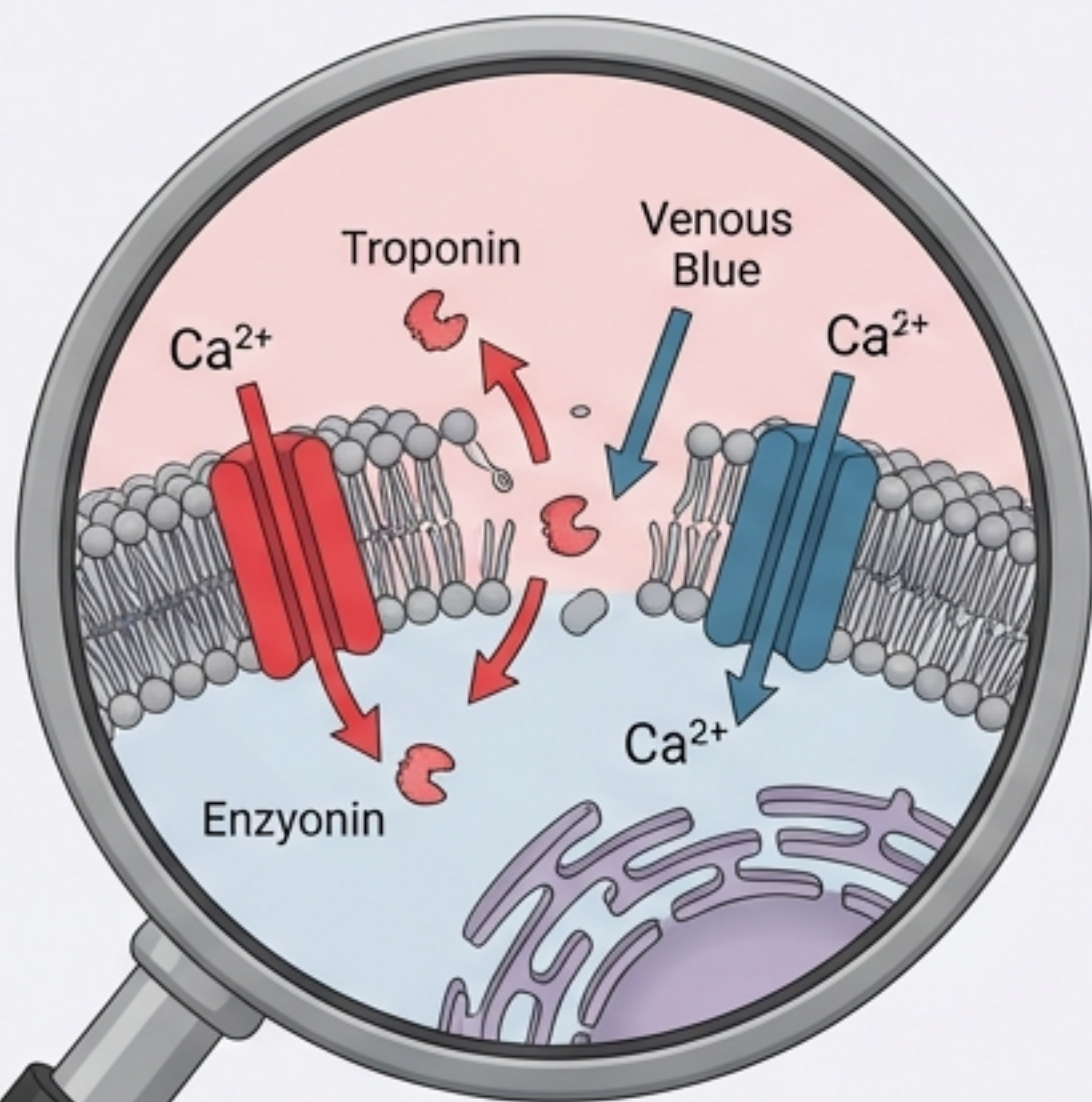


Phase II Injury: The Point of No Return



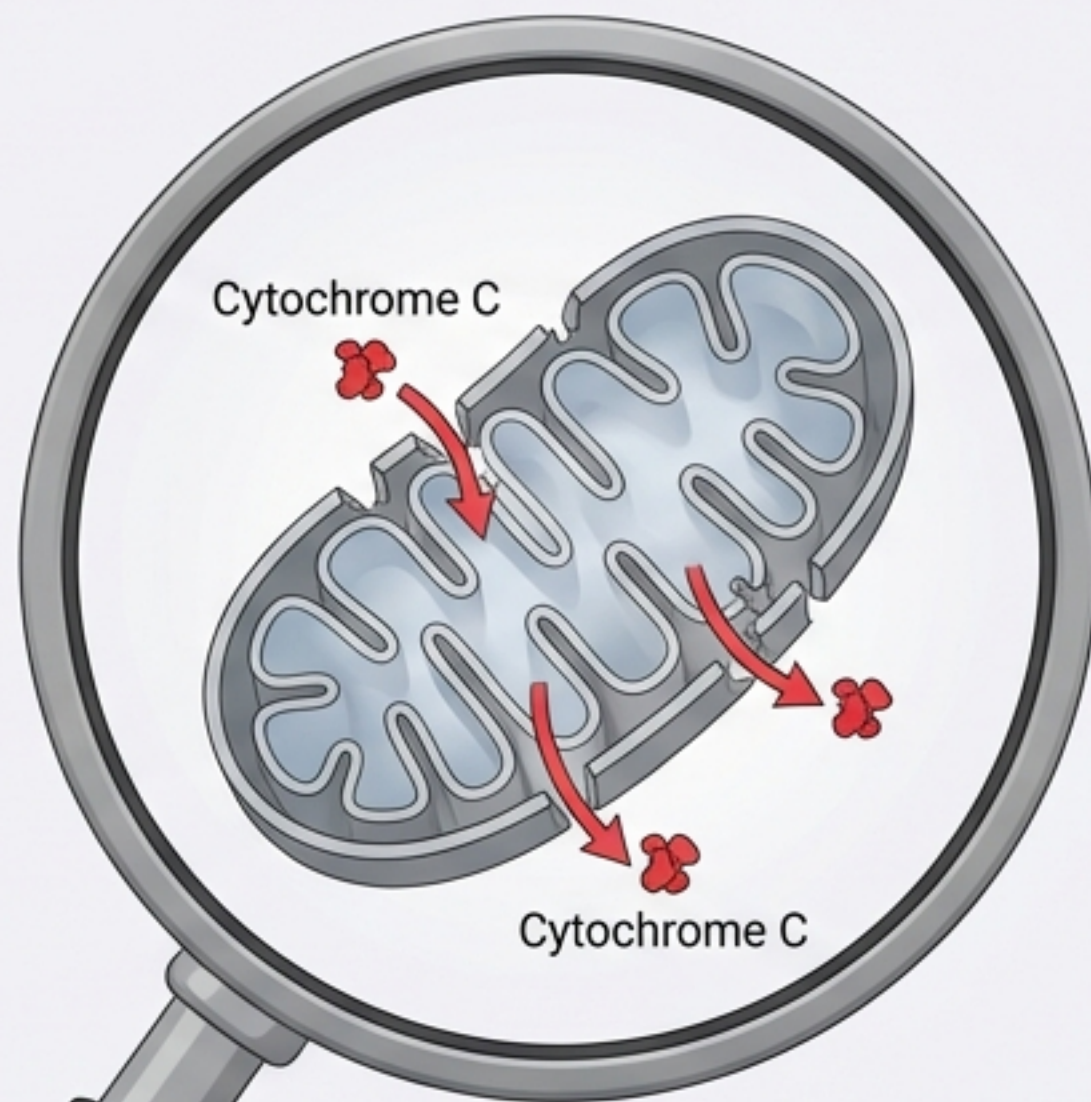
The Mechanics of Irreversibility

Plasma Membrane



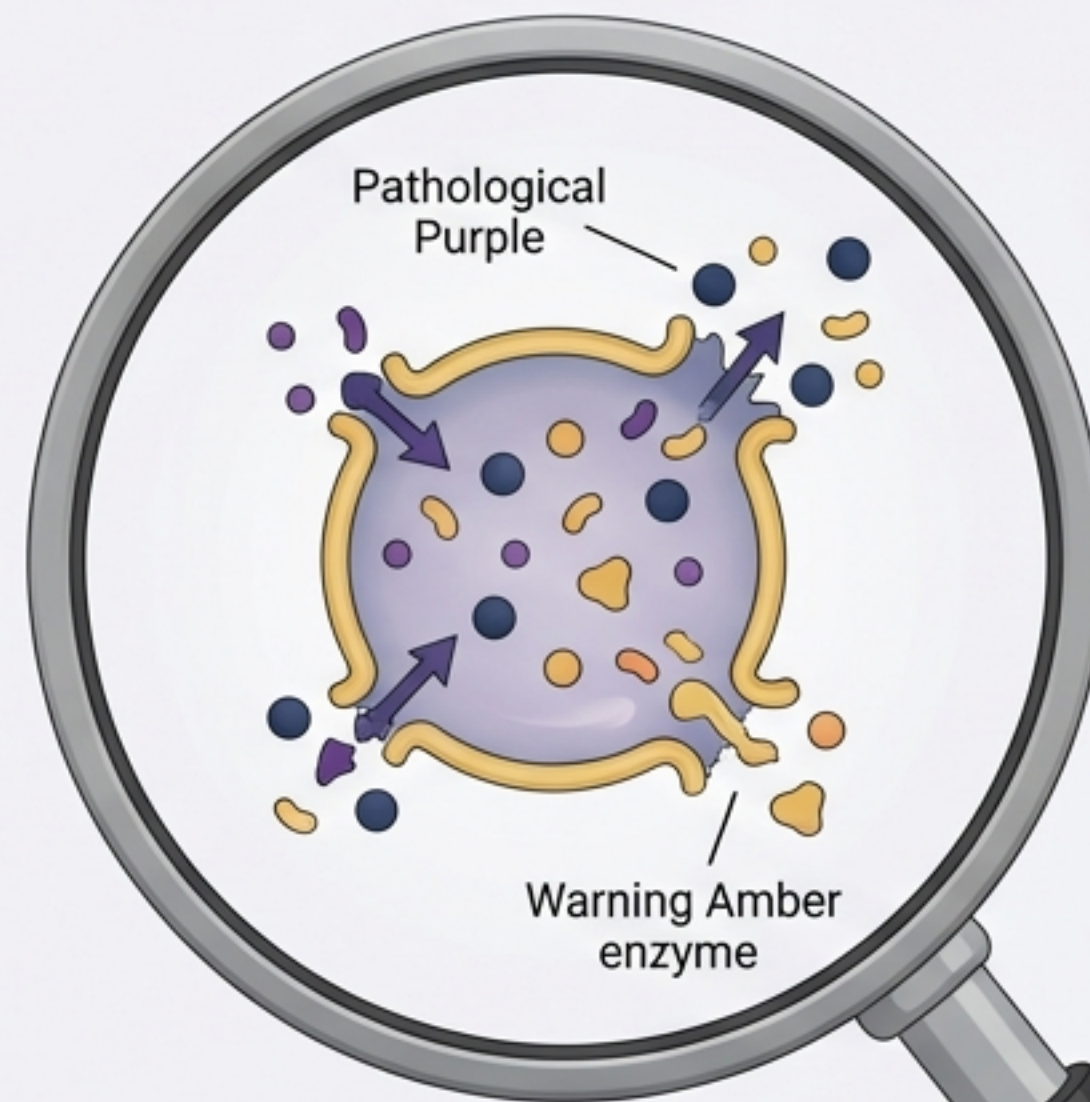
Plasma Membrane
in Roboto

Mitochondria



Triggers Apoptosis
in Charcoal Roboto

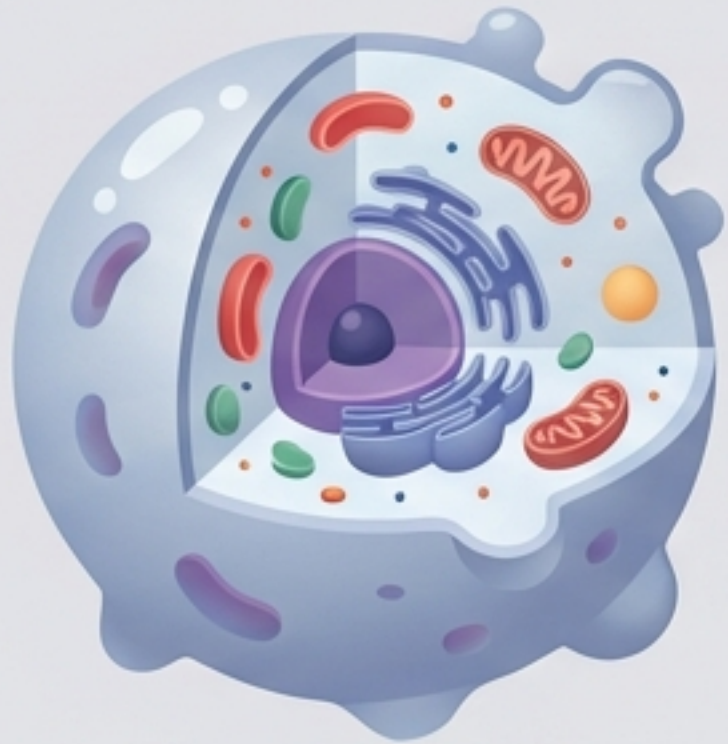
Lysosome



Autodigestion
in Charcoal Roboto

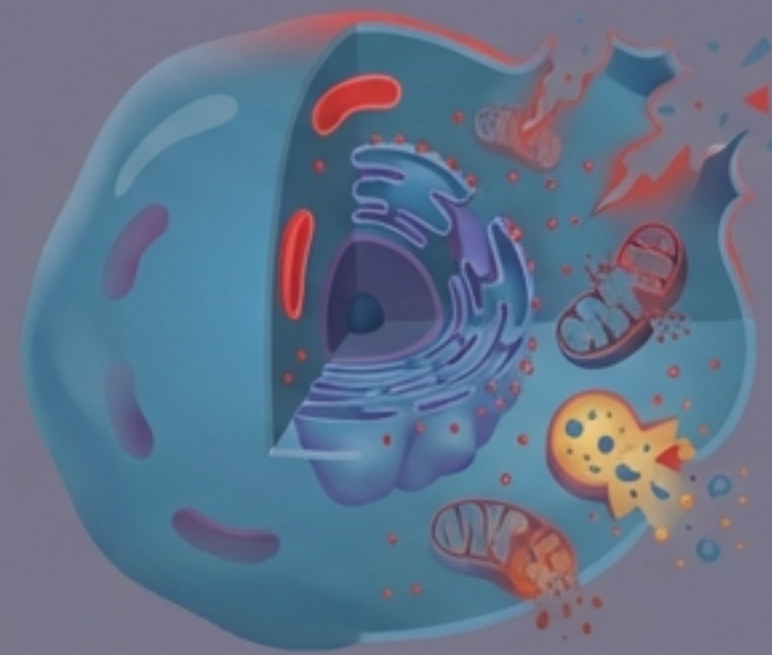
Summary: Reversible vs. Irreversible

Reversible Injury



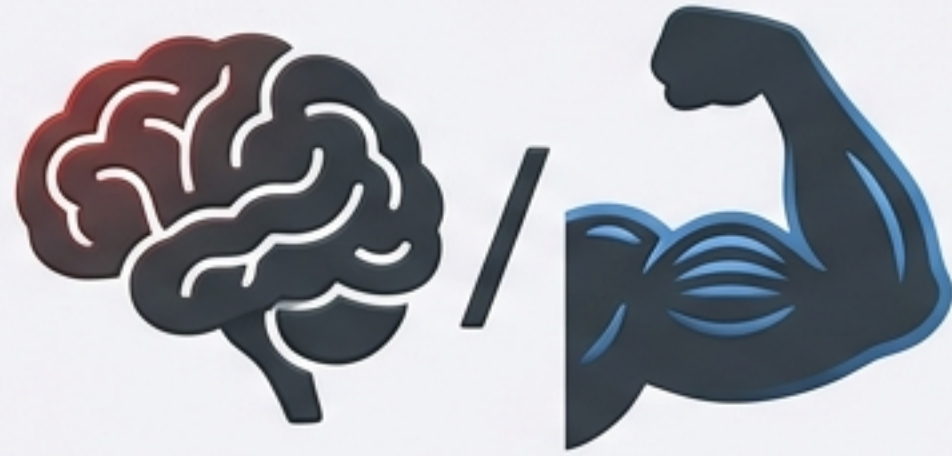
- Cellular Swelling
- Membrane Blebbing
- Loss of Microvilli
- Ribosome Dissociation

Irreversible Injury



- Membrane Damage
- Enzyme Leakage
- Mitochondrial Rupture
- Nuclear Condensation
- Cell Death (Necrosis)

Clinical Axioms



Susceptibility Varies.

Neurons die in minutes;
Muscle survives for hours.



Calcium is the Executioner.

Intracellular accumulation
activates destructive enzymes.



Diagnostic Markers.

We detect injury by finding
intracellular enzymes in the
blood.