Shock: The Physiologic Perspective

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Shock

A “rude unhinging” of the machinery of life.

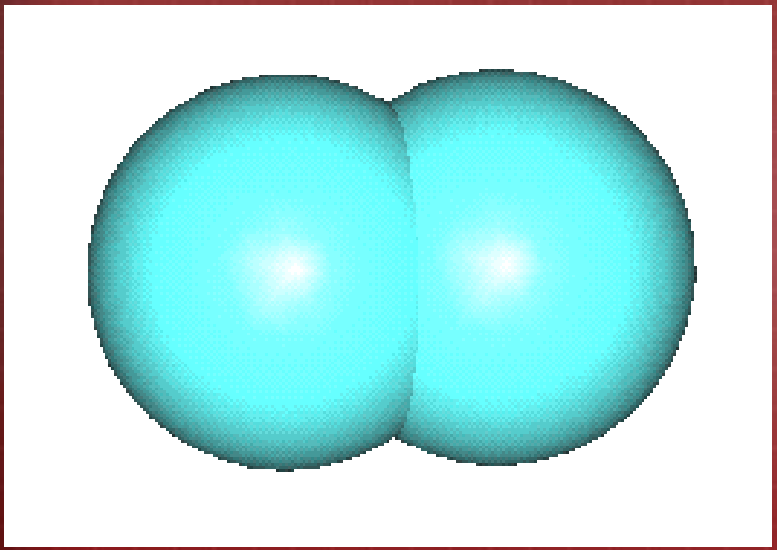
- Samuel Gross (1862)

Shock

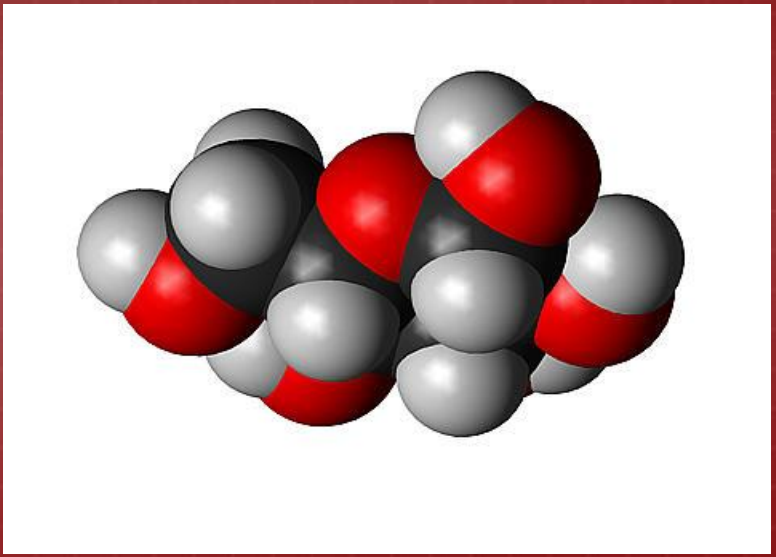
Shock is inadequate tissue perfusion.

Cellular Requirements

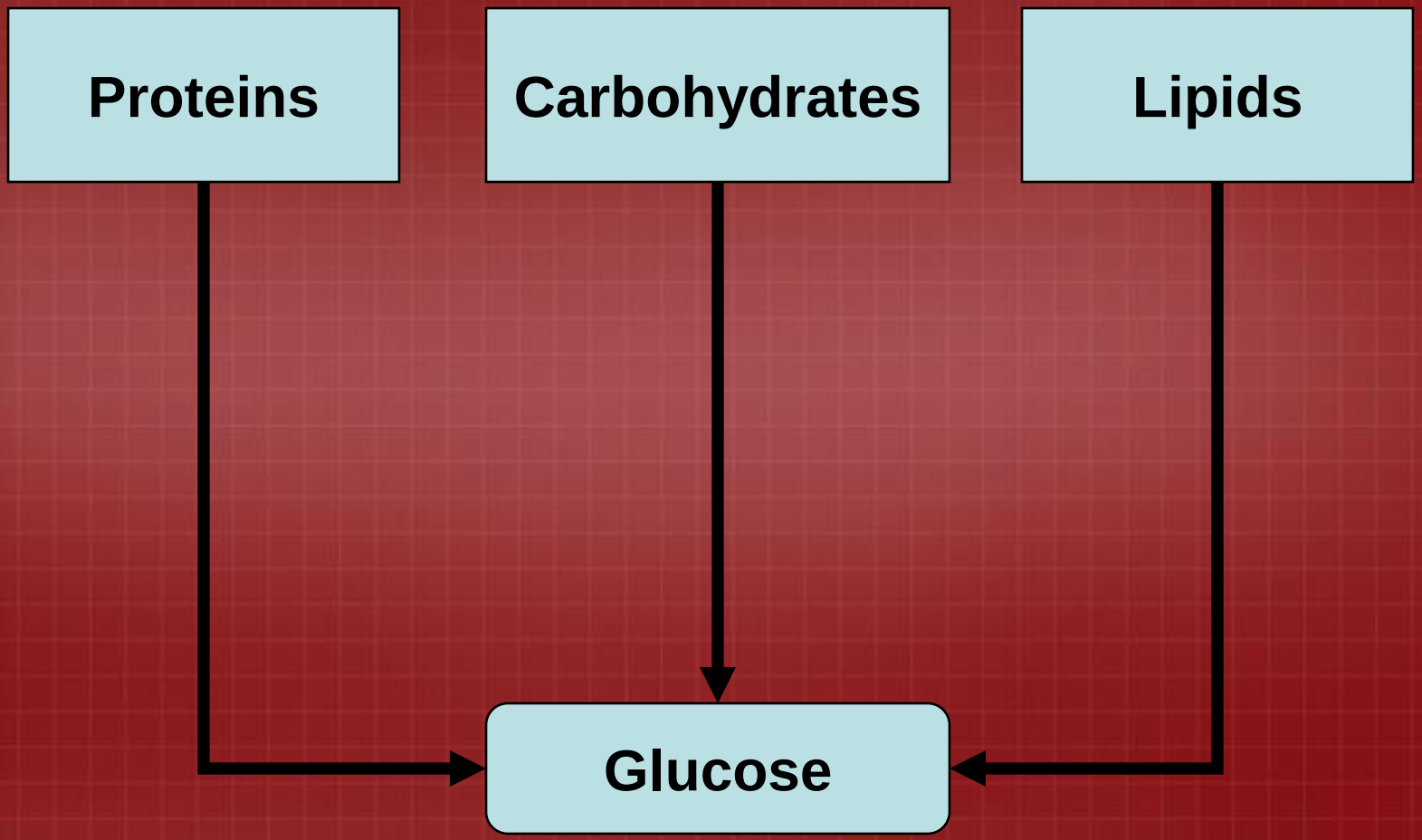
Oxygen



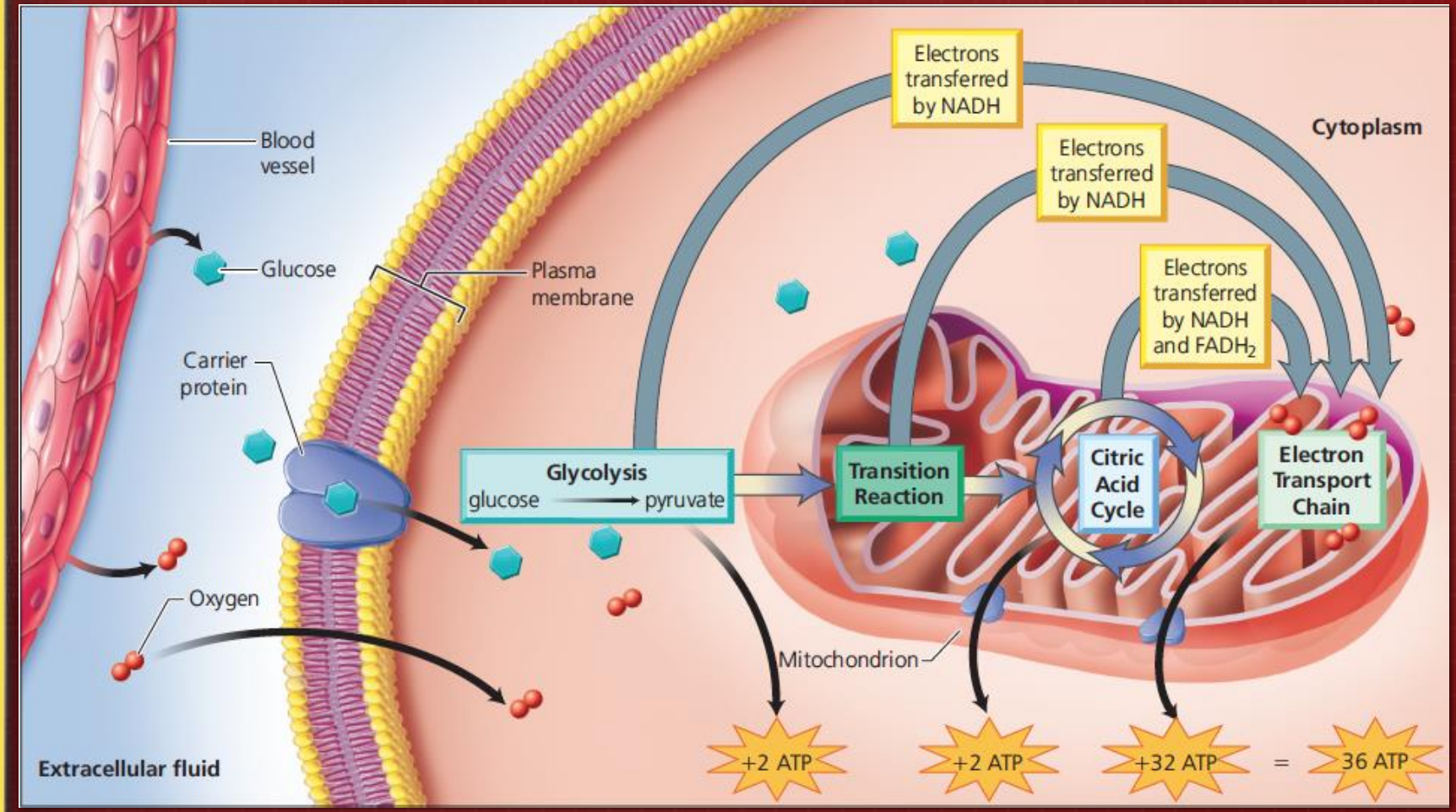
Glucose



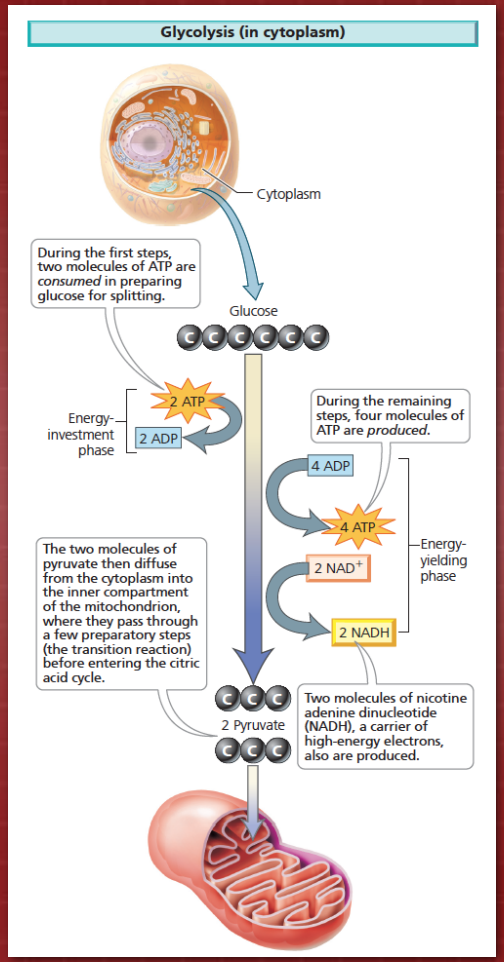
Cellular Requirements



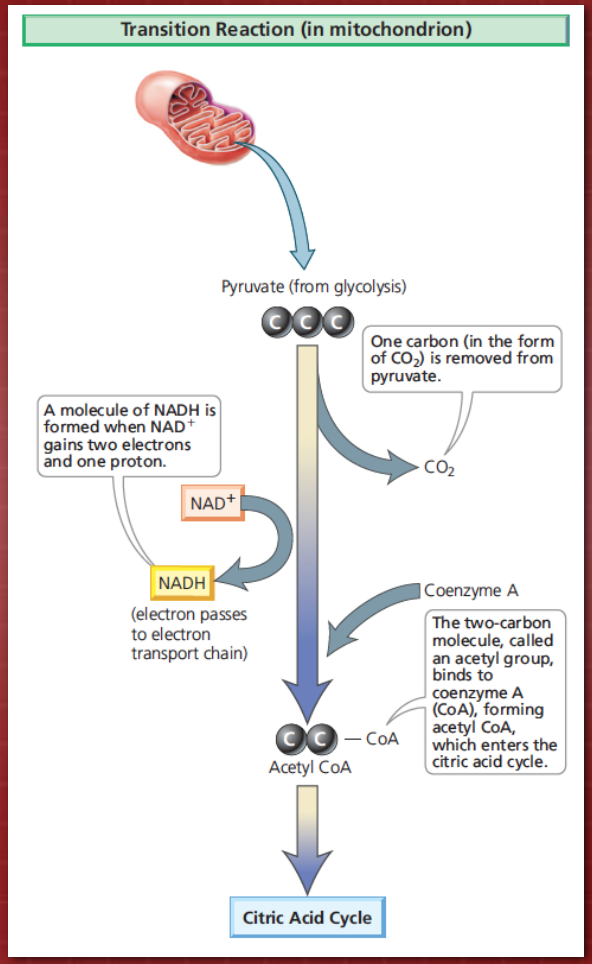
Cellular Energy Production



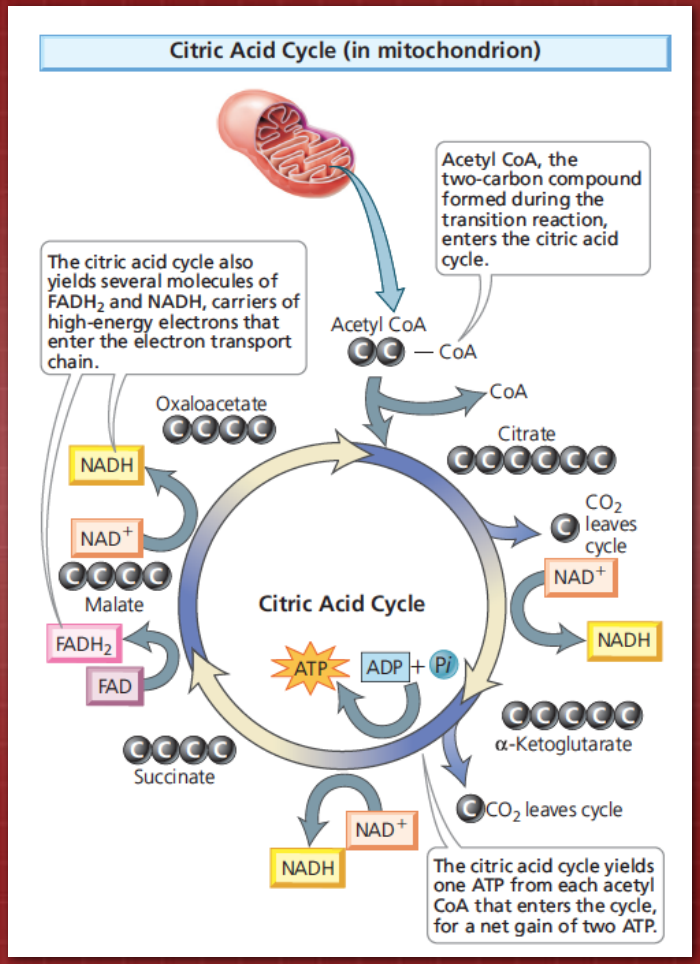
Glycolysis


Glycolysis (in cytoplasm)
Cytoplasm
During the first steps, two molecules of ATP are *consumed* in preparing glucose for splitting.
Glucose
2 ATP
2 ADP
Energy-investment phase
During the remaining steps, four molecules of ATP are *produced*.
4 ADP
4 ATP
2 NAD+
2 NADH
Energy-yielding phase
The two molecules of pyruvate then diffuse from the cytoplasm into the inner compartment of the mitochondrion, where they pass through a few preparatory steps (the transition reaction) before entering the citric acid cycle.
2 Pyruvate
Two molecules of nicotine adenine dinucleotide (NADH), a carrier of high-energy electrons, also are produced.

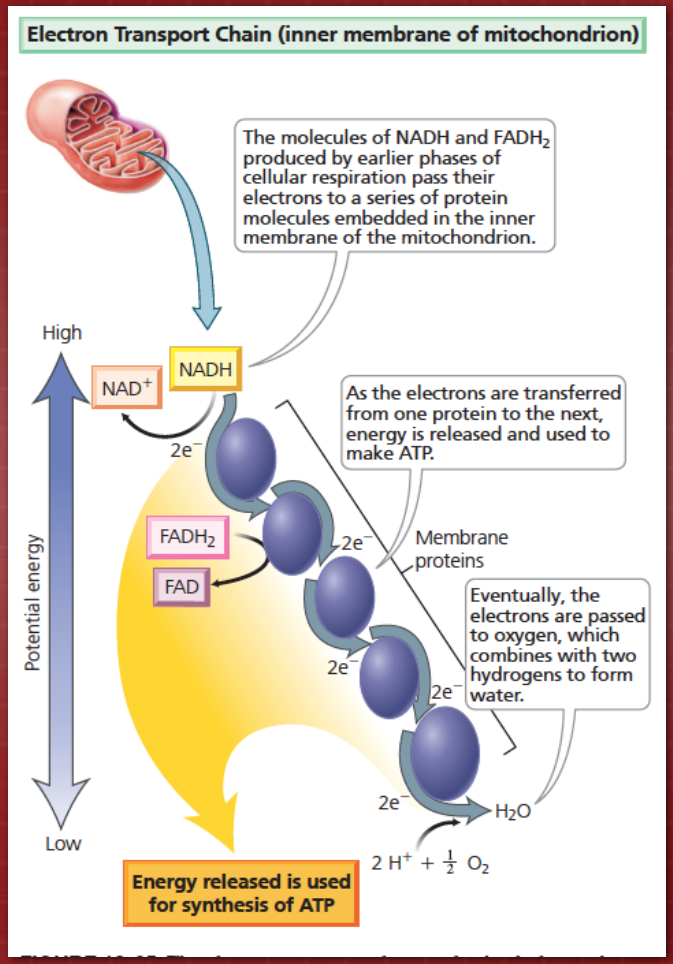
Transition Reaction



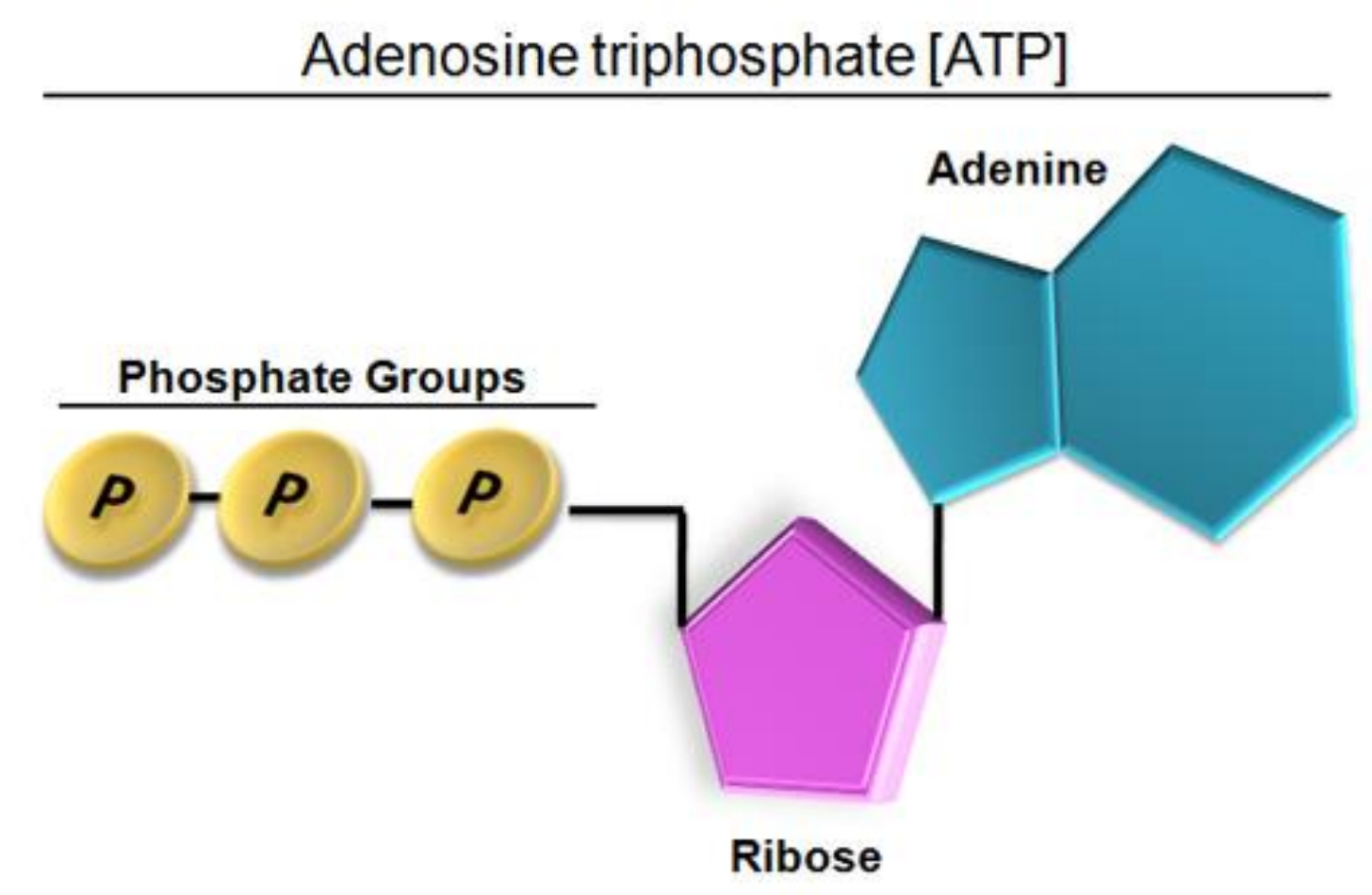
Kreb's (Citric Acid) Cycle



Electron Transport



Adenosine Triphosphate (ATP)



Cellular Requirements

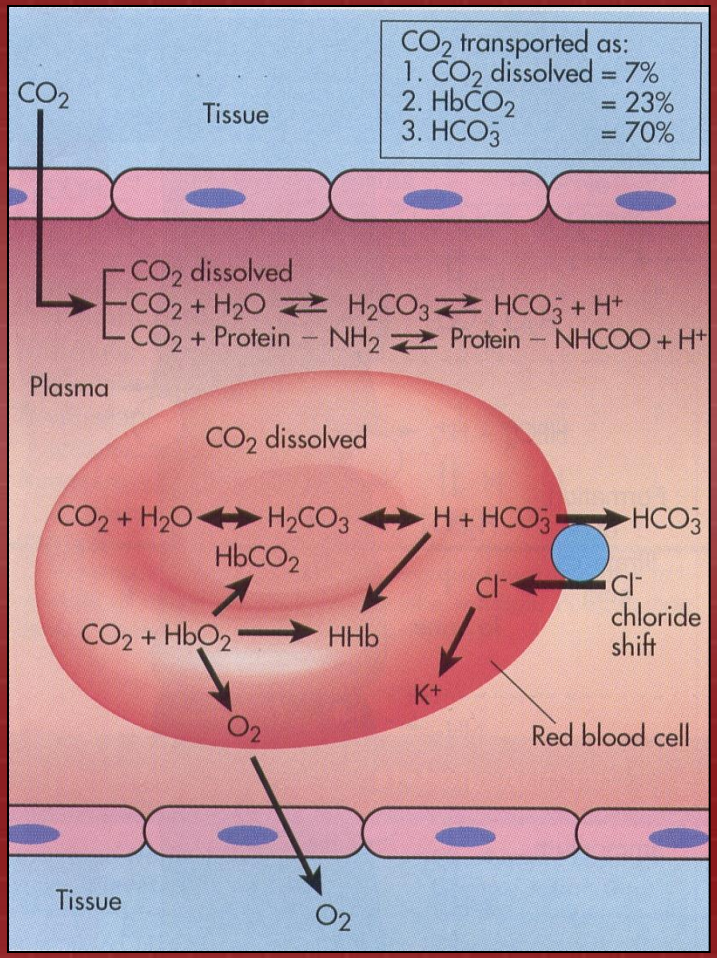
- Oxygen
  - Required for the majority of energy production derived from Krebs Cycle and Electron Transport Chain.
  - Metabolism with Oxygen = Aerobic Metabolism
  - Metabolism without Oxygen = Anaerobic Metabolism

Oxygen Transport

- Oxygen Transport:
  - Hemoglobin-bound (97%)
  - Dissolved in plasma (3%)
- Monitoring:
  - Hemoglobin-bound (SpO_2)
  - Dissolved in plasma (pO_2)

Oxygen Transport

Carbon Dioxide Transport



Oxygen Delivery

DO_2 = Normal Oxygen Delivery

$DO_2 = Q \times CaO_2$

$DO_2 = Q \times (1.34 \times Hb \times SpO_2) \times 10$

Normal DO_2 is 520 to 570 $mL/minute/m^2$

Clinical Correlation

$DO_2 = Q \times (1.34 \times Hb \times SpO_2) \times 10$

What factors can affect oxygen delivery to the tissues?

Cardiac Output (Q)

Available Hemoglobin (Hb)

Oxygen Saturation (SpO_2)

Oxygen Uptake

$VO_2 = Q \times 13.4 \times Hb \times (SpO_2 - SvO_2)$

Oxygen Extraction Ratio

$O_2ER = VO_2 / DO_2 \times 100$

Normal O_2ER = 0.2-0.3 (20 to 30%)

Metabolic Demand

- MRO_2 :
  - 1. The metabolic demand for oxygen at the tissue level.
  - 2. The rate at which oxygen is utilized in the conversion of glucose to energy and water through glycolysis and Kreb's cycle.

Shock

$VO_2 \geq MRO_2$ = Normal Metabolism

$VO_2 < MRO_2$ = SHOCK

Shock

- Causes of Shock:
  - Inadequate oxygen delivery:
    - Inadequate respiration and oxygenation
    - Inadequate hemoglobin
    - Inadequate fluid in the vascular system
    - Inadequate blood movement
  - Impaired oxygen uptake

Shock

- Causes of Shock:
  - Inadequate nutrient delivery:
    - Inadequate nutrient intake
    - Inadequate nutrient delivery
    - Inadequate fluid in the vascular system
    - Inadequate blood movement
  - Impaired nutrient (glucose) uptake

Shock

- Causes of Shock:
  - Inadequate oxygen delivery
    - Inadequate respiration and oxygenation
      - Respiratory failure (mechanical, toxins)
    - Inadequate hemoglobin
      - Hemorrhage or anemia
    - Inadequate fluid in the vascular system
      - Hemorrhage or fluid loss (burns, vomiting, diarrhea, sepsis)
    - Inadequate blood movement
      - Cardiac pump failure
  - Impaired oxygen uptake
    - Biochemical poisoning (hydrogen cyanide)

Shock

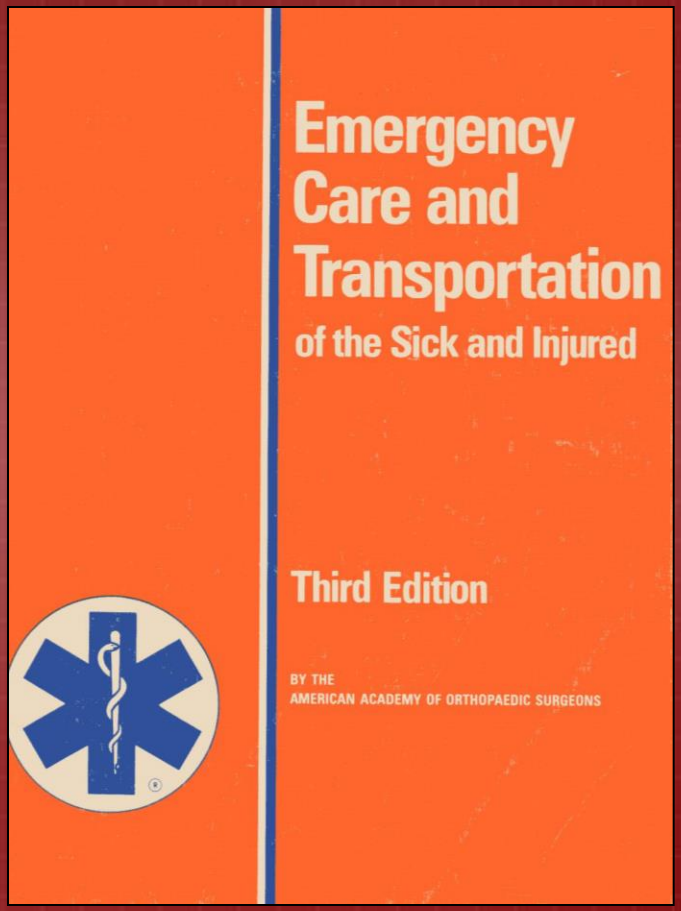
- Impaired oxygen uptake
- Cyanide:
  - Inhibits metal-containing enzymes (i.e., cytochrome oxidase)
  - Halts cellular respiration

Shock

- **Causes of Shock:**
  - **Inadequate nutrient delivery**
    - **Inadequate nutrient intake**
      - Malnutrition, GI absorption disorder
    - **Inadequate nutrient delivery**
      - Malnutrition, hypoproteinemia
    - **Inadequate fluid in the vascular system**
      - Hemorrhage, fluid loss (burns, vomiting, diarrhea)
    - **Inadequate blood movement**
      - Cardiac pump failure
  - **Impaired nutrient (glucose) uptake**
    - **Lack of insulin (Diabetes Mellitus)**

Shock (Types)

- Hemorrhagic
- Respiratory
- Neurogenic
- Psychogenic
- Cardiogenic
- Septic
- Anaphylactic
- Metabolic

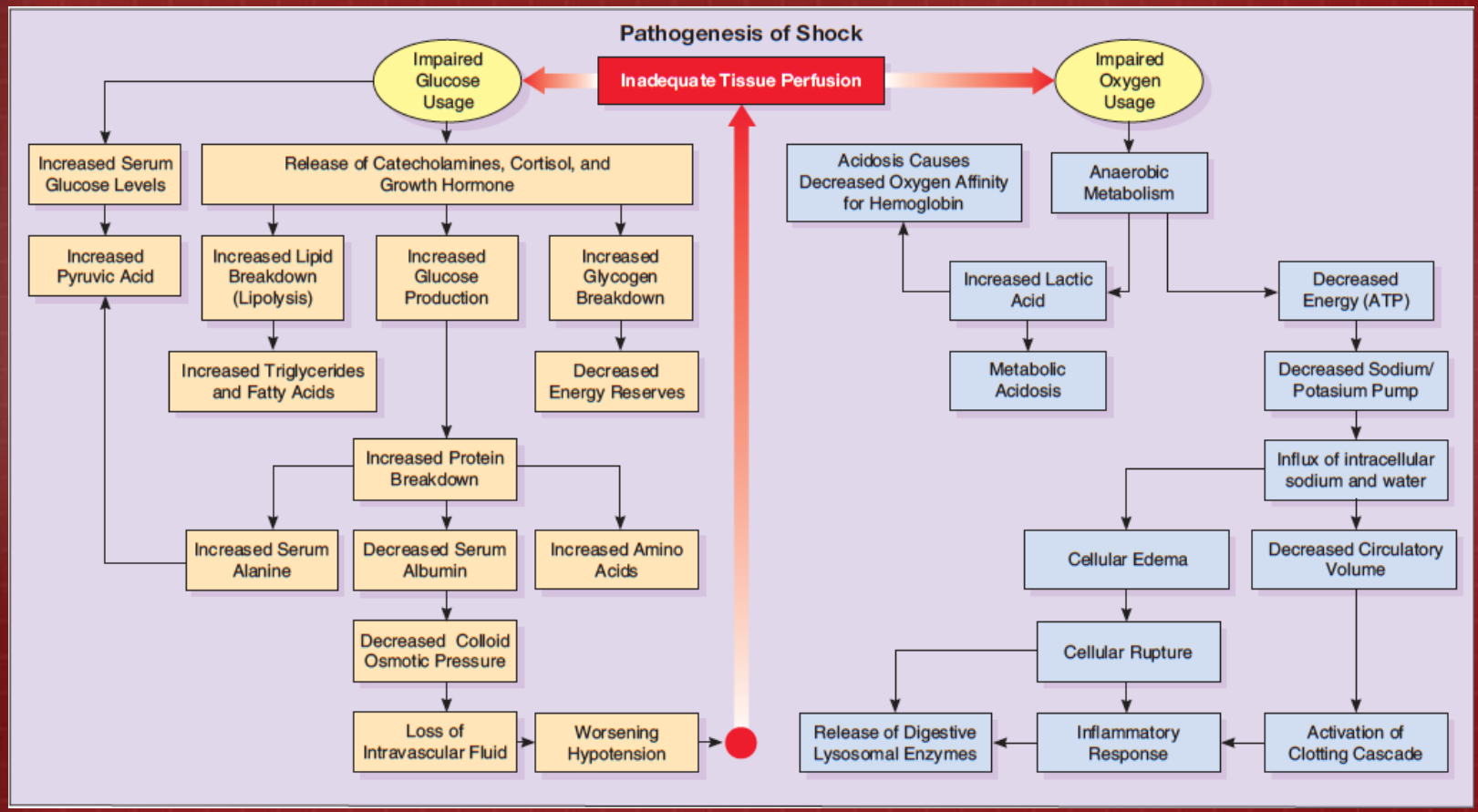


Shock (Classifications)

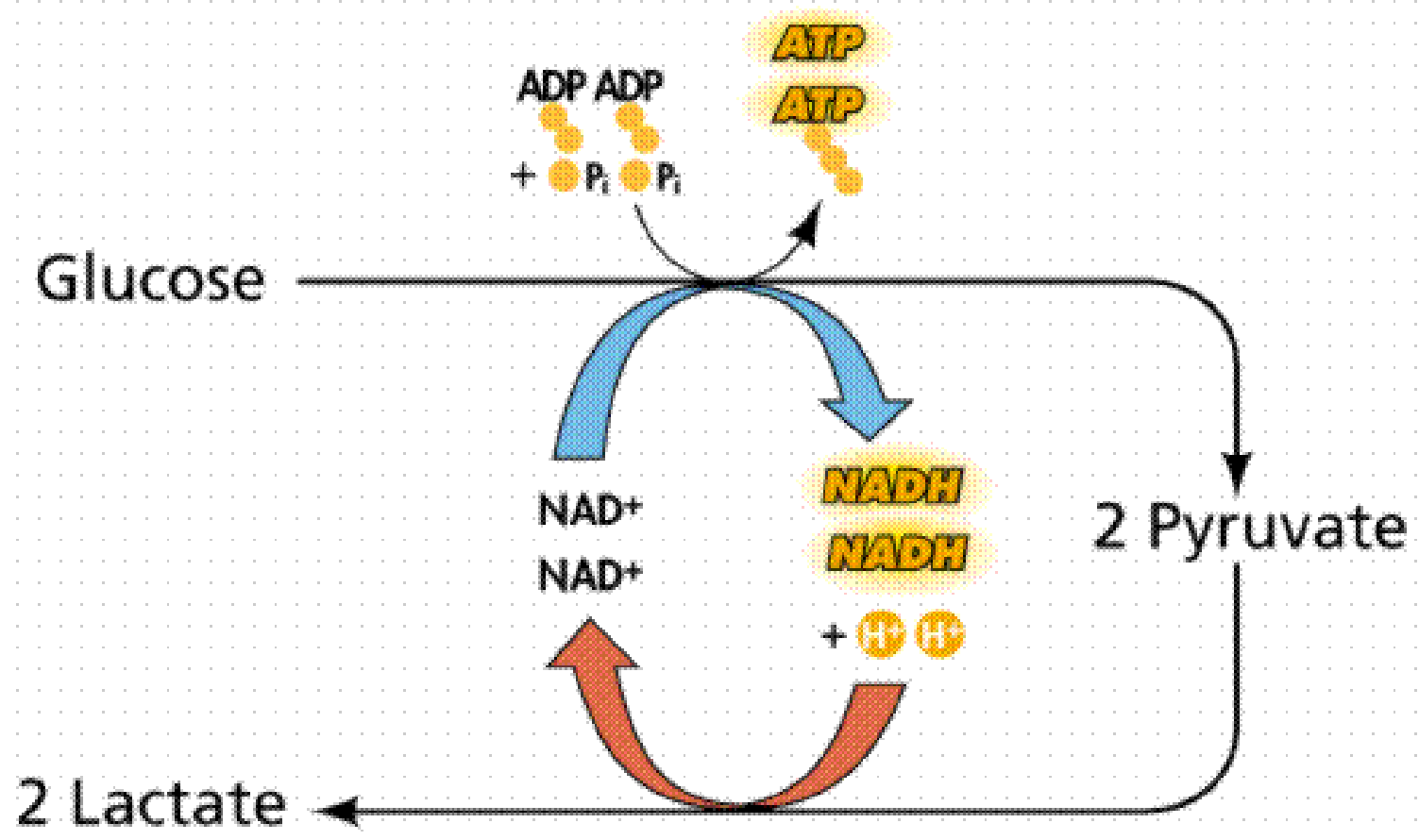
- Physiological classifications better describe underlying problem:
  - Cardiogenic Shock
  - Hypovolemic Shock
  - Distributive Shock
    - Spinal Shock
    - Septic Shock
    - Anaphylactic

Shock

The pathway to shock follows a common metabolic pattern.

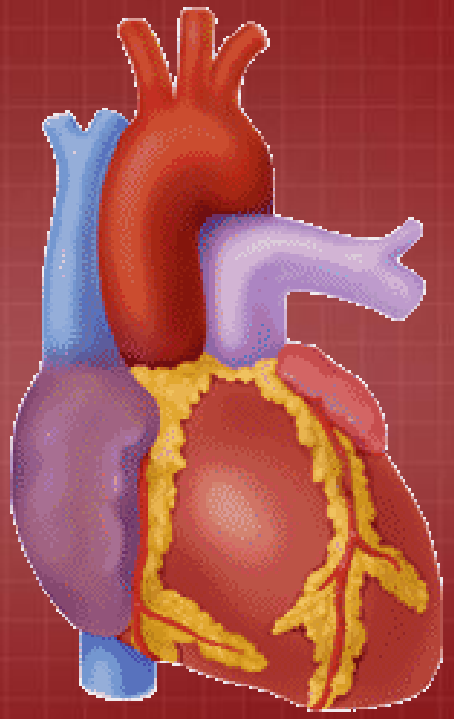

Pathogenesis of Shock
Inadequate Tissue Perfusion
Impaired Glucose Usage
Impaired Oxygen Usage
Increased Serum Glucose Levels
Release of Catecholamines, Cortisol, and Growth Hormone
Increased Pyruvic Acid
Increased Lipid Breakdown (Lipolysis)
Increased Glucose Production
Increased Glycogen Breakdown
Increased Triglycerides and Fatty Acids
Decreased Energy Reserves
Increased Protein Breakdown
Increased Serum Alanine
Decreased Serum Albumin
Increased Amino Acids
Decreased Colloid Osmotic Pressure
Loss of Intravascular Fluid
Worsening Hypotension
Acidosis Causes Decreased Oxygen Affinity for Hemoglobin
Anaerobic Metabolism
Increased Lactic Acid
Decreased Energy (ATP)
Metabolic Acidosis
Decreased Sodium/ Potasium Pump
Influx of intracellular sodium and water
Cellular Edema
Decreased Circulatory Volume
Cellular Rupture
Release of Digestive Lysosomal Enzymes
Inflammatory Response
Activation of Clotting Cascade

Pathogenesis of Shock



Cardiogenic Shock

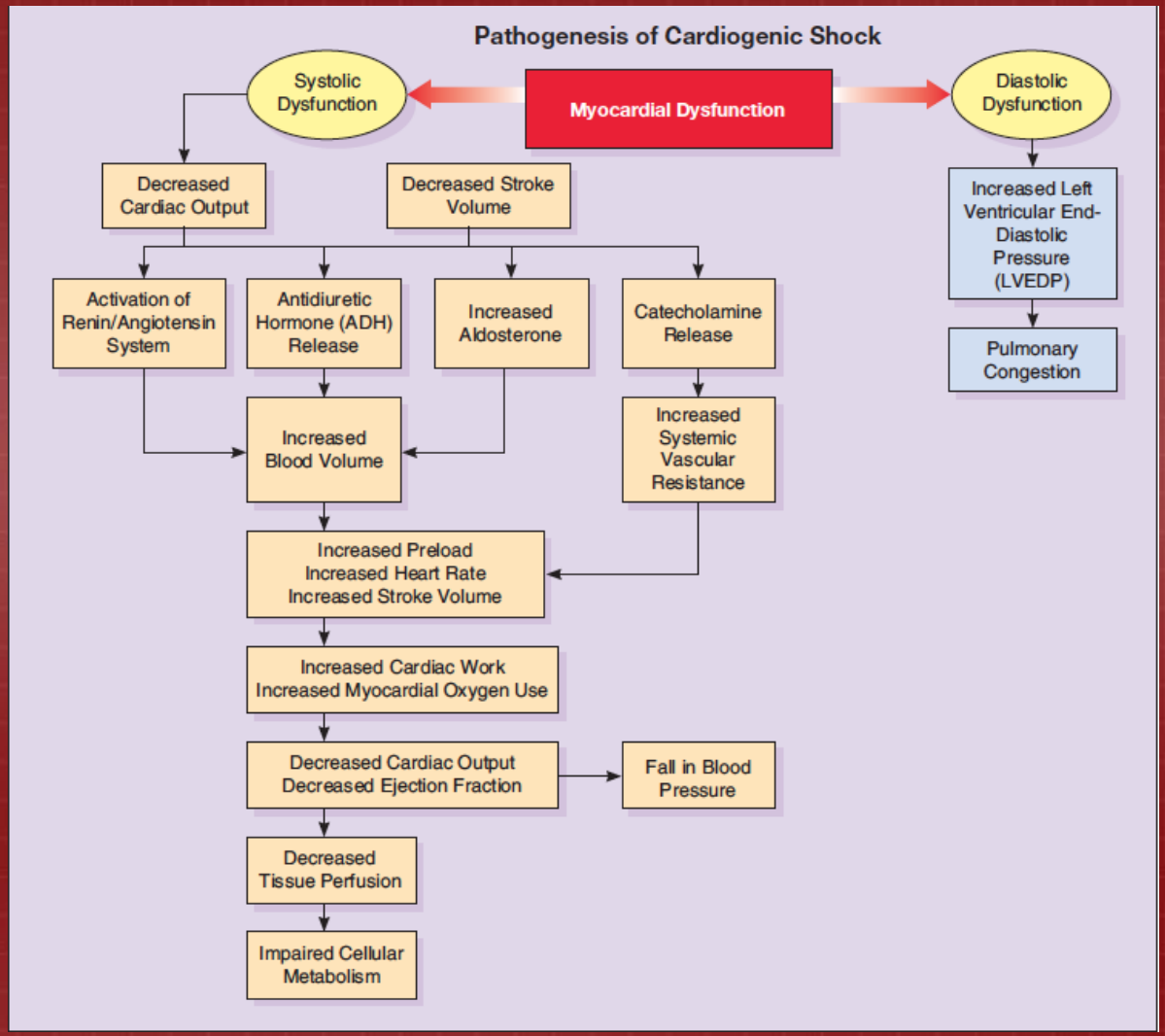
The heart cannot pump enough blood to meet the metabolic demands of the body.



Cardiogenic Shock

- **Loss of contractility:**
  - AMI
  - Loss of critical mass of left ventricle
  - RV pump failure
  - LV aneurysm
  - End-stage cardiomyopathy
  - Myocardial contusion
  - Acute myocarditis
  - Toxic global LV dysfunction
  - Dysrhythmias/heart blocks
- **Mechanical impairment of blood flow:**
  - Valvular disease
  - Aortic dissection
  - Ventricular septal wall rupture
  - Massive pulmonary embolus
  - Pericardial tamponade

Cardiogenic Shock



Hypovolemic Shock

Fluid (blood or plasma) is lost from the intravascular space.

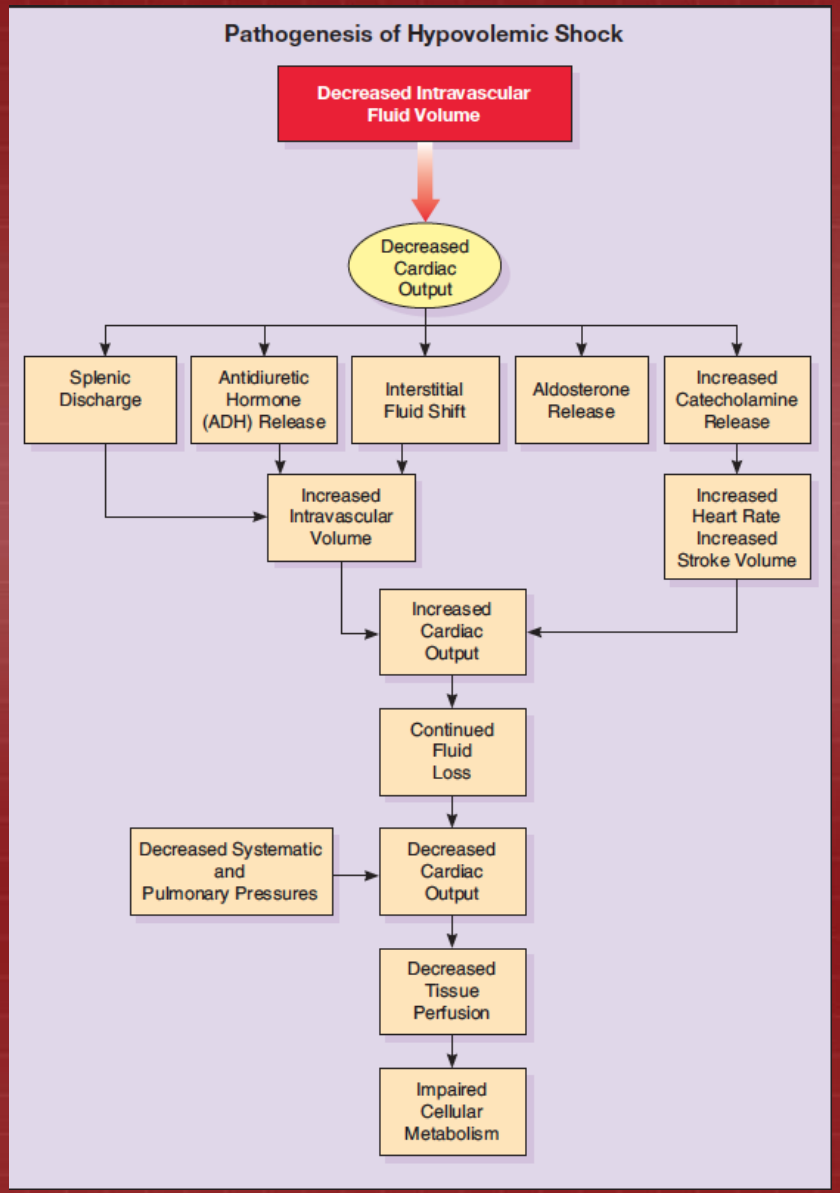
Hypovolemic Shock

- **Trauma:**
  - Solid organ injury
  - Pulmonary parenchymal injury
  - Myocardial laceration/rupture
  - Vascular injury
  - Retroperitoneal hemorrhage
  - Fractures
  - Lacerations
  - Epistaxis
  - Burns
- **GI Tract:**
  - Esophageal varices
  - Ulcer disease
  - Gastritis/esophagitis
  - Mallory-Weiss tear
  - Malignancies
  - Vascular lesions
  - Inflammatory bowel disease
  - Ischemic bowel disease
  - Infectious GI disease
  - Pancreatitis

Hypovolemic Shock

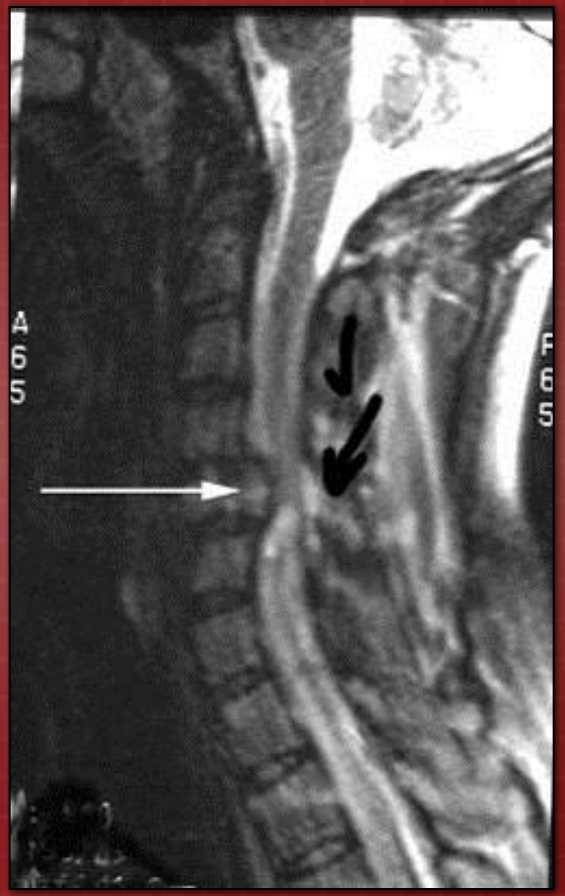
- GI Tract:
  - Infectious diarrhea
  - Vomiting
- Vascular:
  - Aneurysms
  - Dissections
  - AV malformations
- Reproductive Tract:
  - Vaginal bleeding
    - Malignancies
    - Miscarriage
    - Metrorrhagia
    - Retained products of conception
    - Placenta previa
  - Ectopic Pregnancy
  - Ruptured ovarian cyst

Hypovolemic Shock



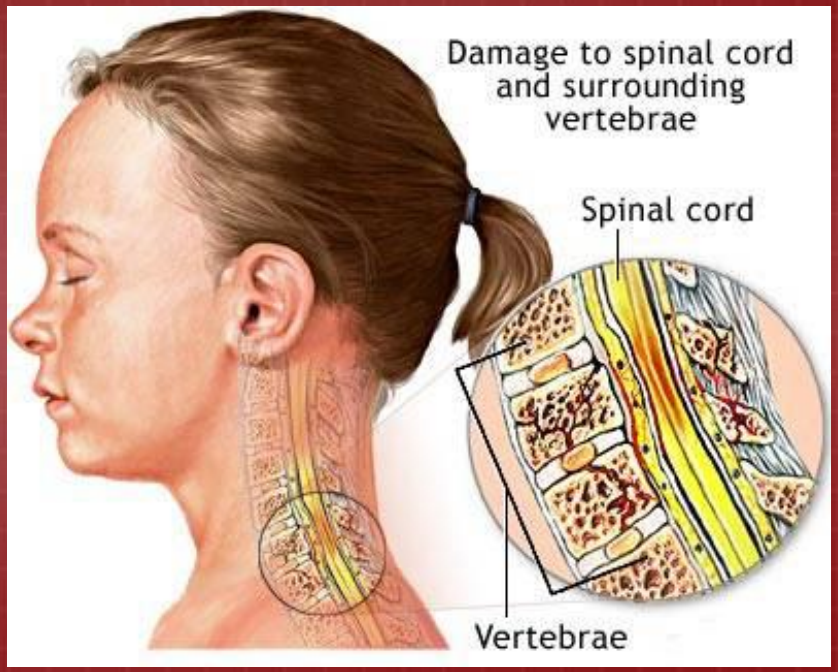
Neurogenic Shock

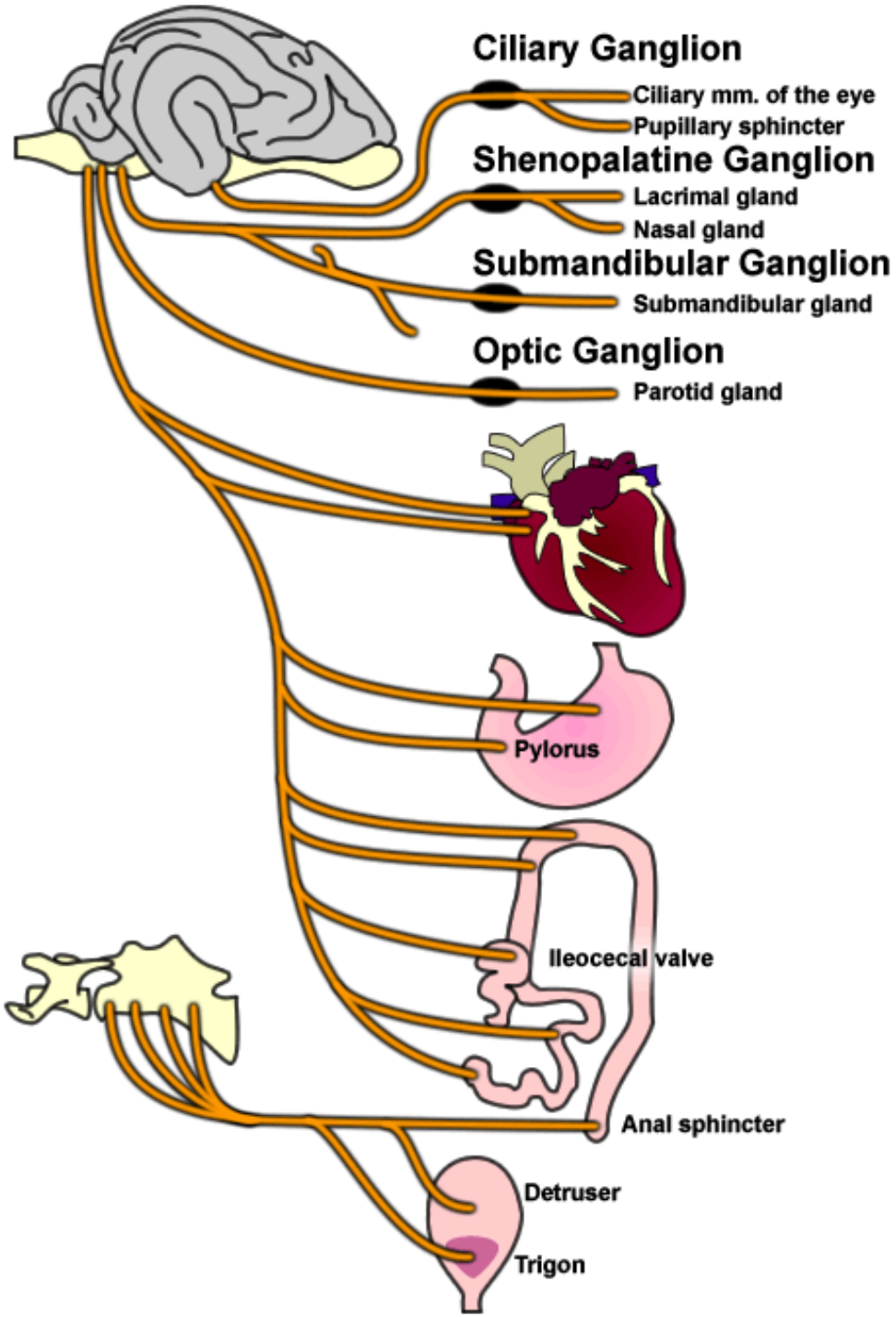
- Interruption in the CNS connections with the periphery (spinal cord injury).
- Form of distributive shock.

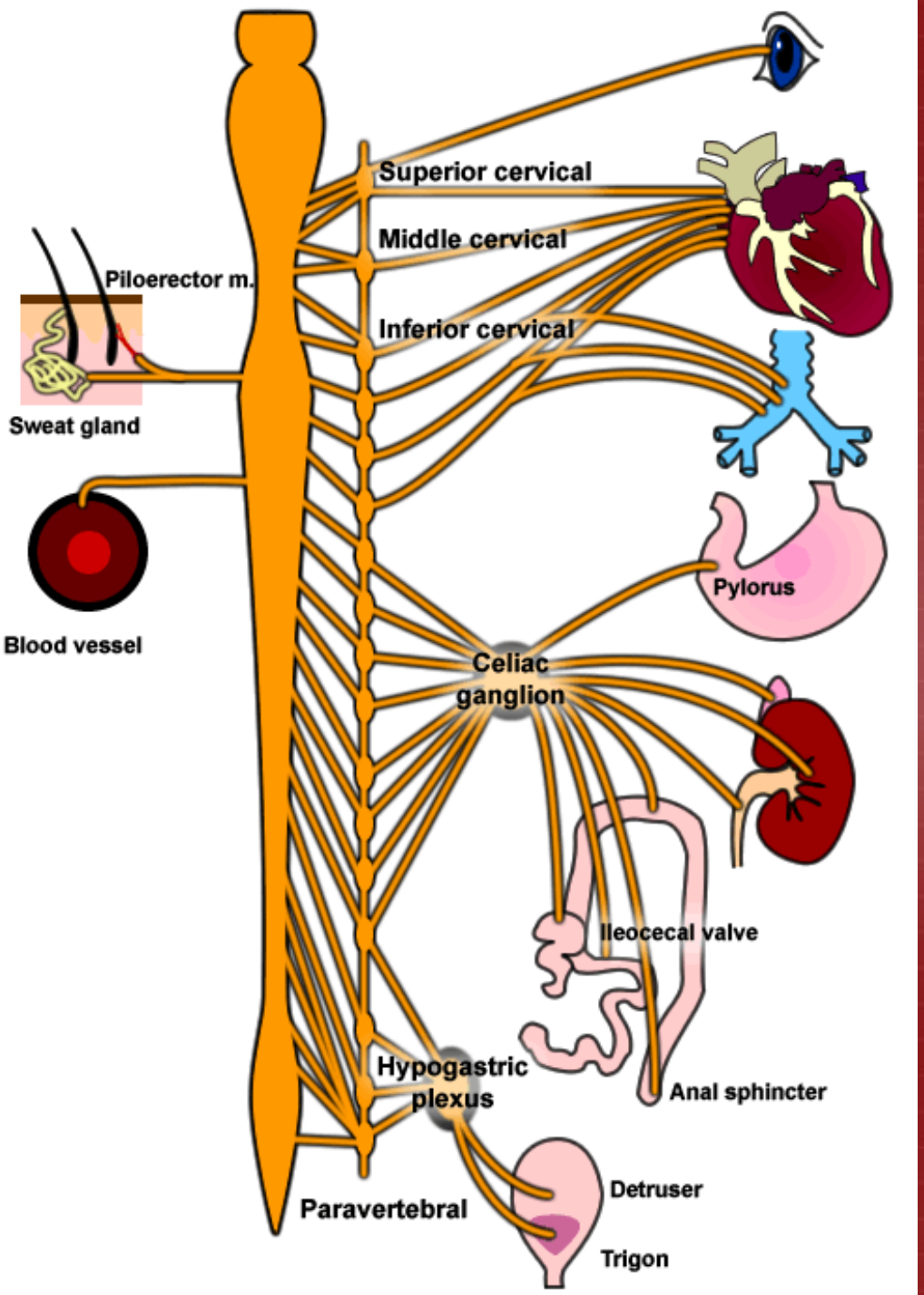


Neurogenic Shock

- Spinal cord injury
- Spinal anesthetic




Ciliary Ganglion
Ciliary mm. of the eye
Pupillary sphincter
Shenopalatine Ganglion
Lacrimal gland
Nasal gland
Submandibular Ganglion
Submandibular gland
Optic Ganglion
Parotid gland
Pylorus
Ileocecal valve
Anal sphincter
Detruser
Trigon


Superior cervical
Middle cervical
Inferior cervical
Piloerector m.
Sweat gland
Blood vessel
Pylorus
Celiac ganglion
Ileocecal valve
Hypogastric plexus
Anal sphincter
Paravertebral
Detruser
Trigon

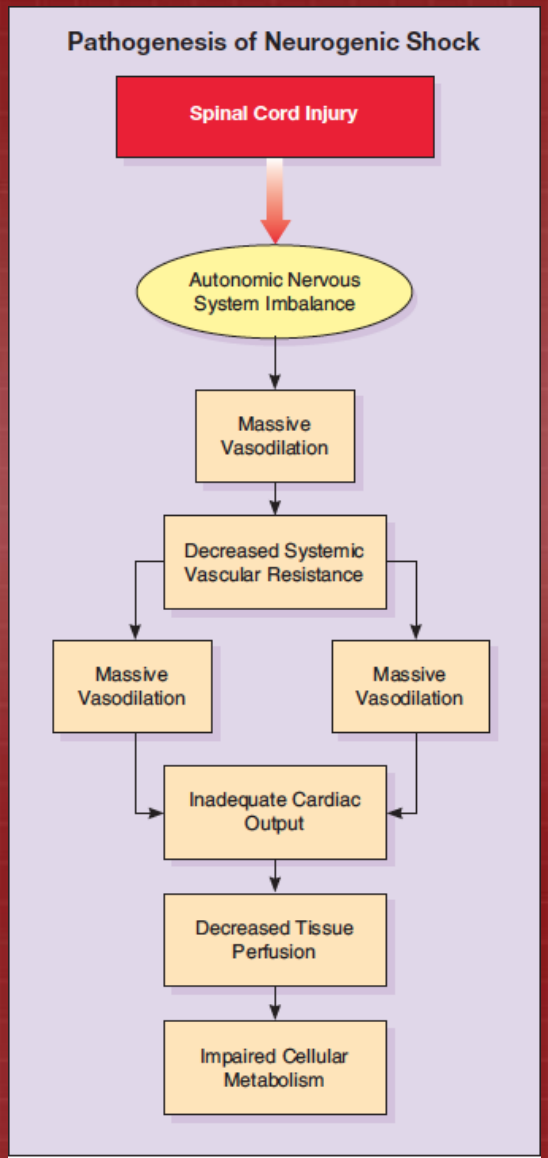
Neurogenic Shock

BP = CO X PVR

CO = HR X SV

BP = (HR X SV) X PVR

Neurogenic Shock



Anaphylactic Shock

- Shock resulting from widespread hypersensitivity.
- Form of distributive shock.

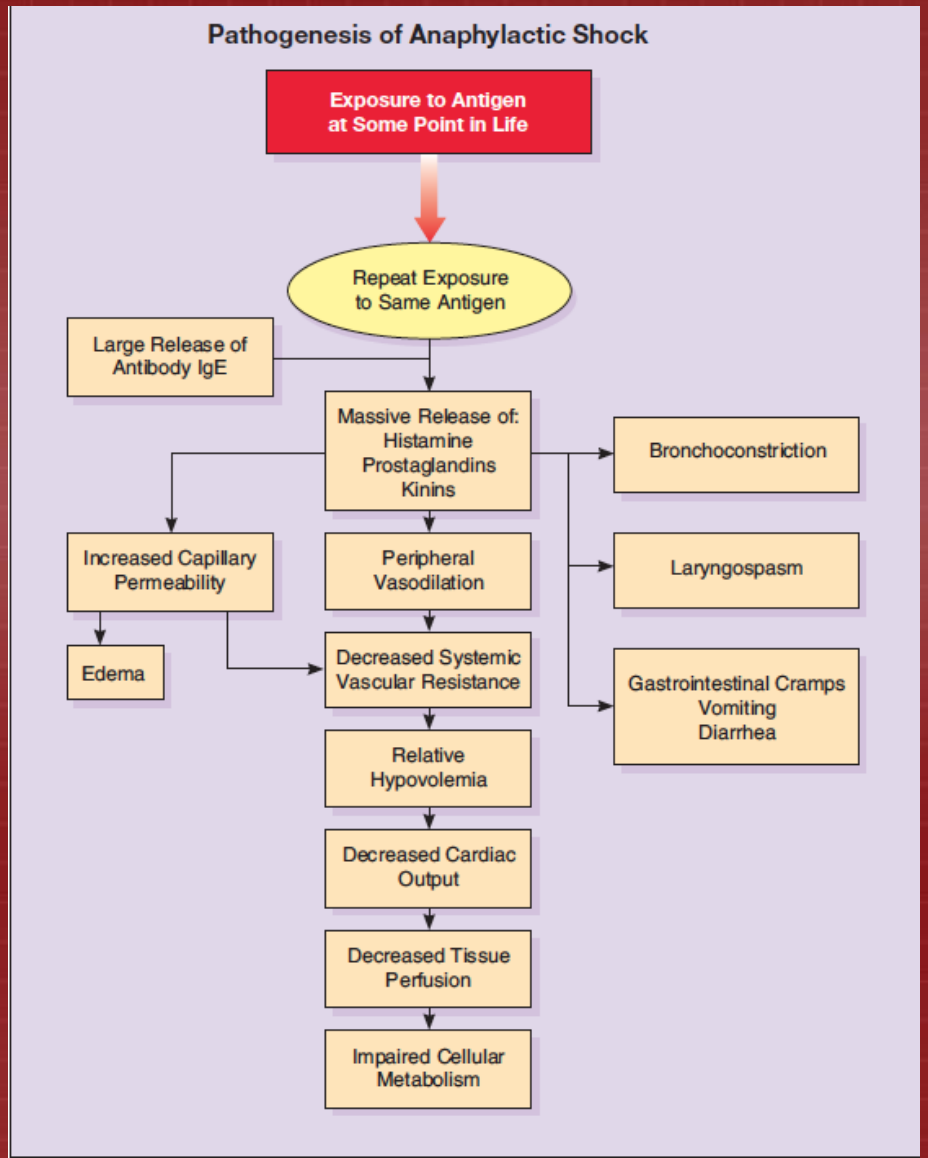
Killer Bee

Anaphylactic Shock

- **Drugs:**
  - Penicillin and related antibiotics
  - Aspirin
  - Trimethoprim-sulfamethoxazole (Bactrim, Septra)
  - Vancomycin
  - NSAIDs
- **Other:**
  - *Hymenoptera* stings
  - Insect parts and molds
  - X-Ray contrast media (ionic)

- **Foods and Additives:**
  - Shellfish
  - Soy beans
  - Nuts
  - Wheat
  - Milk
  - Eggs
  - Monosodium glutamate
  - Nitrates and nitrites
  - Tartrazine dyes (food colors)

Anaphylactic Shock



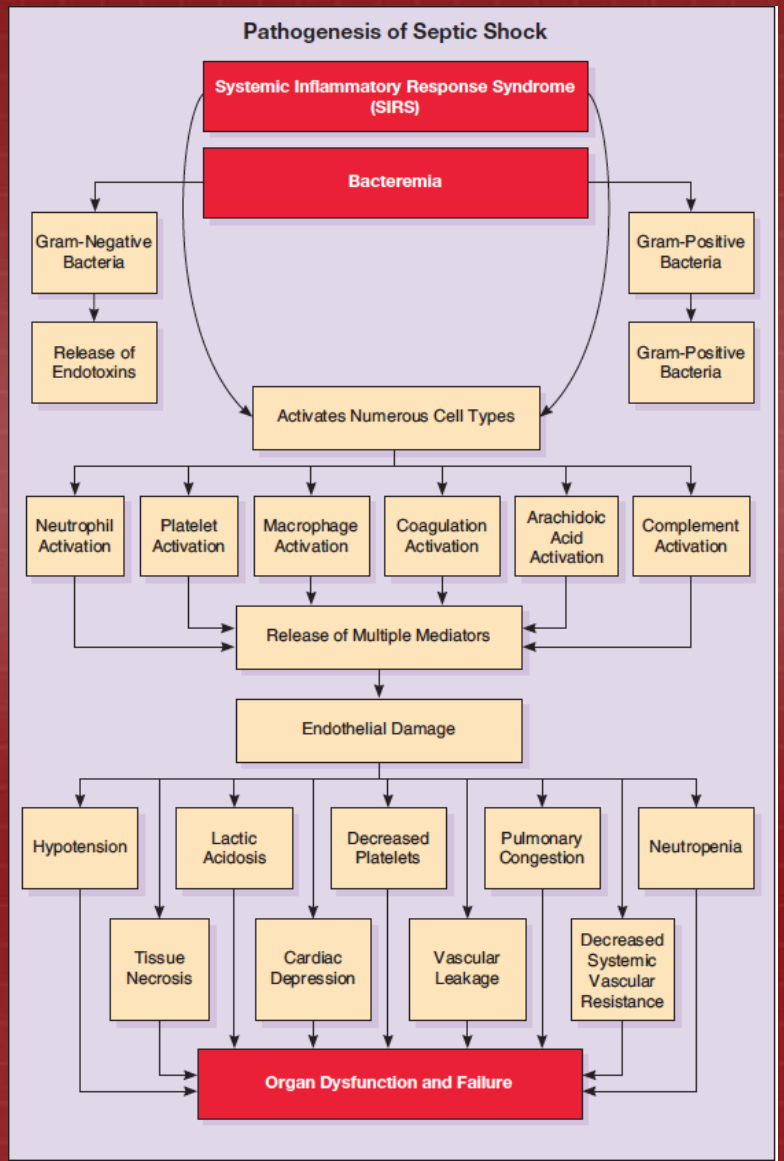
Septic Shock

- Component of systemic inflammatory response syndrome (SIRS).
- Form of distributive shock.

Septic Shock

- Patient has nidus of infection.
- Causative organism releases:
  - Endotoxin
    - Toxic shock syndrome toxin-1
    - Toxin A (*Pseudomonas aeruginosa)*
  - Structure Components
    - Teichoic acid antigen
    - Endotoxin
  - Activates immune system cascade

Septic Shock



Septic Shock

2016 Consensus Definitions:

- **Sepsis:** Life-threatening organ dysfunction caused by a dysregulated host response to infection.
- **Septic shock:** Sepsis with circulatory and cellular/metabolic abnormalities profound enough to substantially increase mortality.

Septic Shock

2016 Consensus Clinical Criteria:

- **Sepsis.** Suspected or documented infection and an acute increase ≥ 2 SOFA points.
- **Septic shock:** Sepsis and vasopressor therapy needed to elevate MAP ≥ 65 mm Hg and lactate ≥ 2 mmol/L (18 mg/dL) after adequate fluid resuscitation.

Septic Shock

Sequential Organ Failure Assessment (SOFA) Score

	1	2	3	4
Neurologic (GCS)	13-14	10-12	6-9	< 9
Pulmonary PaO_2/FiO_2	< 400	< 300	< 200 With Respiratory Support	< 100 With Respiratory Support
Cardiac MSAP	< 70	Dopamine ≤ 5 or Dobutamine (whatever dose)	Dopamine > 5 or Epinephrine ≤ 0.1 or Norepinephrine ≤ 0.1	Dopamine > 15 or Epinephrine > 0.1 or Norepinephrine > 0.1
Renal Creatinine or Diuresis	1.2-1.9	2.0-3.4	3.5-4.9	> 5.0
Platelets	< 150	< 100	< 50	< 20
Bilirubin	1.2-1.9	2.0-5.9	6.0-11.9	> 12.0

Septic Shock

- qSOFA:
  - An alteration in mental status.
  - A decrease in systolic blood pressure of < 100 mm Hg.
  - A respiration rate greater than > breaths/min.

Stages of Shock

- Compensated
  - The body's compensatory mechanisms are able to maintain some degree of tissue perfusion.
- Decompensated
  - The body's compensatory mechanisms fail to maintain tissue perfusion (blood pressure falls).
- Irreversible
  - Tissue and cellular damage is so massive that the organism dies even if perfusion is restored.

Clinical Findings

- What is the first physiological factor in the development of shock?
- $VO_2 < MRO_2$
- So, what are the first symptoms you would expect to find?
  - ↑ respiratory rate
  - ↑ heart rate

Clinical Findings

- What is often the second physiological response to the development of shock?
- Peripheral vasoconstriction
- What symptoms would you expect to see?
  - pale skin
  - cool skin
  - weakened peripheral pulses

Clinical Findings

- As shock progresses, what physiological effects are seen?
- End-organ perfusion falls
- What symptoms would you expect to see?
  - altered mental status
  - decreased urine output

Clinical Findings

- As compensatory mechanisms fully engage, what signs and symptoms would you expect to see?
  - tachycardia
  - tachypnea
  - pupillary dilation
  - decreased capillary refill
  - pale cool skin

Clinical Findings

- When compensatory mechanisms fail, what signs and symptoms would you expect to see?
  - hypotension
  - falling SpO_2
  - bradycardia
  - loss of consciousness
  - dysrhythmias
  - death

Cardiogenic Shock

- Treatment:
  - Oxygen
  - Monitors
  - Nitrates (if possible)
  - Morphine or fentanyl
  - Pressor support (dopamine or dobutamine)
  - If no pulmonary edema, consider small fluid boluses
  - IABP
  - Definitive therapy (fibrinolytic therapy, PCI, CABG, ventricular assist device, cardiac transplant)

Hypovolemic Shock

- Treatment:
  - Oxygen
  - Supine position
  - Monitors
  - IV access
  - Fluid replacement
  - Pressor support (rarely needed)
  - Correct underlying cause

Hypovolemic Shock

- Fluid replacement:
  - Hypovolemia:
    - Isotonic crystalloids
    - Colloids
  - Hemorrhage:
    - Whole blood
    - Packed RBCs
    - Isotonic crystalloids
    - Colloids

Hypovolemic Shock

- **Caveat:**
  - If shock due to trauma, and bleeding cannot be controlled, give only enough small fluid boluses to maintain radial pulse (SBP≈ 80 mm Hg).
  - If bleeding can be controlled, control bleeding and administer enough fluid or blood to restore normal blood pressure.

Neurogenic Shock

- Treatment:
  - ABCDE
  - Fluid resuscitation with crystalloid.
  - PA catheter helpful in preventing overhydration.
  - Look for other causes of hypotension.
  - Consider vasopressor support with dopamine or dobutamine.
  - Transfer patient to regional spine center.

Anaphylactic Shock

- Treatment:
  - Airway (have low threshold for early intubation)
  - Oxygenation and ventilation
  - Epinephrine (IV, IM)
  - IV Fluids (crystalloids)
  - Antihistamines
    - Benadryl
    - Zantac
  - Steroids
  - Beta agonists
  - Aminophylline
  - Pressor support (dopamine, dobutamine or epinephrine)

Septic Shock

- Treatment:
  - Airway and ventilatory management
  - Oxygenation
  - IV fluids (crystalloids)
  - Pressor support (dopamine, norepinephrine)
  - Empiric antibiotics
  - Removal of source of infection
  - $NaHCO_3$?
  - Steroids?
  - Anti-endotoxin antibodies

Shock Treatments

- Not supported by clinical evidence:
  - MAST/PASG
  - High-dose steroids for acute SCI
  - Trendelenburg position
- Less important than formerly thought:
  - Pressure infusion devices
  - IO access

Summary

- To understand the shock, you must first understand the pathophysiology.
- Once you understand the pathophysiology, then recognition of the signs and symptoms and treatment becomes intuitive.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