The Pathophysiology of Hemorrhagic Shock

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Learning Objectives

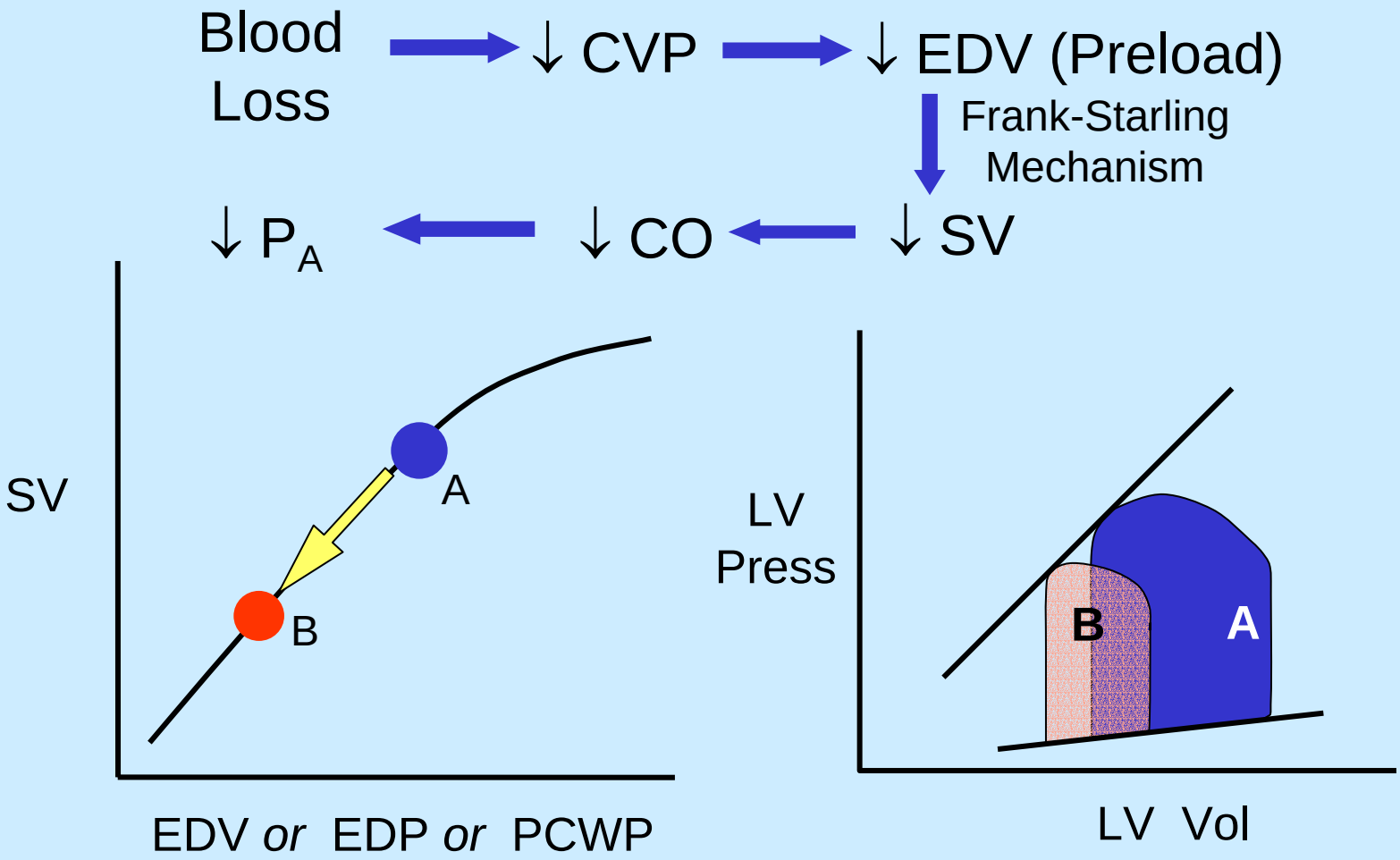
- Describe how acute blood loss leads to hypotension.
- Describe the compensatory mechanisms that operate to restore arterial pressure following hemorrhage.
- Describe the decompensatory mechanisms that lead to irreversible shock.
- Describe the rationale for different medical interventions following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

General Definition of Hemorrhagic Shock

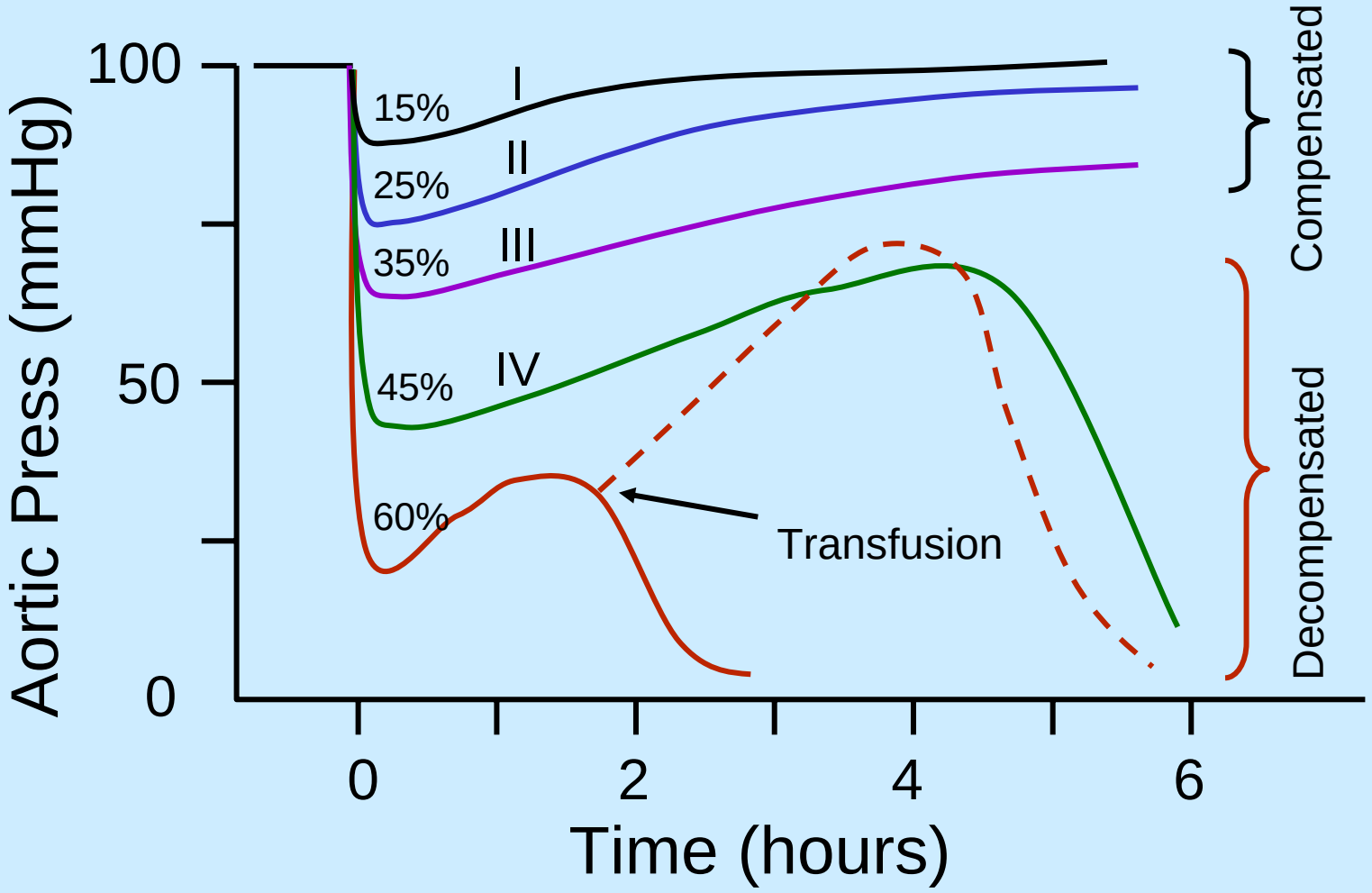
A clinical syndrome resulting from decreased blood and oxygen perfusion of vital organs resulting from a loss of blood volume.

Hemorrhagic Shock

(Initial Uncompensated Responses)



Effects Blood Volume Loss on Mean Arterial Pressure



(Adapted from Guyton & Crowell, 1961)

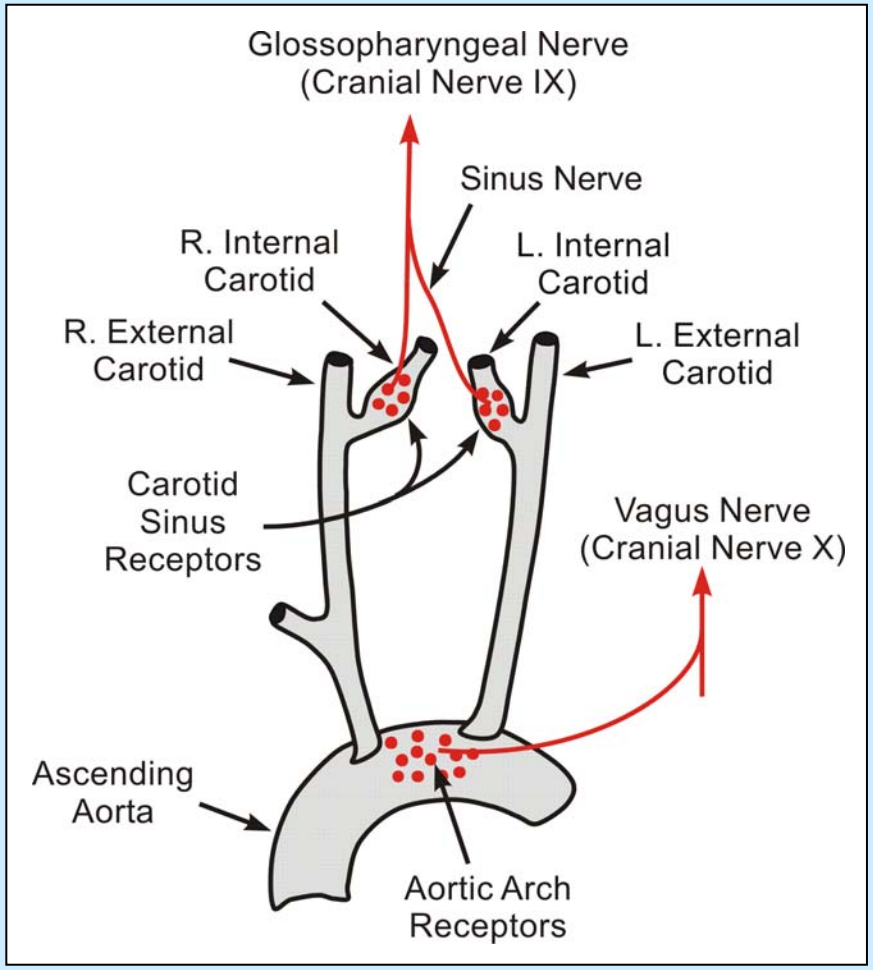
Classes of Hemorrhagic Shock

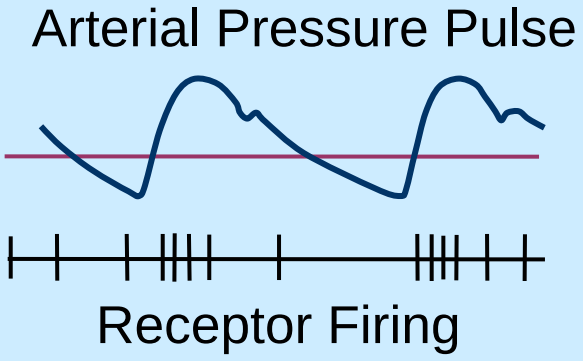
- Class I hemorrhage (loss of 0-15%)
  - Little tachycardia
  - Usually no significant change in BP, pulse pressure, respiratory rate
- Class II hemorrhage (loss of 15-30%)
  - HR >100 beats per minute, tachypnea, decreased pulse pressure
- Class III hemorrhage (loss of 30-40%)
  - Marked tachycardia and tachypnea, decreased systolic BP, oliguria
- Class IV hemorrhage (loss of >40%)
  - Marked tachycardia and decreased systolic BP, narrowed pulse pressure, markedly decreased (or no) urinary output
  - Immediately life threatening

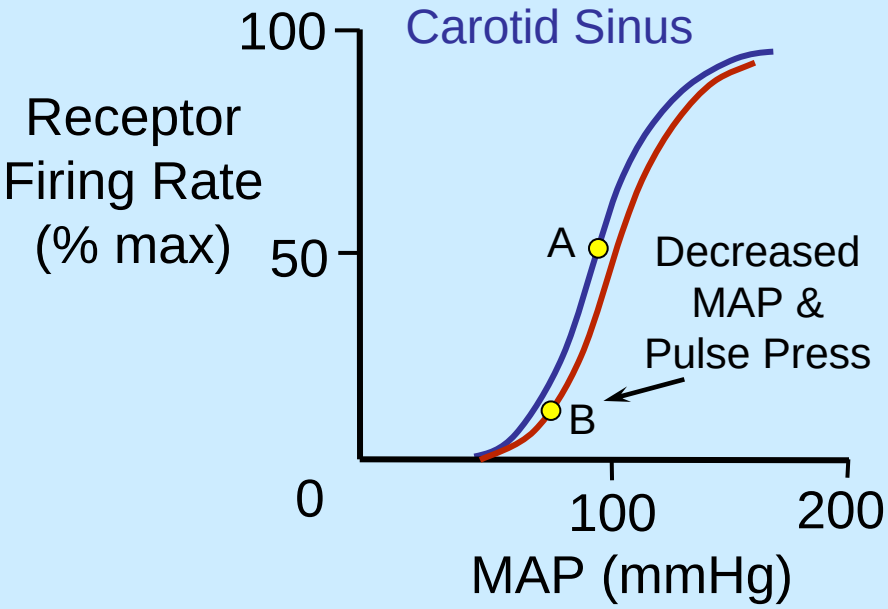
Compensatory Mechanisms

- 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







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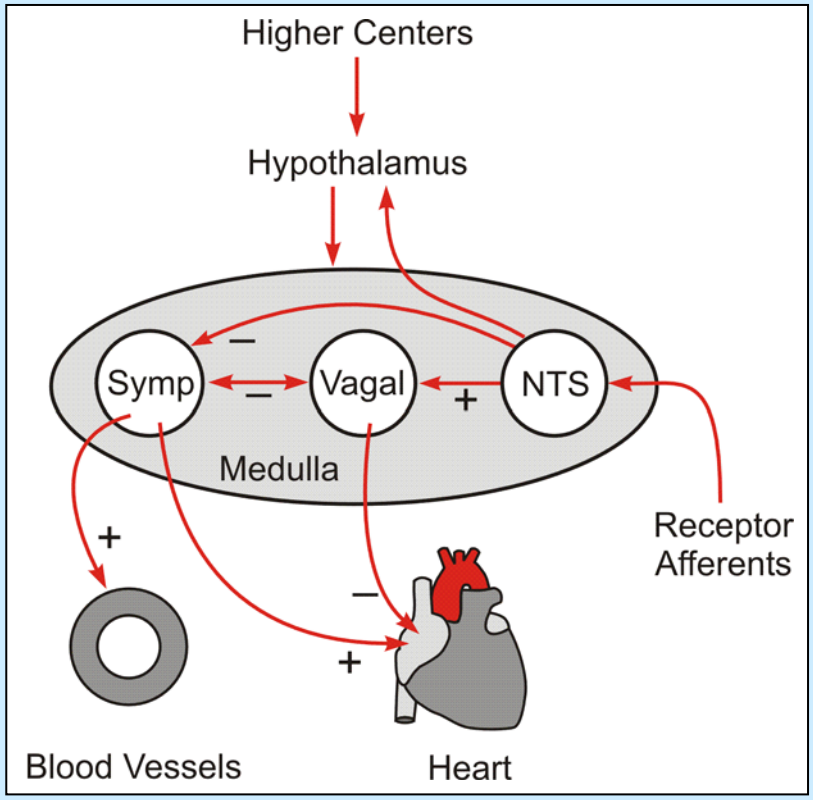
Autonomic Responses to Baroreceptor Activity



- Arterial baroreceptor firing inhibits sympathetic outflow and stimulates parasympathetic outflow
- Therefore, reduced firing, which occurs during hemorrhage, leads to sympathetic activation and parasympathetic inhibition

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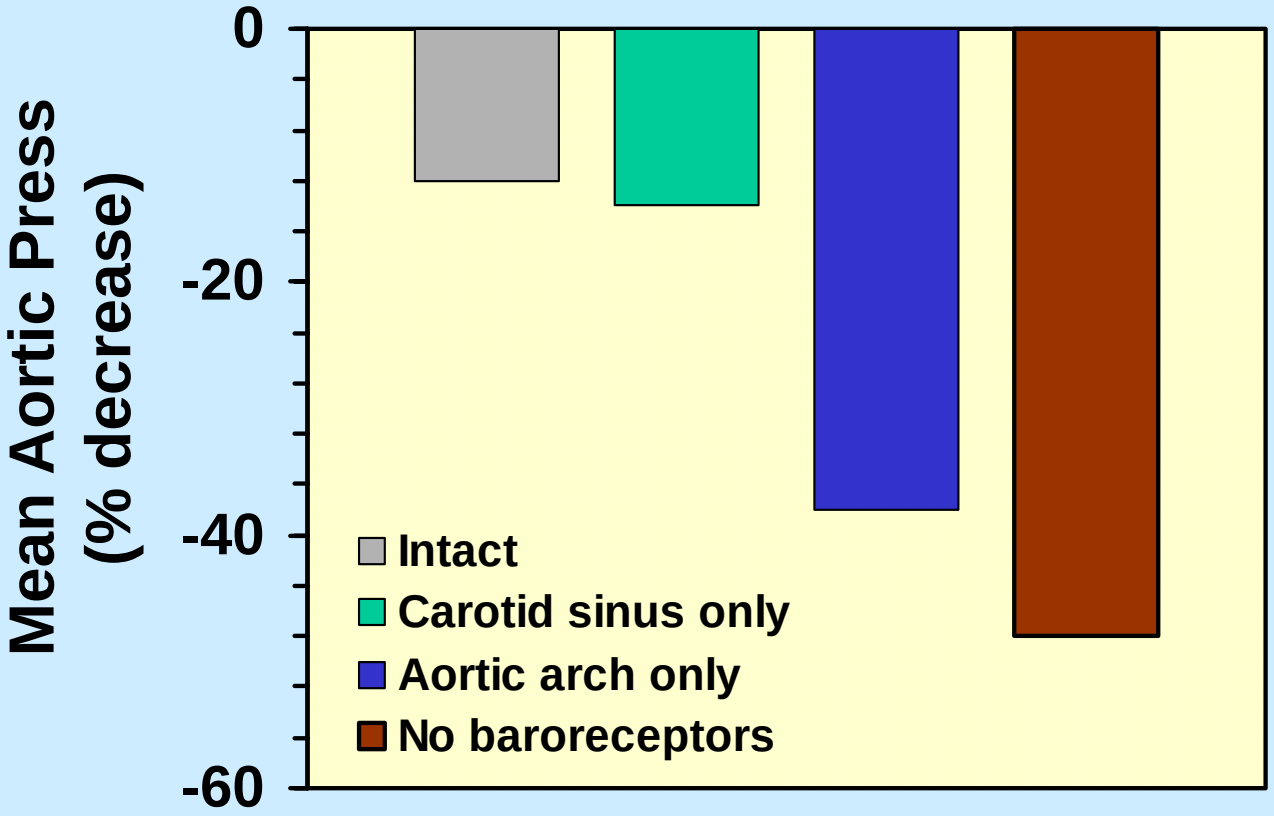
Effects of 8% Blood Loss on Aortic Pressure in Anesthetized Dogs
(Effects of Baroreceptor Denervation)

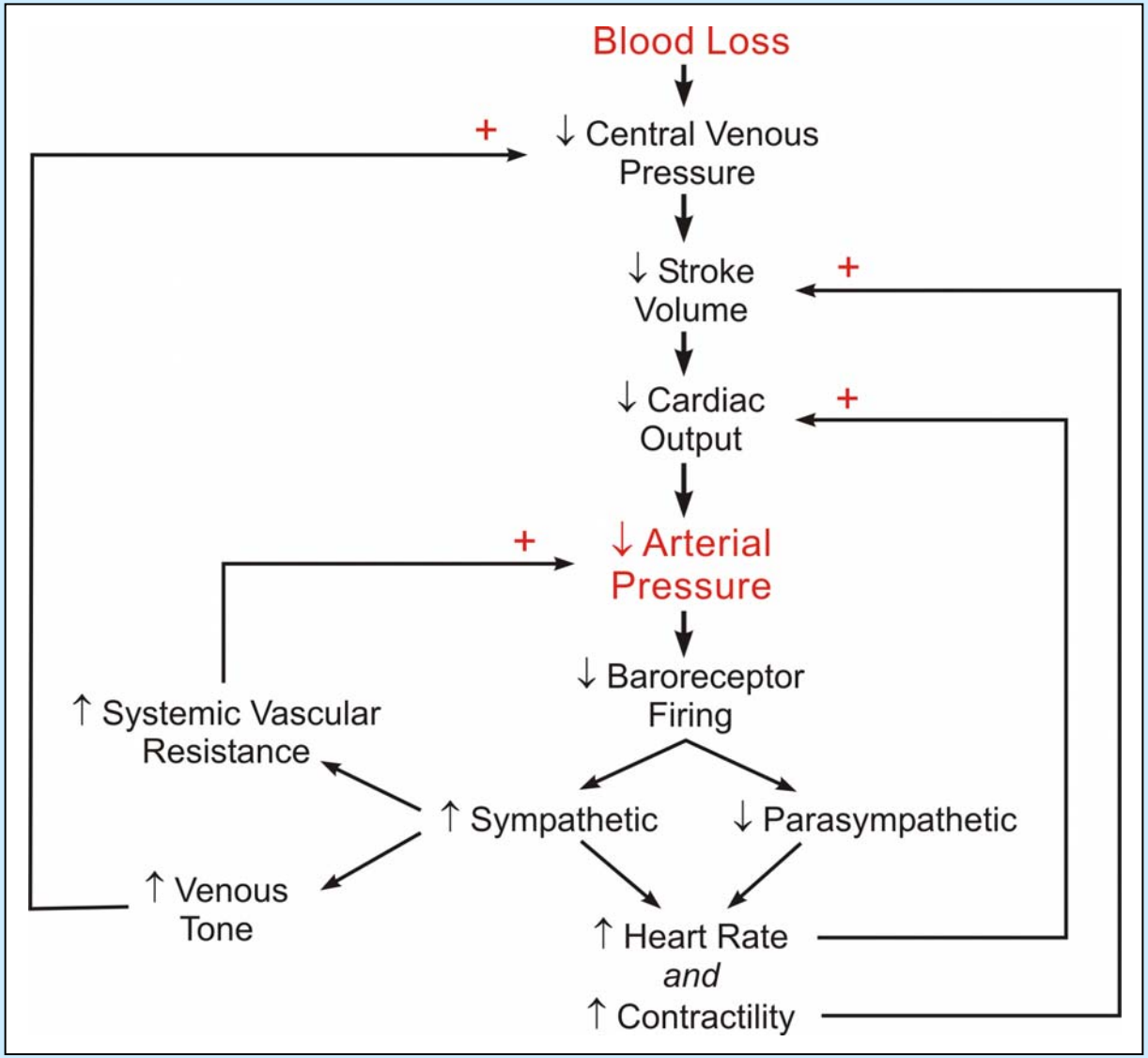


(Adapted from A.J. Edis, 1971)

Cardiopulmonary Baroreceptors

- Location: Venoatrial Junction
  - Tonically active
    - Receptor firing decreases ADH (vasopressin) release leading to diuresis and vasodilation
    - Hemorrhage $\rightarrow$ increase ADH (reduced urine formation and increased vasoconstriction)
- Location: Atria and Ventricles
  - Tonically active
    - affect vagal and sympathetic outflow similar to arterial baroreceptors
    - reinforce arterial baroreceptor responses during hypovolemia

Baroreceptor Reflexes



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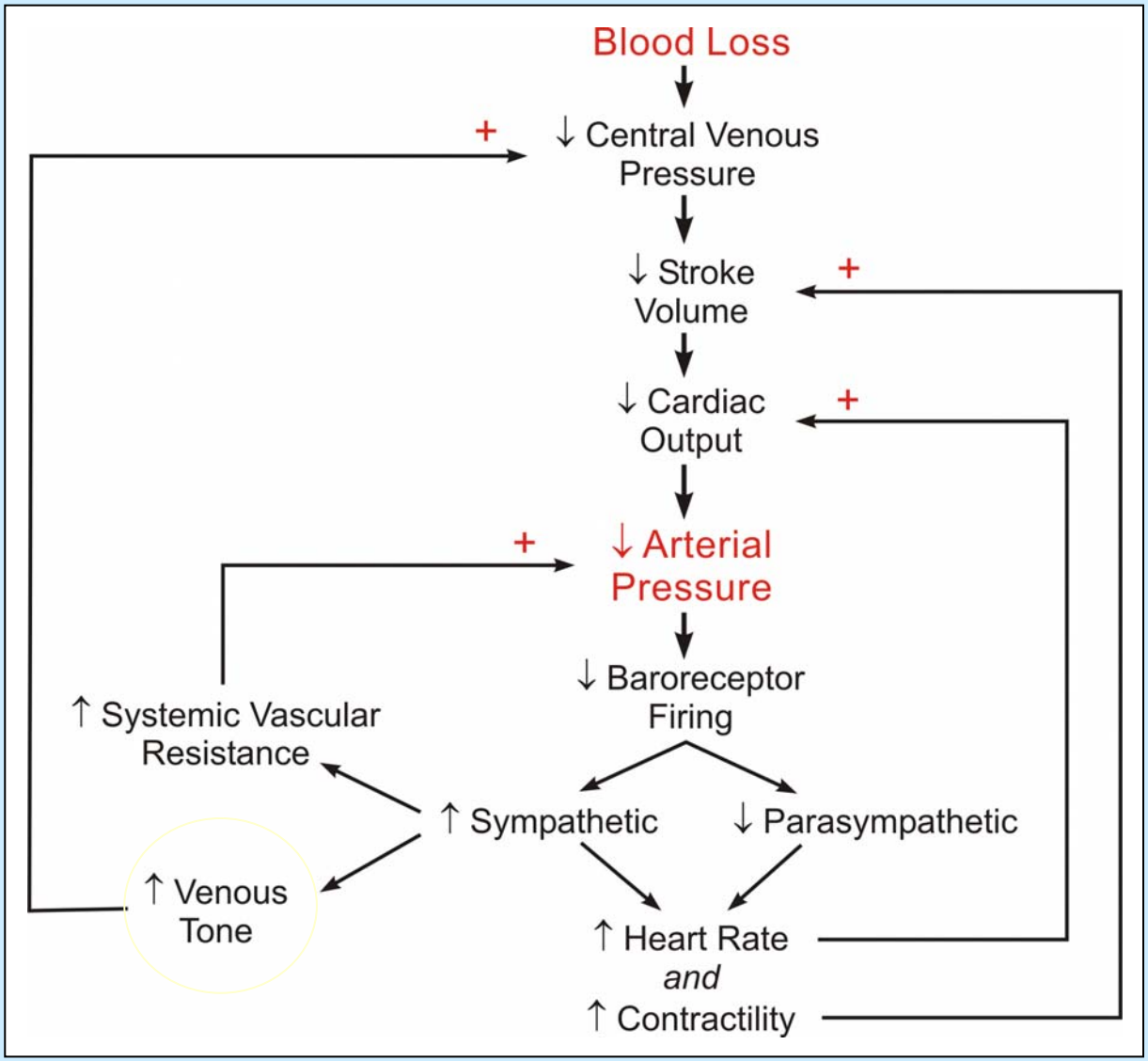
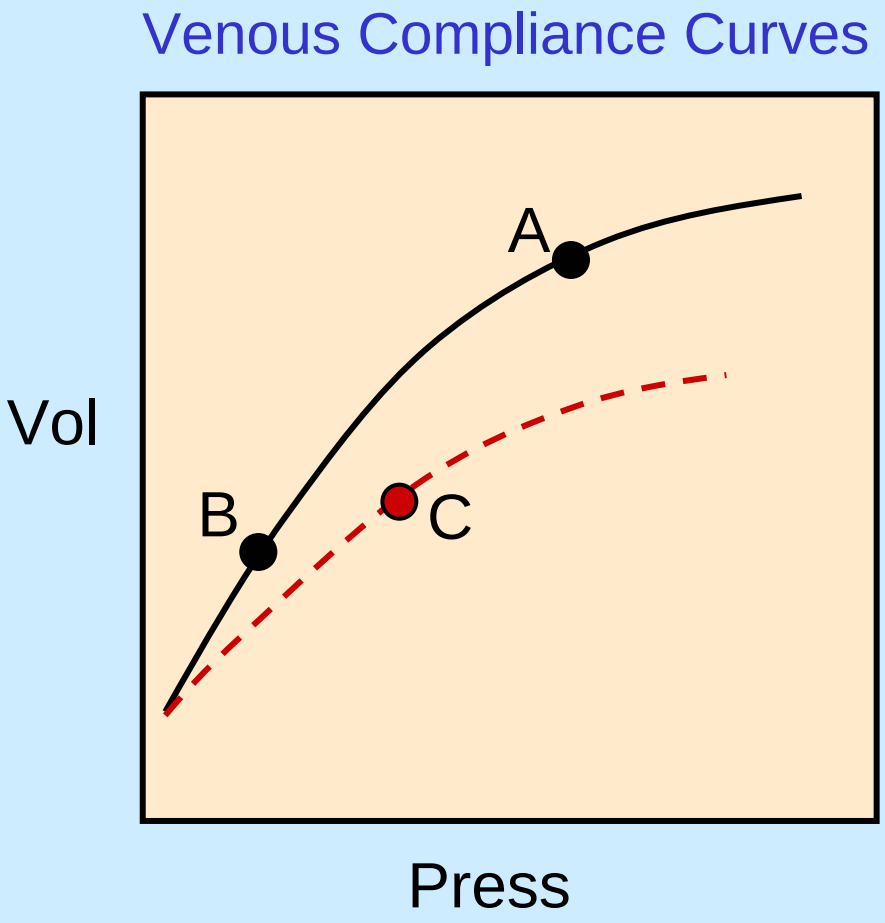
Baroreceptor Reflexes Cont.

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

Importance of Changes in Venous Tone

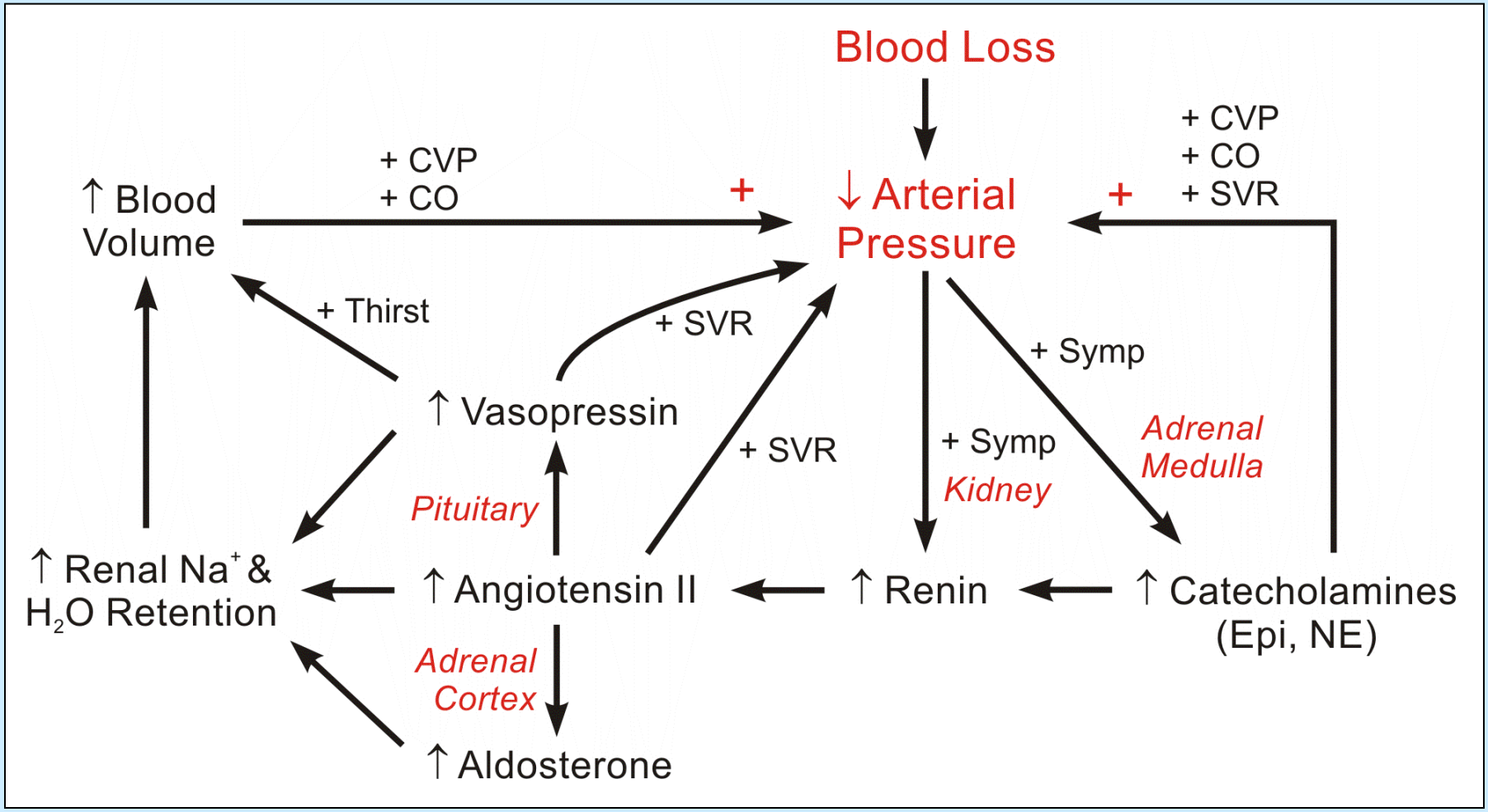


Central Venous Pressure During Hemorrhage



- Hemorrhage decreases blood volume and decreases CVP (A→B)
- Peripheral venous constriction decreases venous compliance (B→C), which increases CVP and shifts blood volume toward heart
- Increased CVP increases ventricular preload and force of contraction (Frank-Starling mechanism)

Humoral Compensatory Mechanisms



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Importance of Humoral Compensatory Mechanisms

- Angiotensin II, vasopressin and catecholamines reinforce sympathetic mediated vasoconstriction to help maintain arterial pressure by
  - increasing systemic vascular resistance
  - decreasing venous compliance, which increases ventricular preload and enhances stroke volume
- Angiotensin II, aldosterone and vasopressin act on the kidneys to increase blood volume

Chemoreceptor Reflexes

- Peripheral chemoreceptors
  - Carotid bodies
  - Aortic bodies
- Central chemoreceptors
  - Medulla (associated with cardiovascular control “centers”)

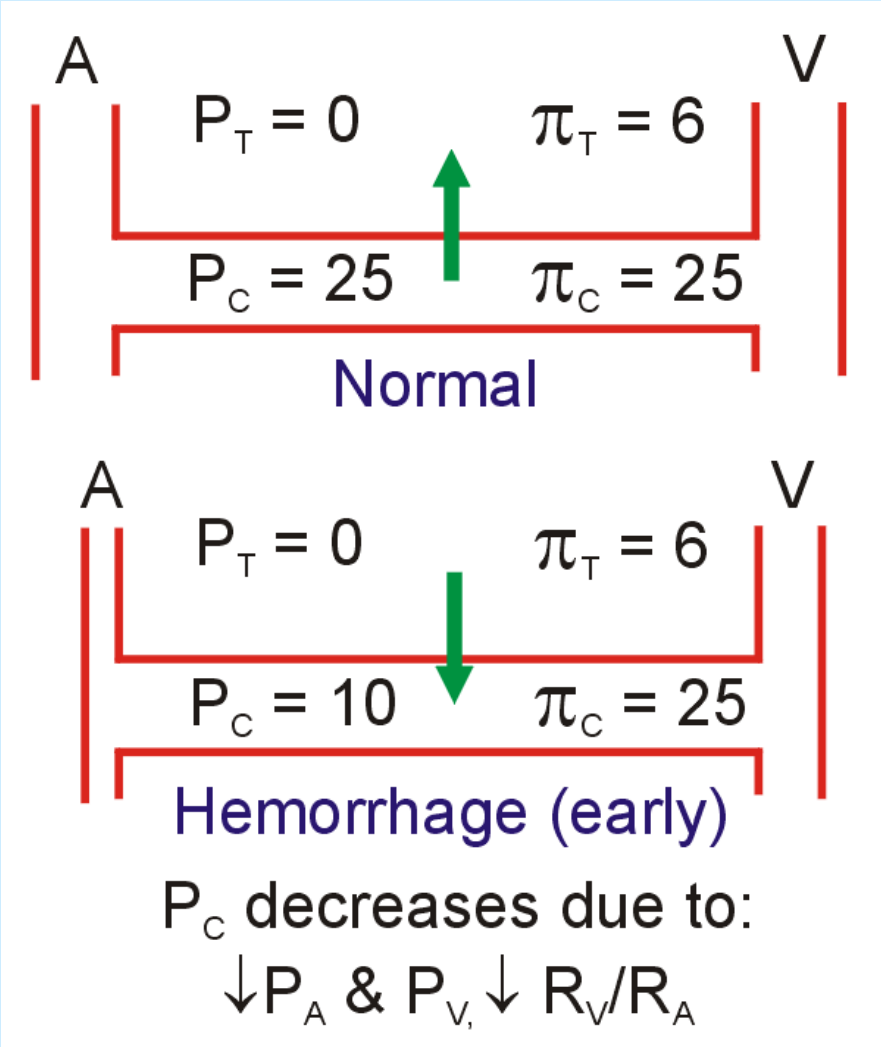
Chemoreceptor Reflexes cont.

- 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 $\rightarrow$ sympathetic activation
- 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

Changes in Starling Forces Following Hemorrhage



Starling Equation for Fluid Balance

$$FM = K \cdot A\left[(P_C - P_T) - (\pi_C - \pi_T)\right]$$

Cerebral Ischemia

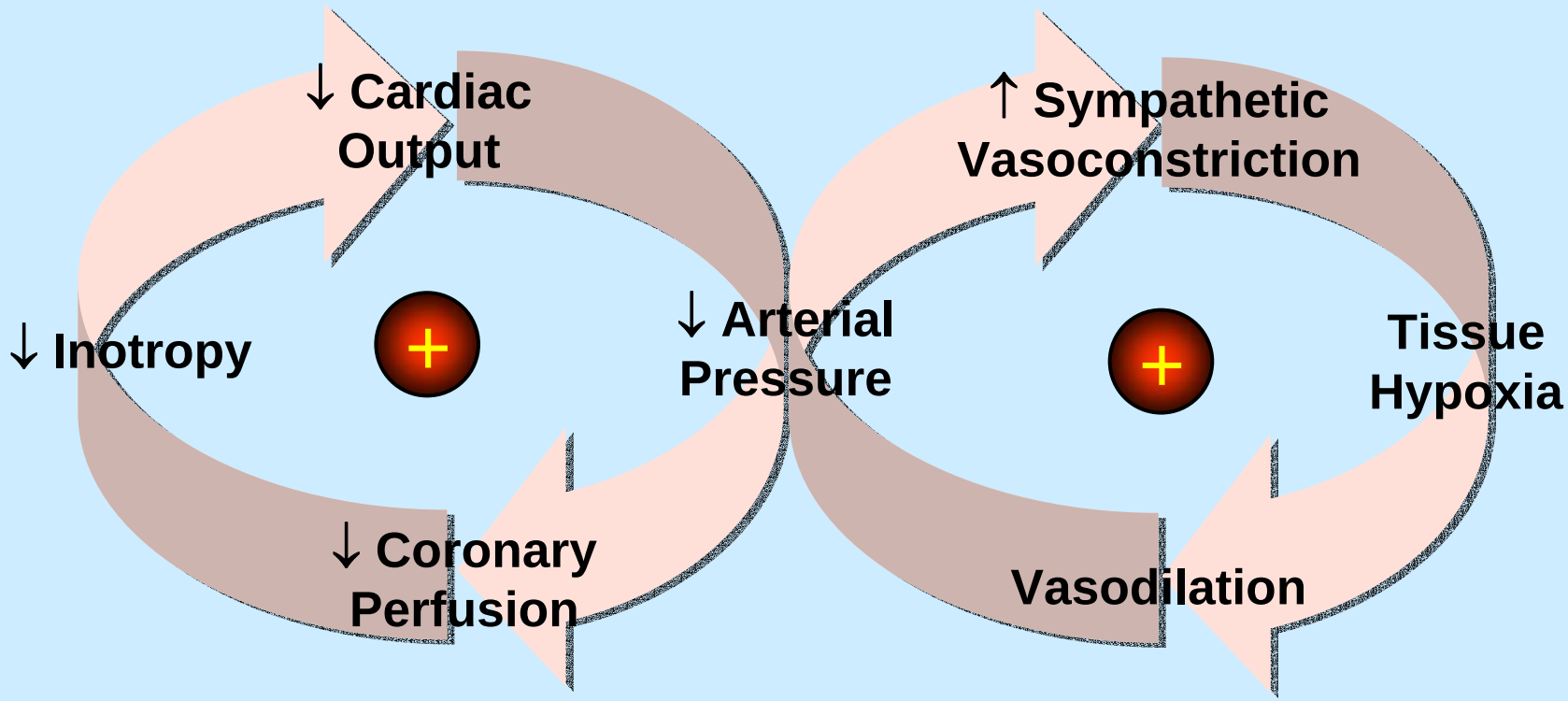
- When mean arterial pressure falls below 60 mmHg, cerebral perfusion decreases because the pressure is below the autoregulatory range
- Cerebral ischemia produces very intense sympathetic discharge that is several-fold greater than the maximal sympathetic activation caused by the baroreceptor reflex

Decompensatory Mechanisms
"Progressive Shock"

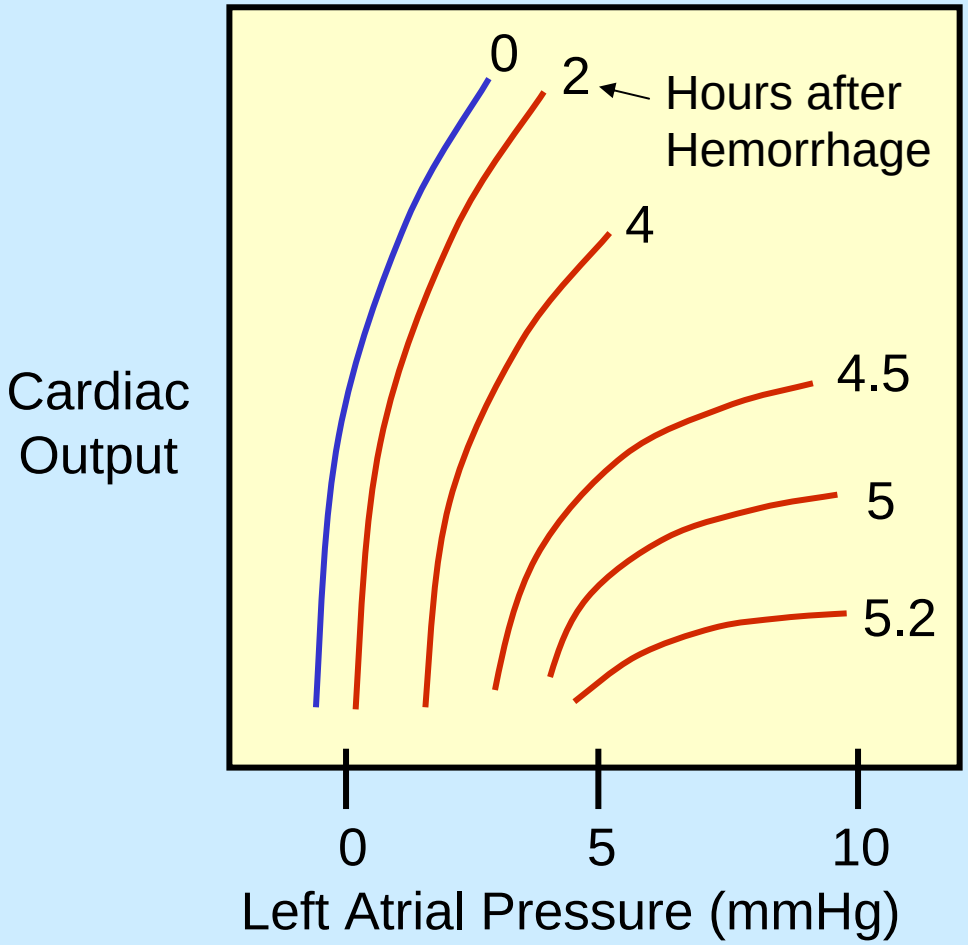
- Cardiogenic Shock
  - Impaired coronary perfusion causing myocardial hypoxia, systolic and diastolic dysfunction, arrhythmias
- Sympathetic Escape
  - Loss of vascular tone (↓SVR) causing progressive hypotension and organ hypoperfusion
  - Increased capillary pressure causing increased fluid filtration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

- Metabolic Acidosis
- Rheological –
  - Increased microvascular viscosity
  - Microvascular plugging by leukocytes and platelets
  - Intravascular coagulation
- Systemic Inflammatory Response
  - Endotoxin release into systemic circulation
  - Cytokine formation – TNF, IL, etc.
  - Enhanced nitric oxide formation
  - Reactive oxygen-induced cellular damage
  - Increased capillary permeability
  - Multiple organ failure

Decompensatory Mechanisms
(Cardiogenic Shock and Sympathetic Escape)



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)

Comparison of Different Forms of Shock

	Cardiogenic Shock	Hemorrhagic Shock	Septic Shock
CV Origin	Cardiac	Volume	Vascular
Cardiac Output	↓	↓	↑↓
Vascular Resistance	↑	↑	↓
Blood Volume	↑	↓	↓
Management	Mechanical Inotropes Vasopressors Vasodilators	IV Fluids/Blood Vasopressors	IV Fluids Antibiotics Vasopressors Inotropes

Resuscitation Issues

- 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

Review Learning Objectives

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