The Pathophysiology of Hemorrhagic Shock

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Learning Objectives

- Describe how acute blood loss leads to hypotension.
- Describe the compensatory mechanisms that operate to restore arterial pressure following hemorrhage.
- Describe the decompensatory mechanisms that lead to irreversible shock.
- Describe the rationale for different medical interventions following hemorrhage.

General Definition of Hemorrhagic Shock

A clinical syndrome resulting from decreased blood and oxygen perfusion of vital organs resulting from a loss of blood volume.

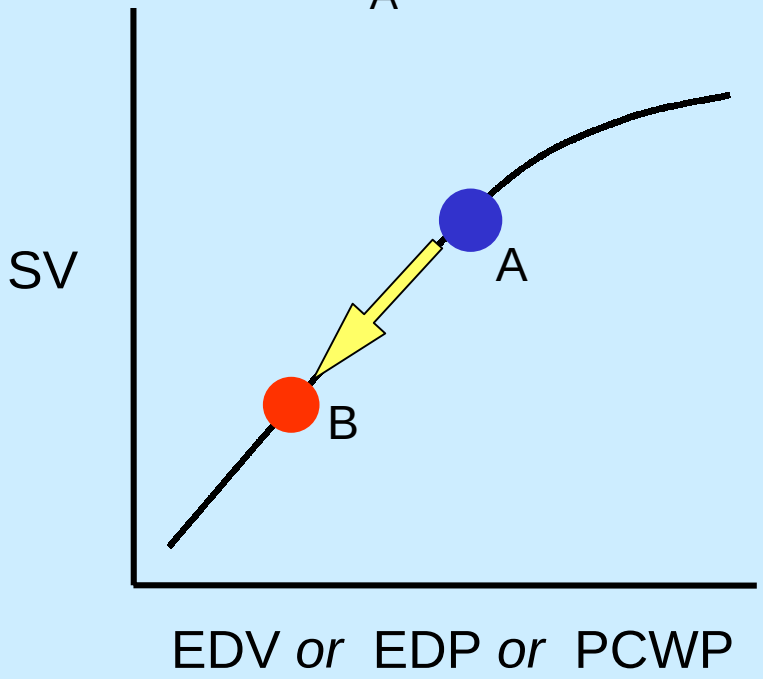
Hemorrhagic Shock

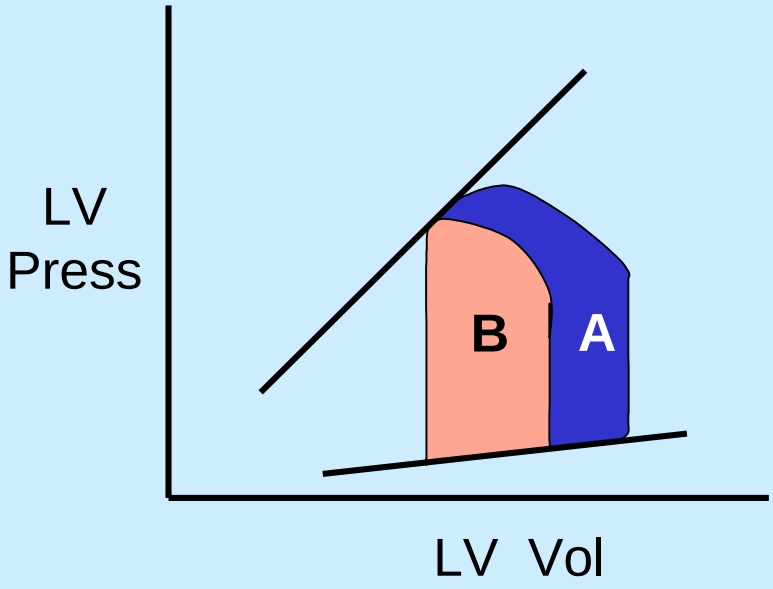
(Initial Uncompensated Responses)

Blood Loss → ↓ P_{RA} → ↓ EDV (Preload)

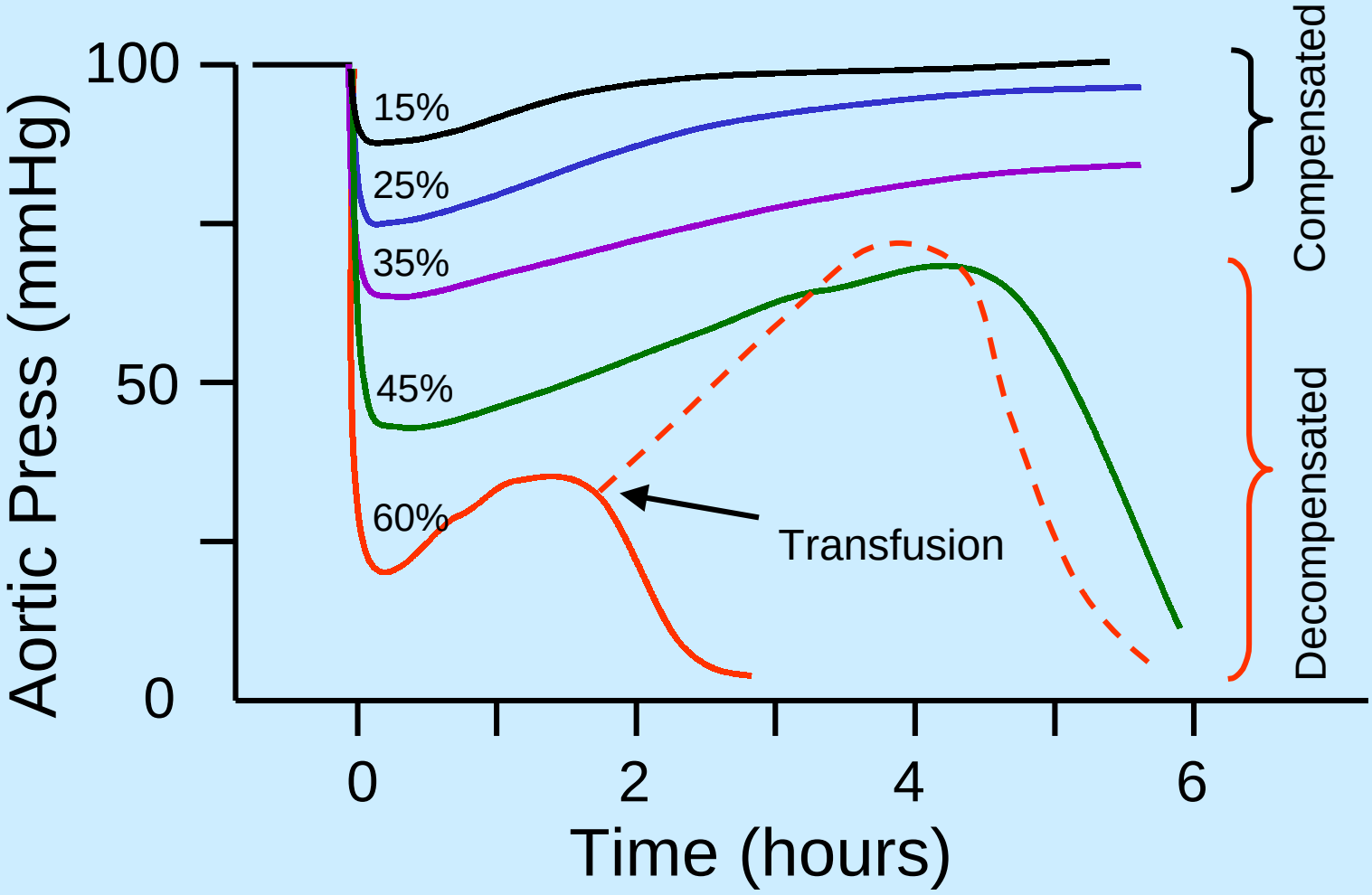
↓ EDV (Preload) → (Frank-Starling Mechanism) → ↓ SV

↓ SV → ↓ CO → ↓ P_A





Effects Blood Volume Loss on Arterial Pressure

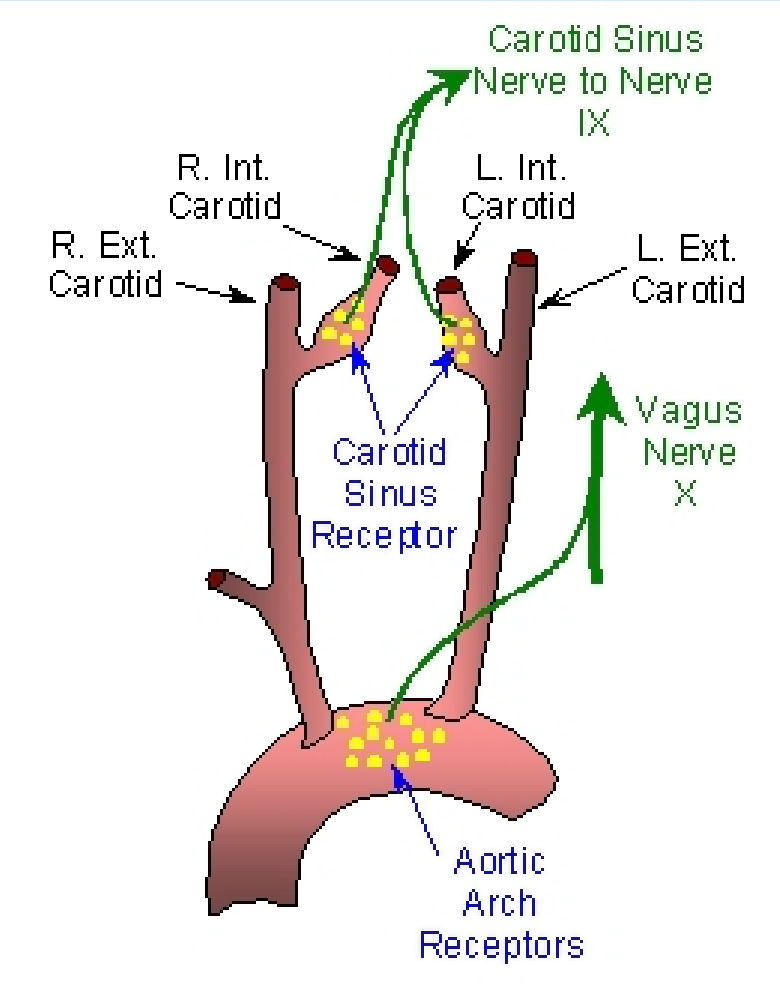


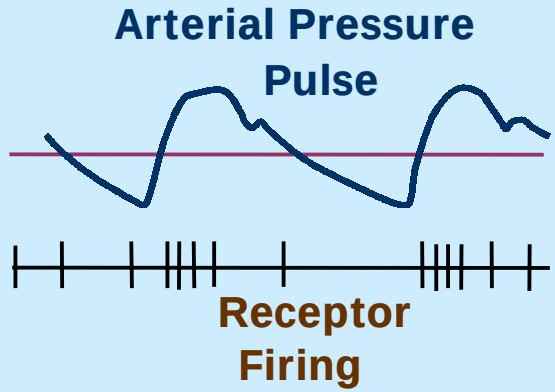
(adapted from Guyton & Crowell, 1961)

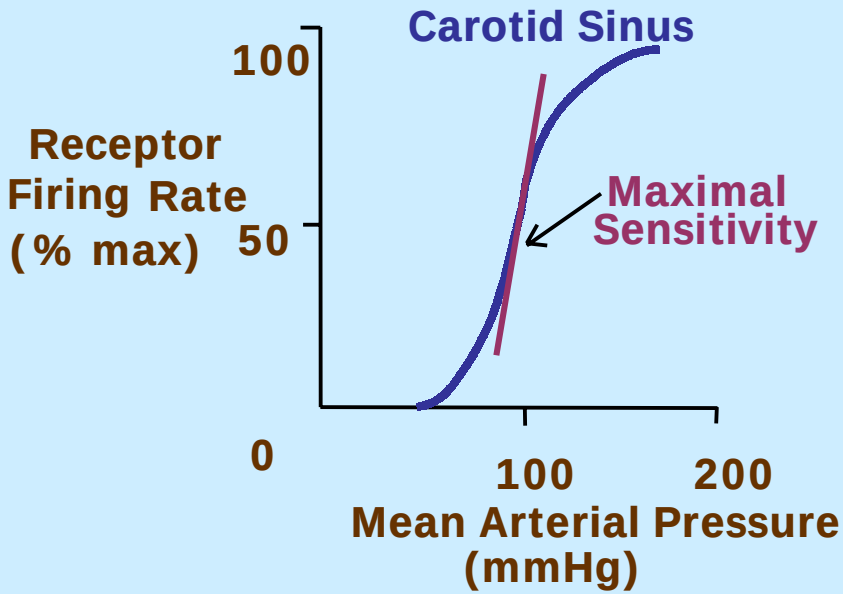
Compensatory Mechanisms

- Baroreceptor reflexes
- Circulating vasoconstrictors
- Chemoreceptor reflexes
- Reabsorption of tissue fluids
- Renal reabsorption of sodium and water
- Activation of thirst mechanisms
- Cerebral ischemia
- Hemapoiesis

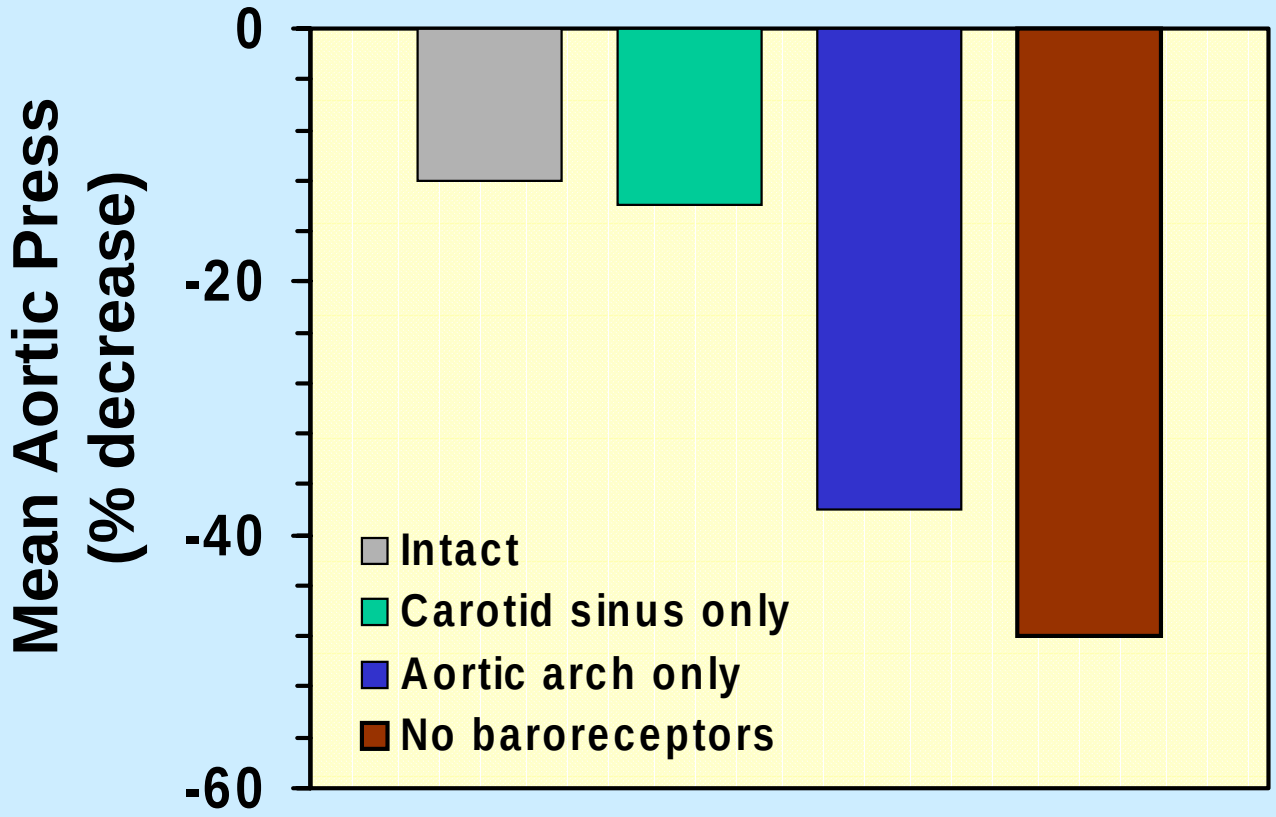
Arterial Baroreceptors







Effects of 8% Blood Loss on Aortic Pressure in Anesthetized Dogs
(Effects of Baroreceptor Denervation)

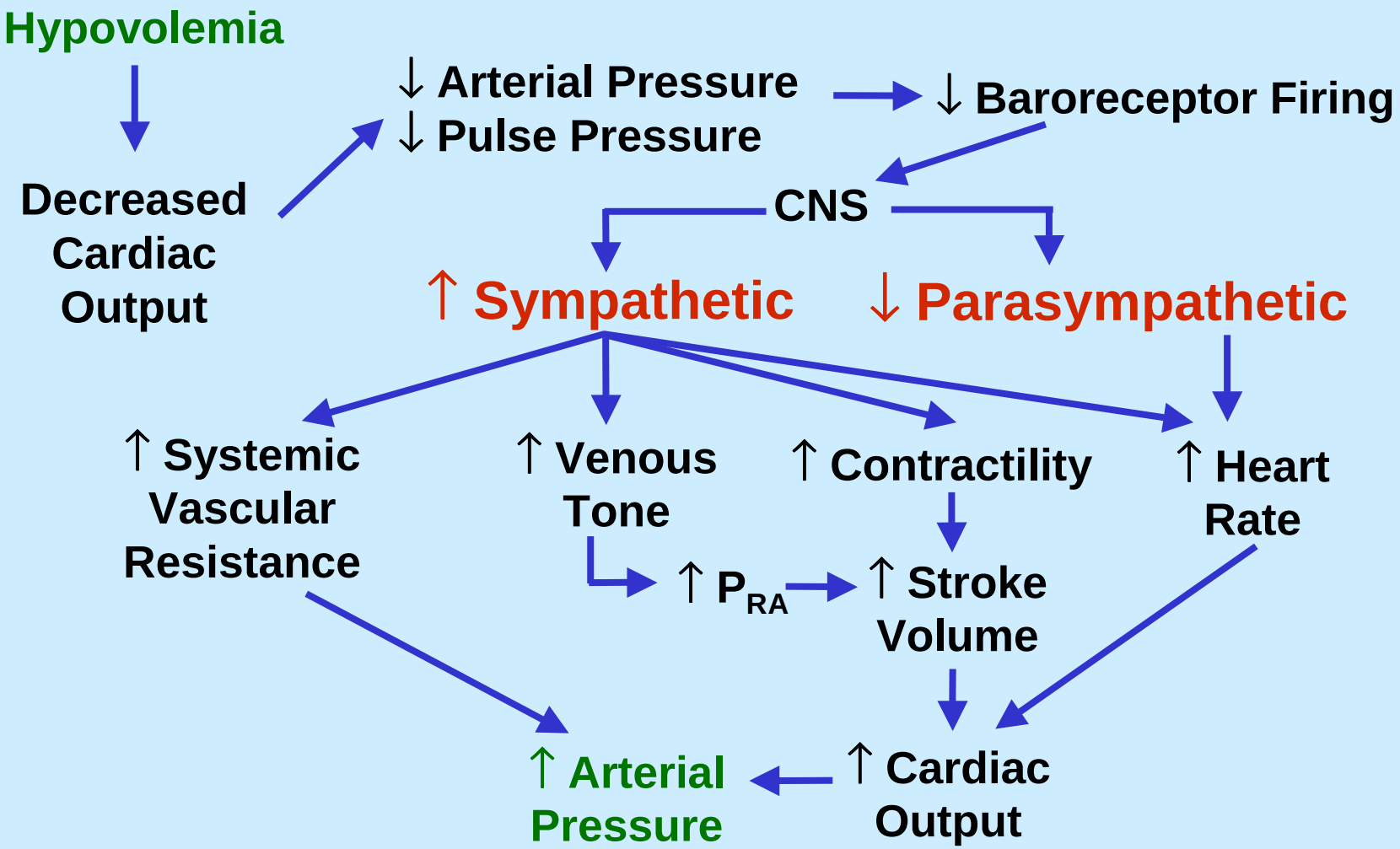


(adapted from A.J. Edis, 1971)

Cardiopulmonary Baroreceptors

- Location: Venoatrial Junction
  - **Tonically active**
    - Receptor firing decreases ADH release leading to diuresis
- Location: Atria and Ventricles
  - **Tonically active**
    - affect vagal and sympathetic outflow similar to arterial baroreceptors
    - reinforce arterial baroreceptor responses during hypovolemia

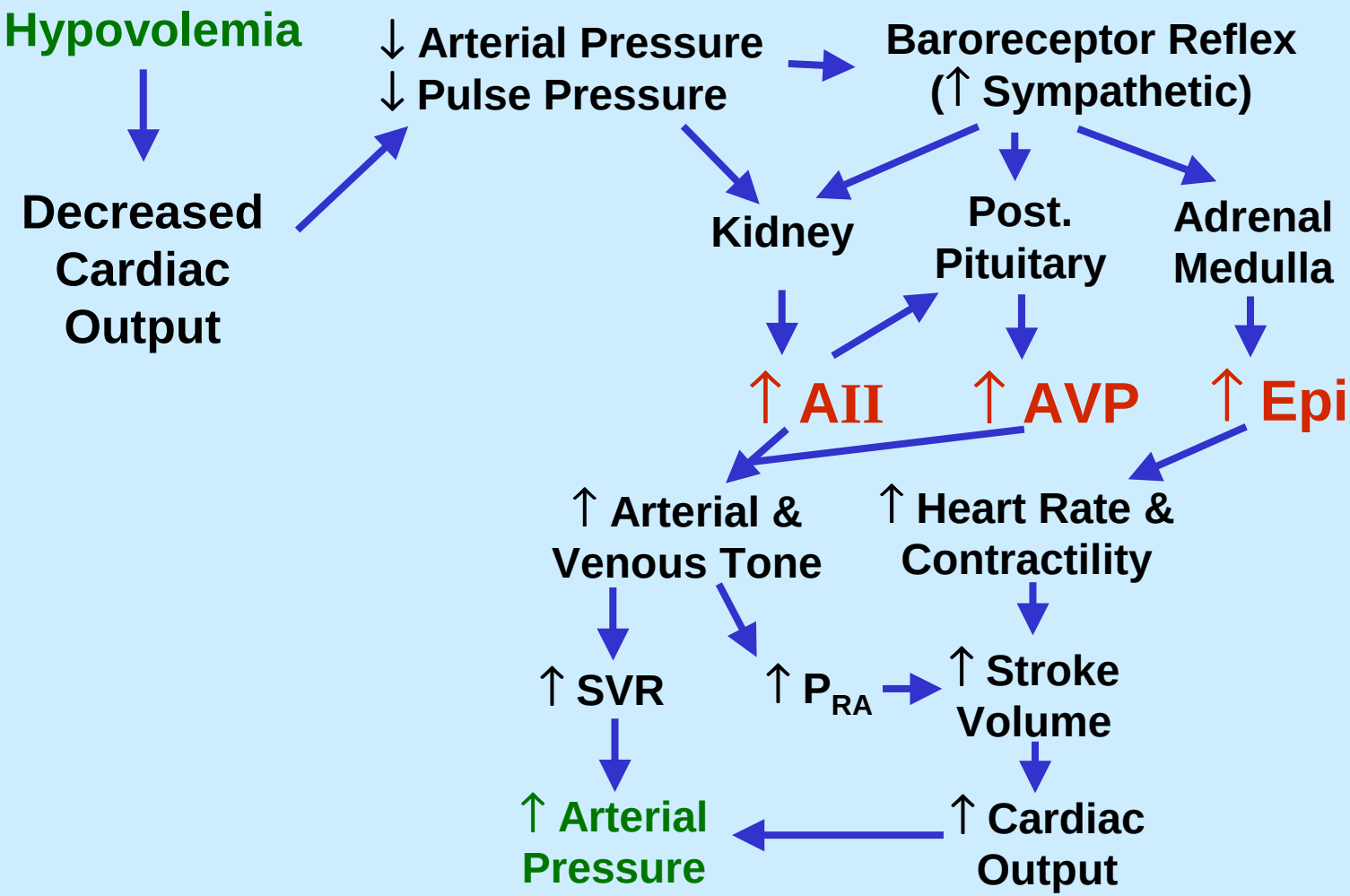
Baroreceptor Reflexes
(Neural Activation)



Baroreceptor Reflexes Cont.

- **Redistribution of cardiac output**
  - Intense vasoconstriction in skin, skeletal muscle, renal (during severe hemorrhage) and splanchnic circulations increases systemic vascular resistance
  - Coronary and cerebral circulations spared
  - Therefore, cardiac output is shunted to essential organs
- **Redistribution of blood volume**
  - Strong venoconstriction in splanchnic and skin circulations
  - Partial restoration of central venous blood volume and pressure to counteract loss of filling pressure to the heart

Circulating Vasoconstrictors



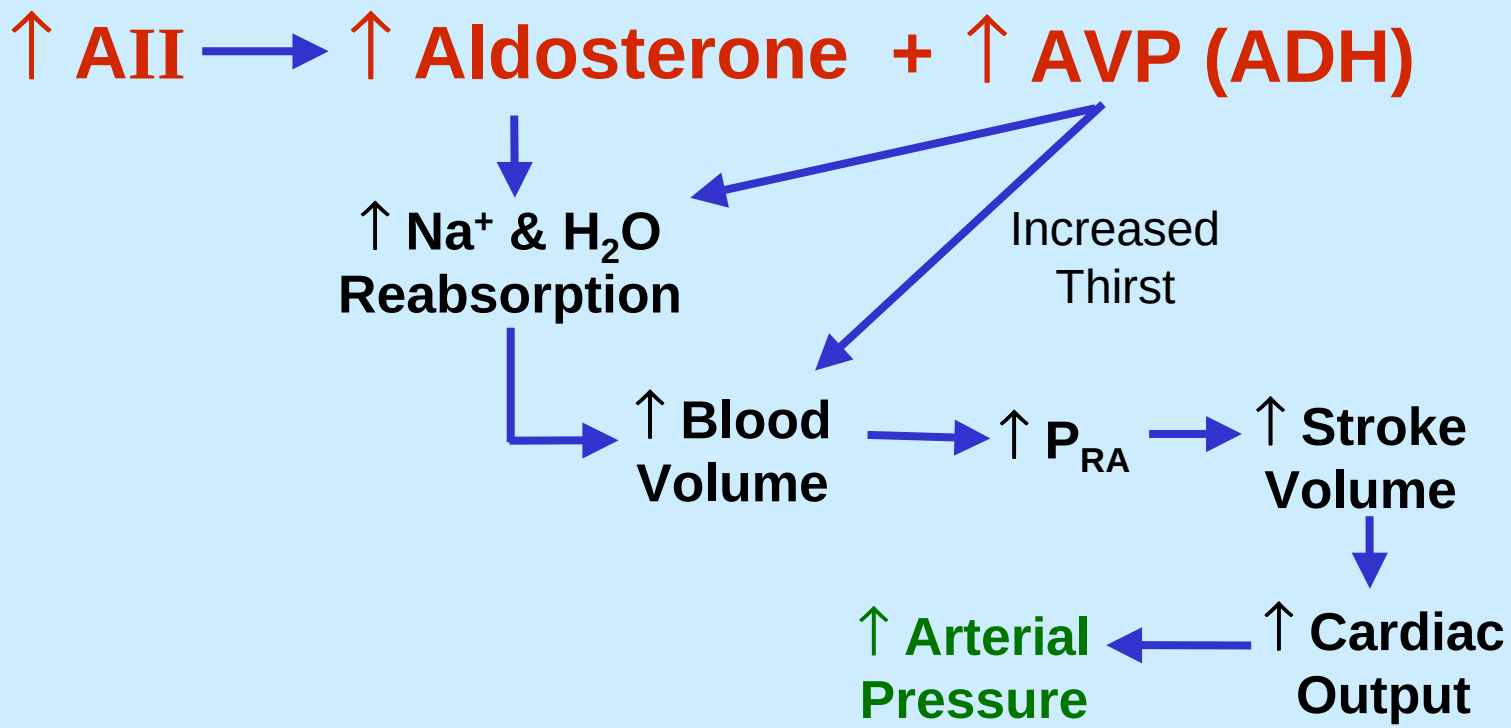
Chemoreceptor Reflexes

- Increasingly important when mean arterial pressure falls below 60 mmHg (i.e., when arterial baroreceptor firing rate is at minimum)
- Acidosis resulting from decreased organ perfusion stimulates central and peripheral chemoreceptors
- Stagnant hypoxia in carotid bodies enhances peripheral vasoconstriction
- Respiratory stimulation may enhance venous return (abdominothoracic pump)

Reabsorption of Tissue Fluids

- Capillary pressure falls
  - Reduced arterial and venous pressures
  - Increased precapillary resistance
  - Transcapillary fluid reabsorption (up to 1 liter/hr autoinfused)
- Capillary plasma oncotic pressure can fall from 25 to 15 mmHg due to autoinfusion thereby limiting capillary fluid reabsorption
- Hemodilution causes hematocrit to fall which decreases blood viscosity
- Up to 1 liter/hr can be autoinfused by this mechanism

Renal Compensation



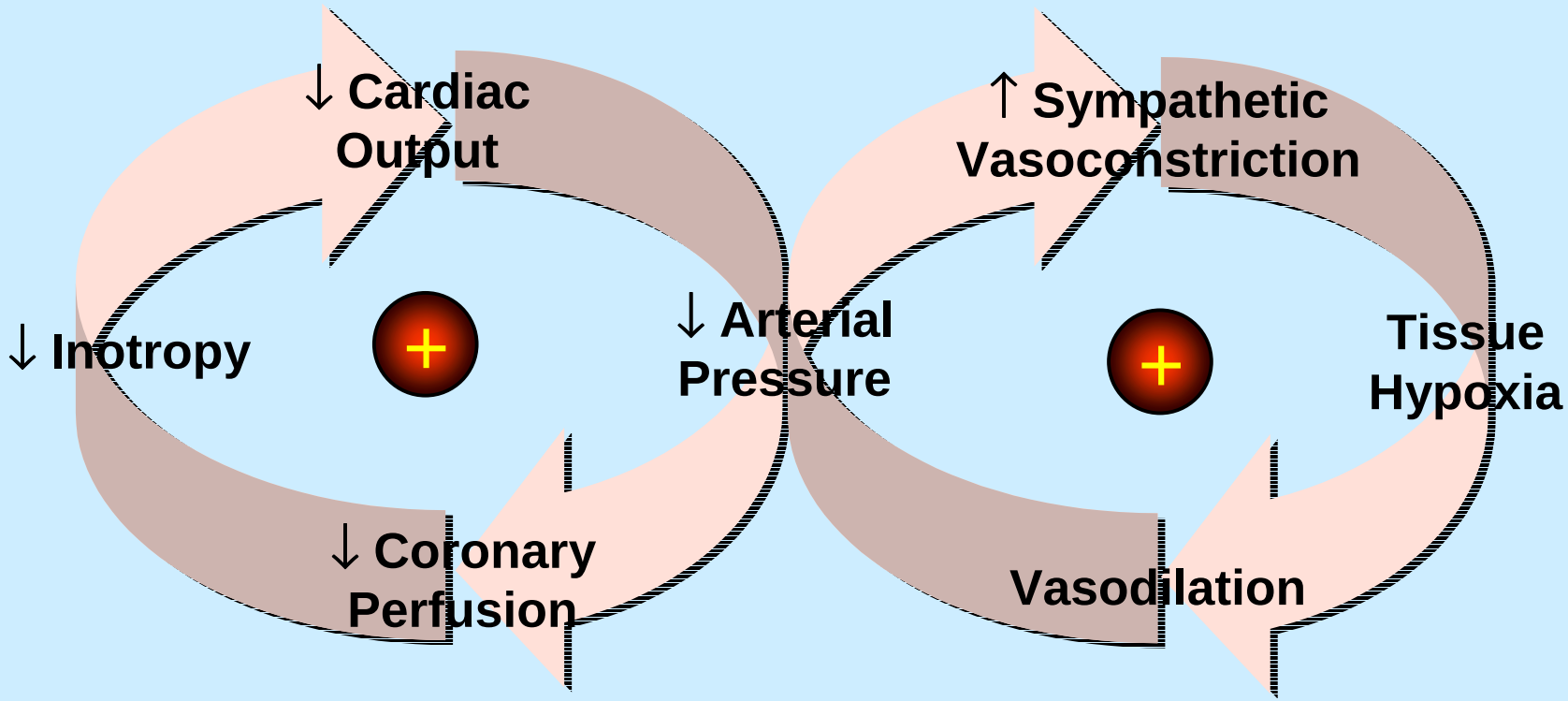
Cerebral Ischemia

- When mean arterial pressure falls below 60 mmHg, cerebral perfusion decreases because the pressure is below the autoregulatory range
- Cerebral ischemia produces very intense sympathetic discharge that is several-fold greater than the maximal sympathetic activation caused by the baroreceptor reflex

Decompensatory Mechanisms

- **Cardiogenic Shock**
  - **Impaired coronary perfusion causing myocardial hypoxia, systolic and diastolic dysfunction**
- **Sympathetic Escape**
  - **Loss of vascular tone (↓SVR) causing progressive hypotension and organ hypoperfusion**
  - **Increased capillary pressure causing increased fluid filtration and hypovolemia**
- **Cerebral Ischemia**
  - **Loss of autonomic outflow due to severe cerebral hypoxia**

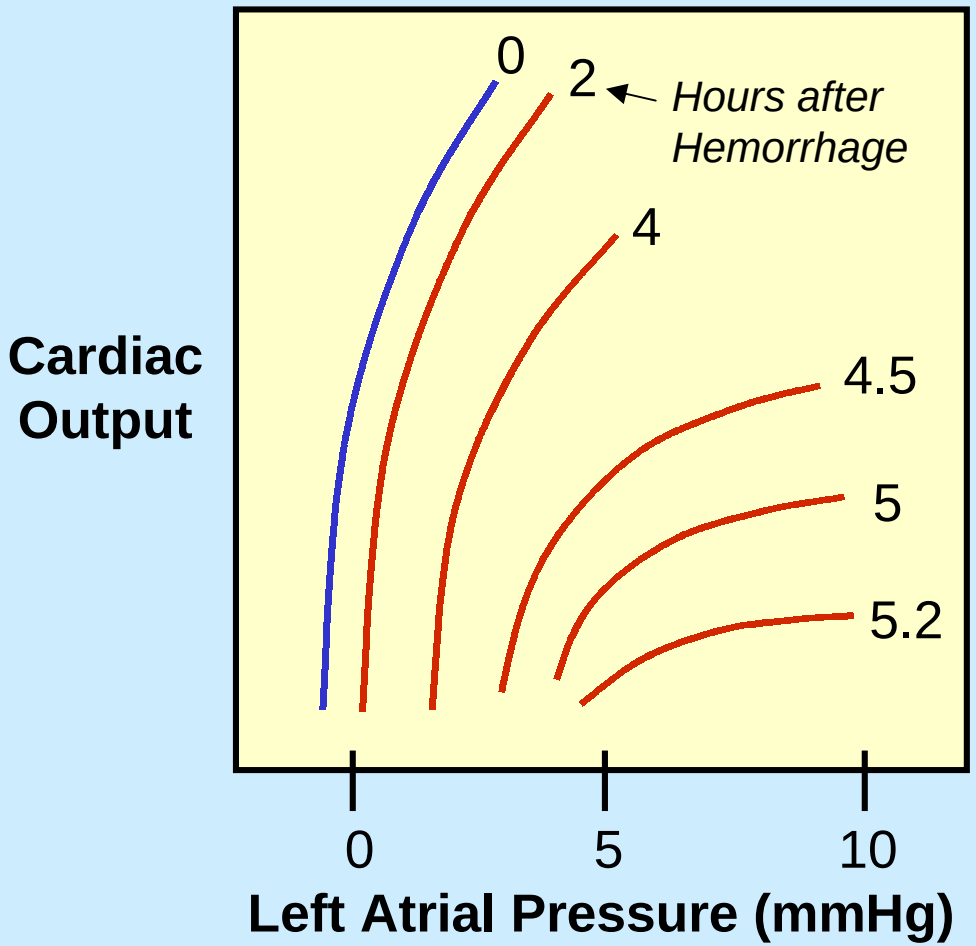
Decompensatory Mechanisms
(Cardiogenic Shock and Sympathetic Escape)



Decompensatory Mechanisms cont.

- **Systemic Inflammatory Response**
  - Endotoxin release into systemic circulation
  - Cytokine formation – TNF, IL, etc.
  - Enhanced nitric oxide formation
  - Reactive oxygen-induced cellular damage
  - Multiple organ failure
  - Microvascular plugging by leukocytes and platelets
- **Cerebral Ischemia**
  - Loss of autonomic outflow due to severe cerebral hypoxia

Time-Dependent Changes in Cardiac Function



- **Dogs hemorrhaged and arterial pressure held at 30 mmHg**
- **Precipitous fall in cardiac function occurred after 4 hours of severe hypotension**

(adapted from Crowell et al., 1962)

Resuscitation Issues
(Current Research)

- **Reducing reperfusion injury & systemic inflammatory response syndrome (SIRS)**
  - **Anti-inflammatory drugs**
  - **NO scavenging and antioxidant drugs**
- **Resuscitation fluids**
  - **Crystalloid vs. non-crystalloid solutions**
  - **Isotonic vs. hypertonic solutions**
  - **Whole blood vs. packed red cells**
  - **Hemoglobin-based solutions**
  - **Perfluorocarbon-based solutions**
  - **Fluid volume-related issues**

Resuscitation Issues cont.
(Current Research)

- **Efficacy of pressor agents**
- **Hypothermic vs. normothermic resuscitation**
- **Tailoring therapy to conditions of shock**
  - **Uncontrolled vs. controlled hemorrhage**
  - **Traumatic vs. atraumatic shock**