Shock

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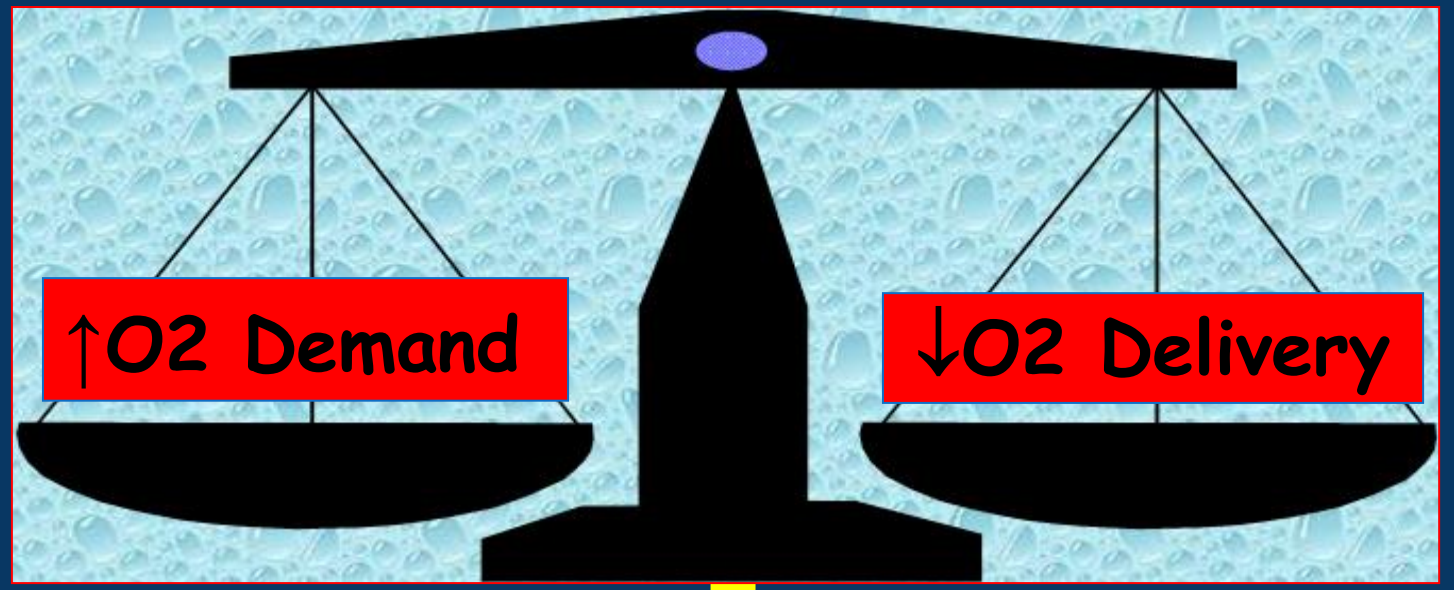
Outline for Today

- Definition
- Ramifications
- Physiologic determinants
- Classification
- Approach to the patient with shock

Shock is:



Reduced Tissue Perfusion

Cellular Hypoxia & Energy Failure

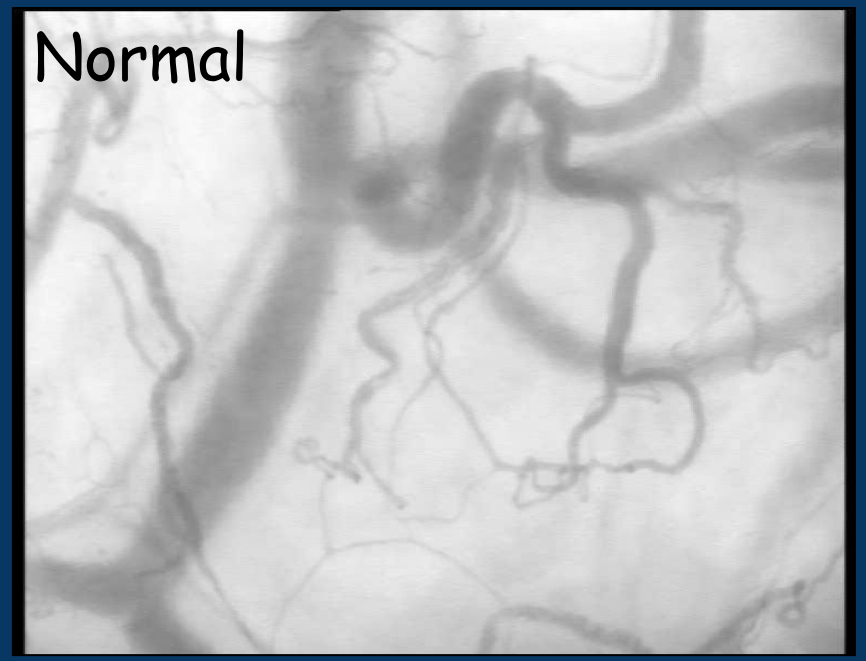
Definition

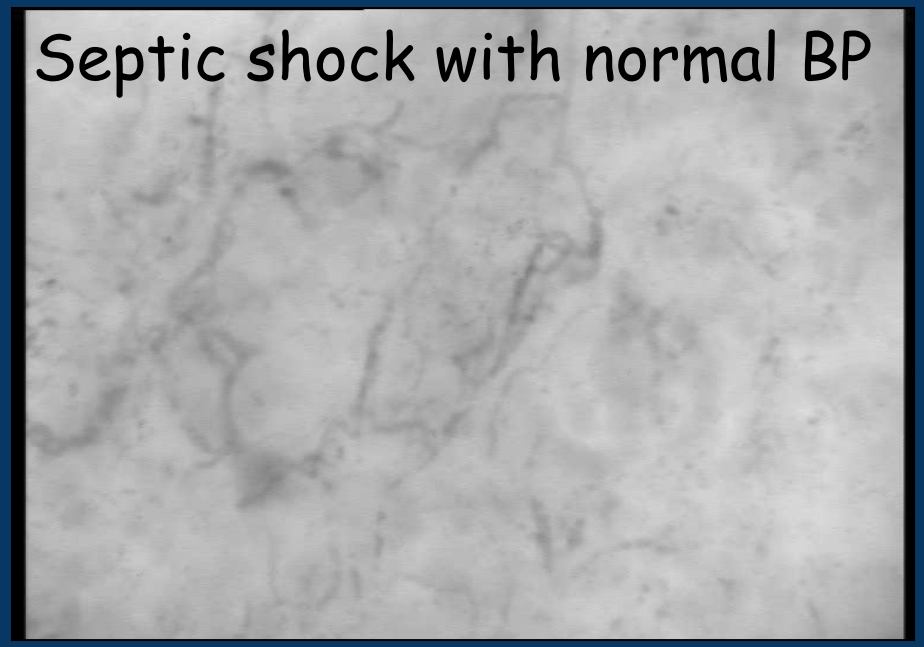
- A physiologic state in which significant, systemic reduction in tissue perfusion results in decreased tissue oxygen delivery

- Shock is not:
  - an absolute blood pressure measurement
  - an independent diagnosis

Key Issues In Shock

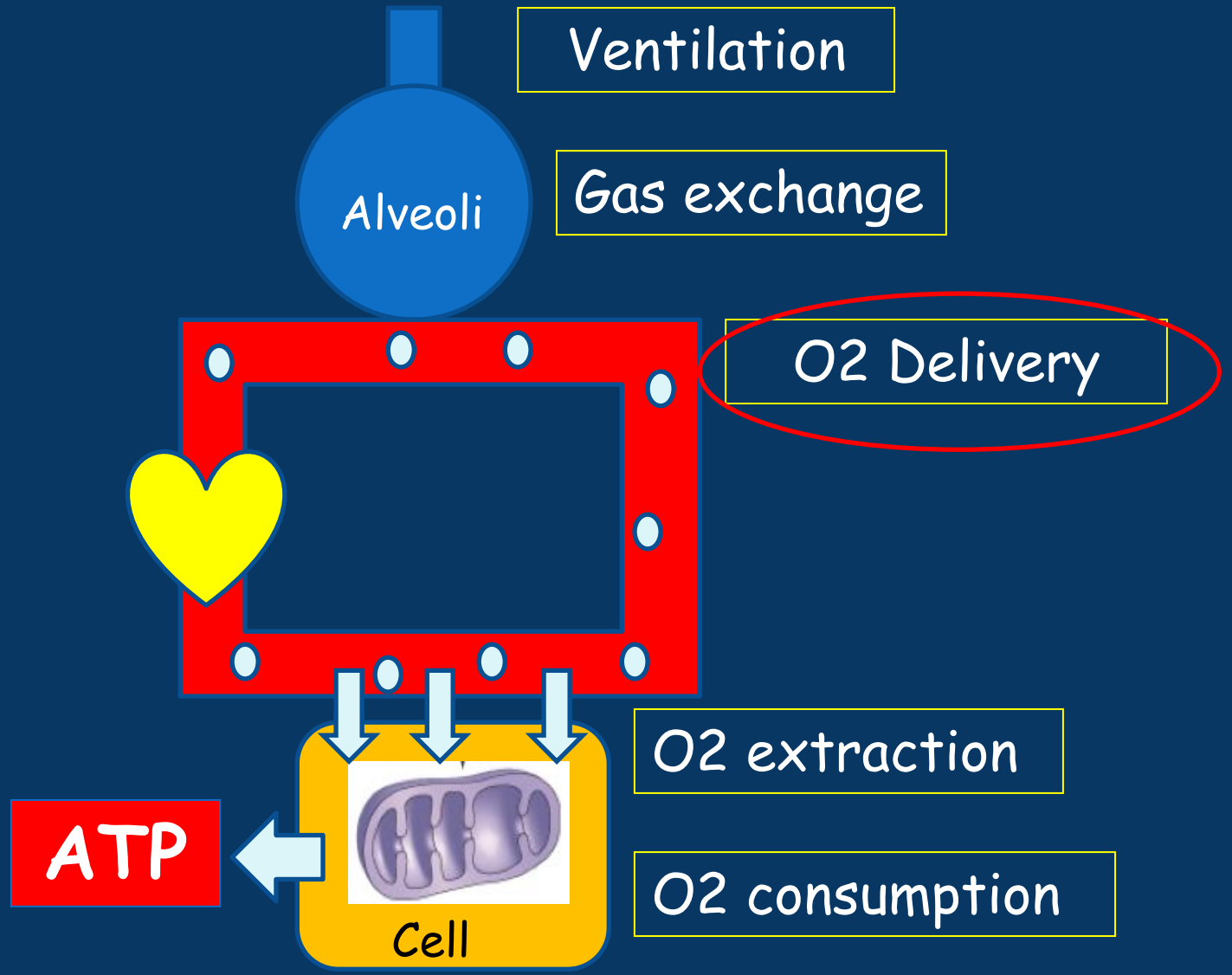
- Falling BP = LATE sign.
- Pallor, tachycardia, slow CFT, restlessness
  = Shock until proven otherwise.
- BP is NOT same as perfusion.



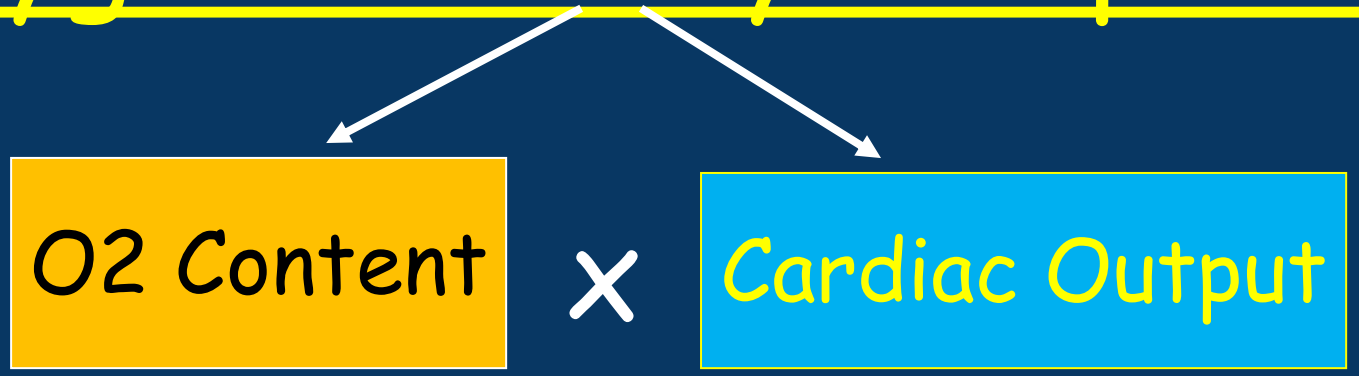


De Baker CCM 2006 34 :403-408

Oxygen Delivery to Tissues



Oxygen Delivery Components



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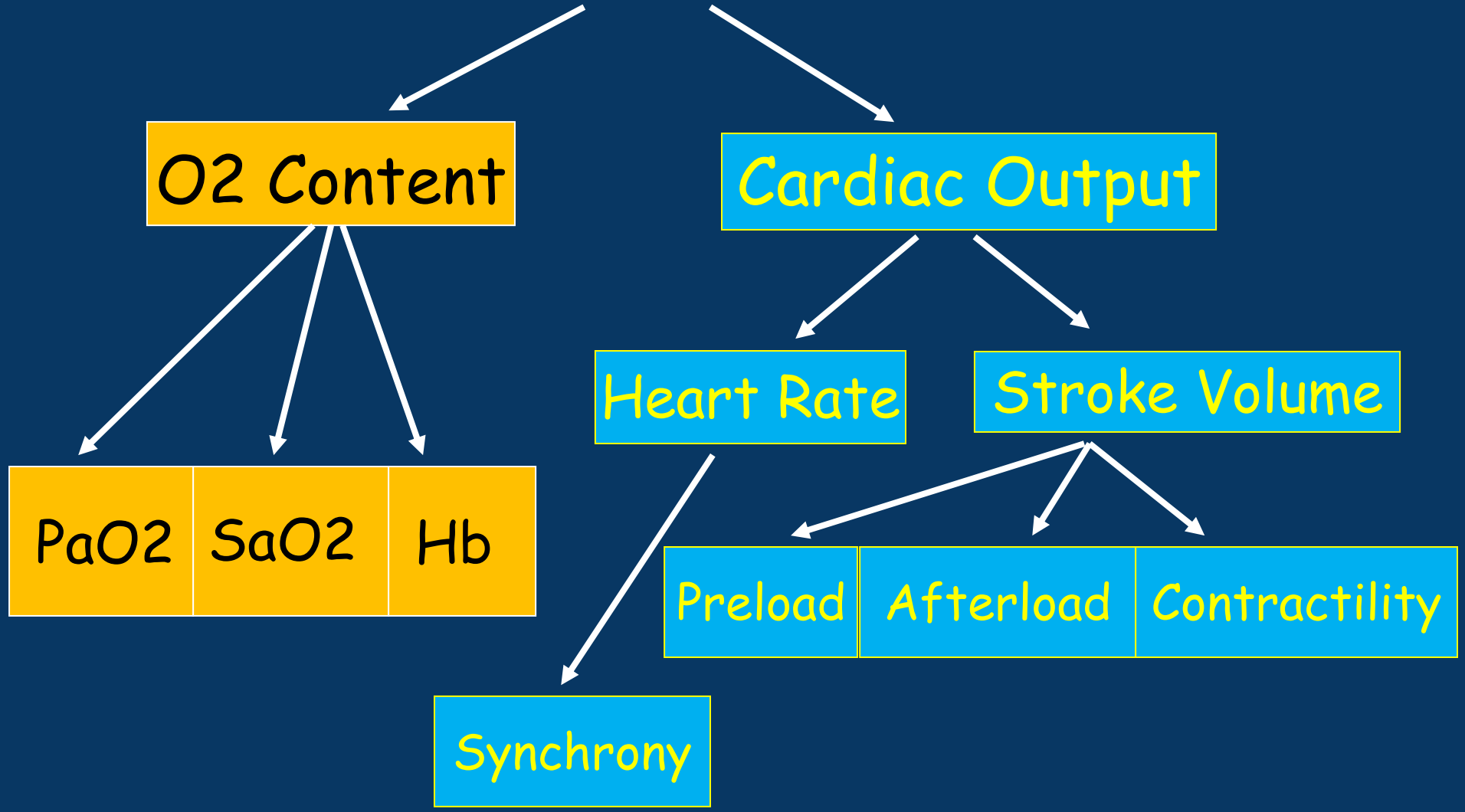
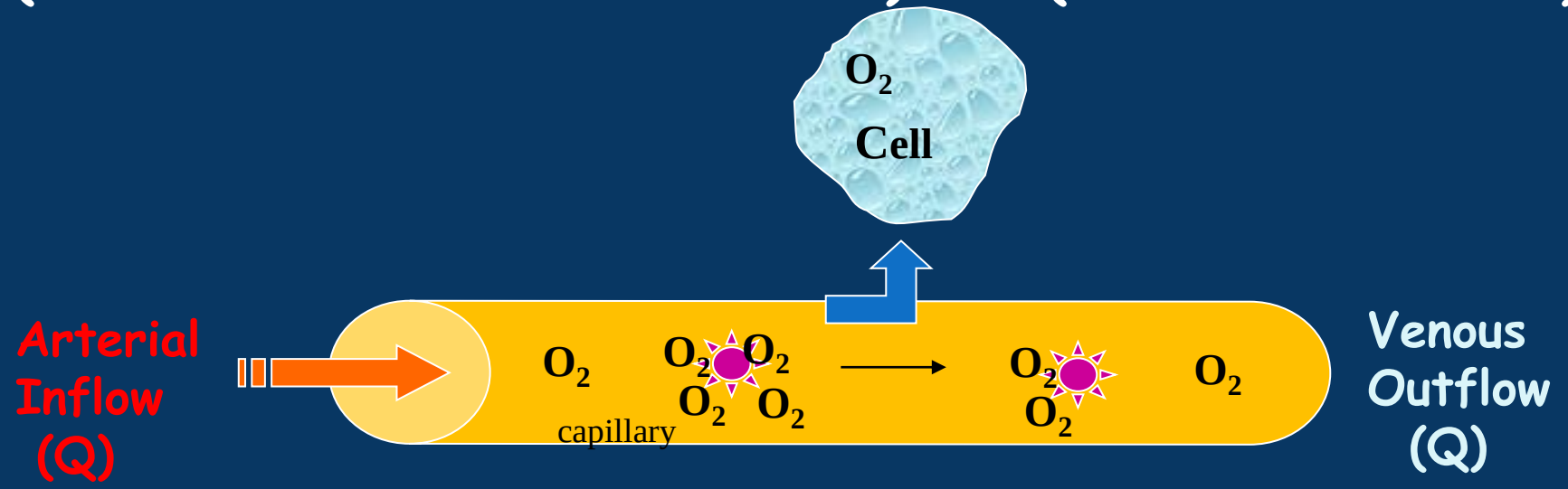


Oxygen Content of Blood

=(O2 carried by Hb) + (O2 in solution)

= (1.34 x Hb x Sats x 0.01) + (0.023 x PaO2)



(Adapted from the ICU Book by P. Marino)

Glucose

2x ATP

Pyruvic Acid

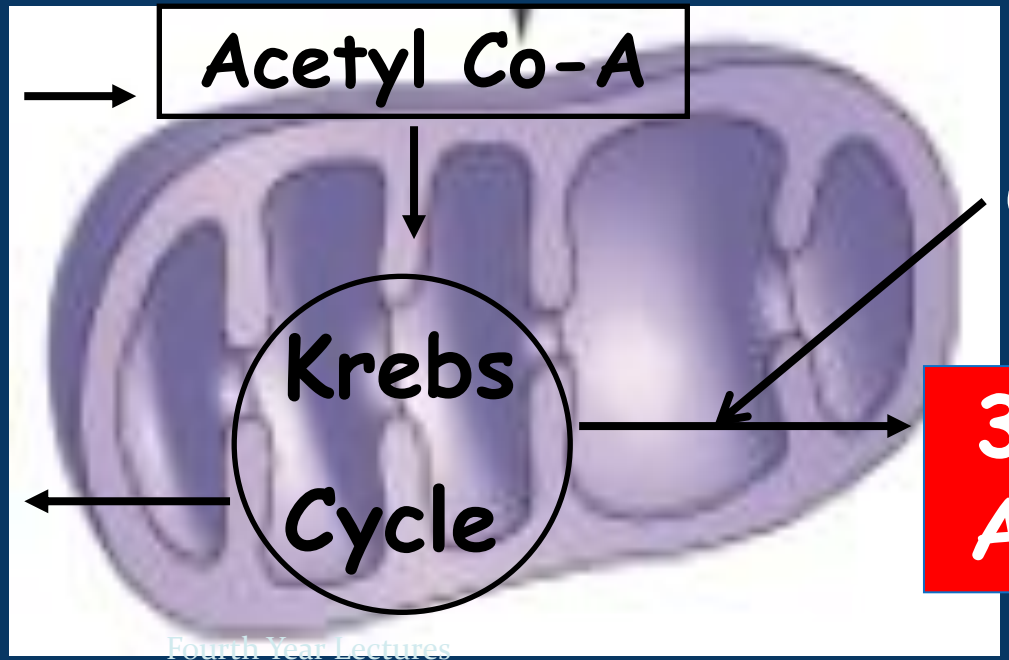
Lactic Acid

Anaerobic

Fatty Acids

Amino Acids

Acetyl Co-A



Krebs Cycle

CO_2

O2

38x ATP

Aerobic

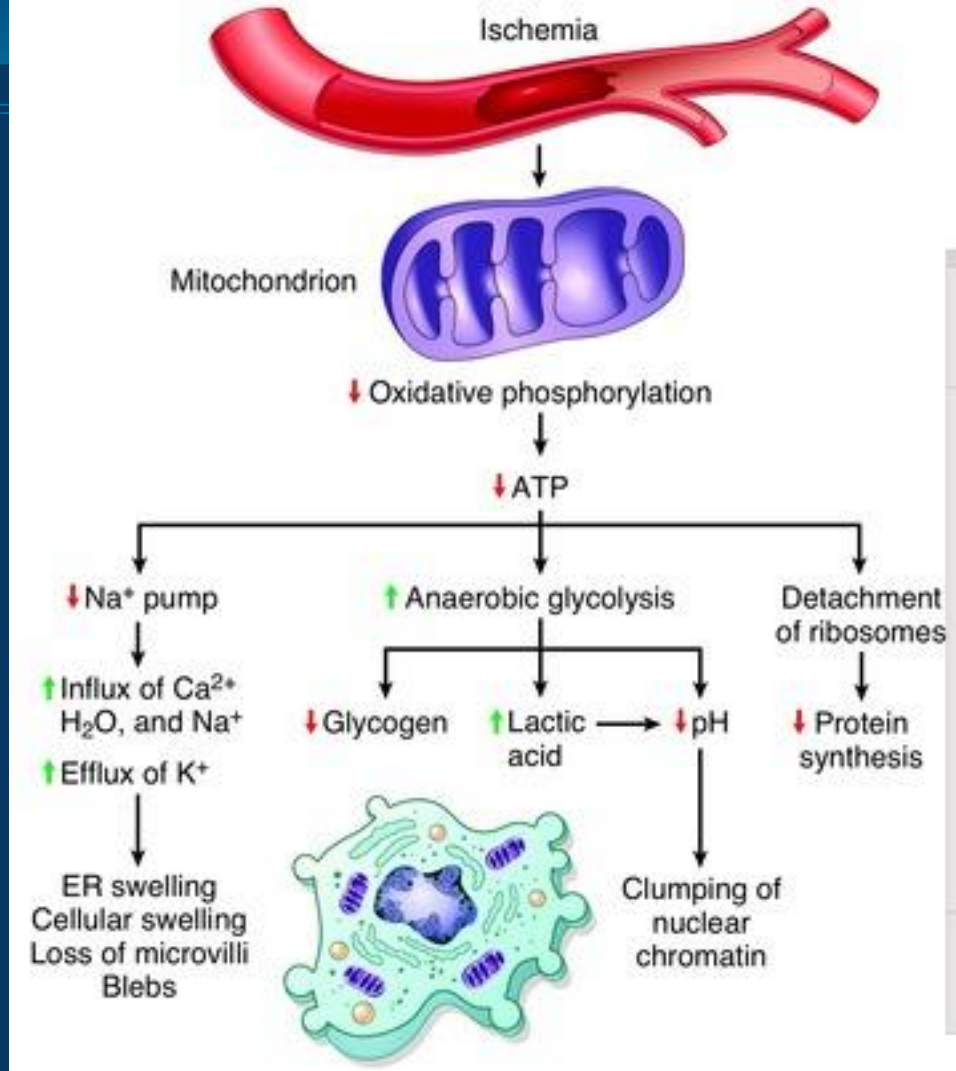


Figure 2-17 Functional and morphologic consequences of decreased intracellular adenosine triphosphate (ATP) during cell injury. The morphologic changes shown here are indicative of reversible cell injury. Further depletion of ATP results in cell death, typically by necrosis. ER, Endoplasmic reticulum.

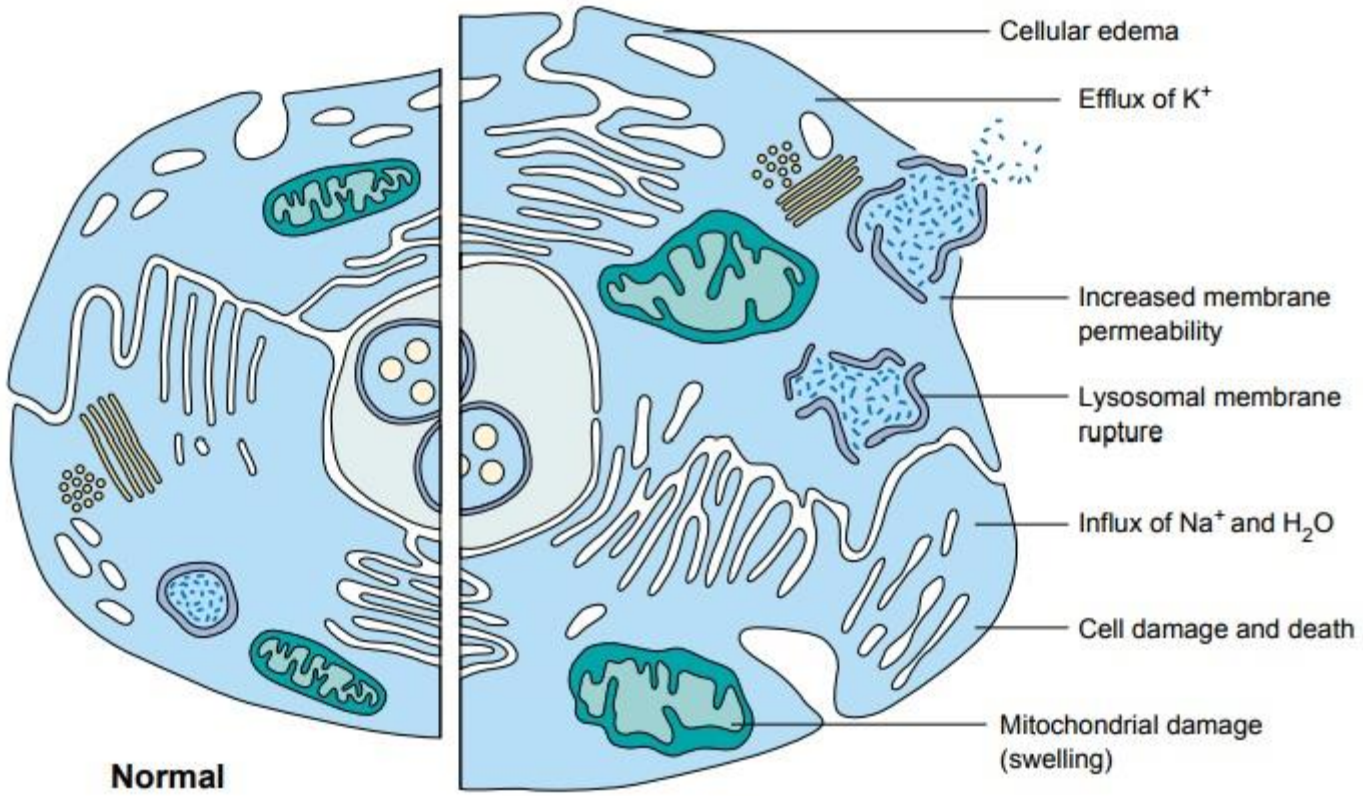
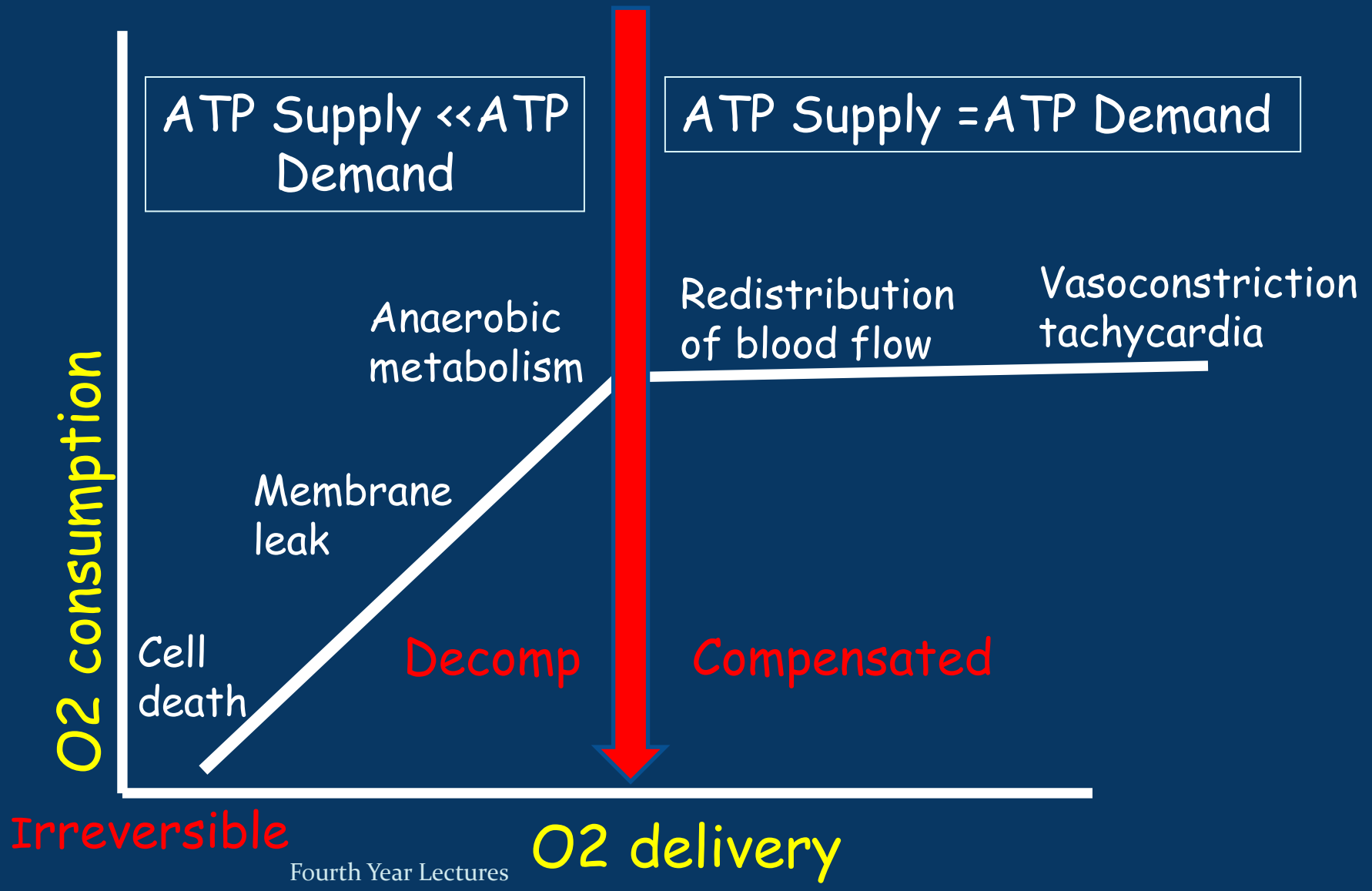


FIGURE 15-1 Cellular effects of shock. The cell swells and the cell membrane becomes more permeable, and fluids and electrolytes seep from and into the cell. Mitochondria and lysosomes are damaged, and the cell dies.

Ramifications of Shock

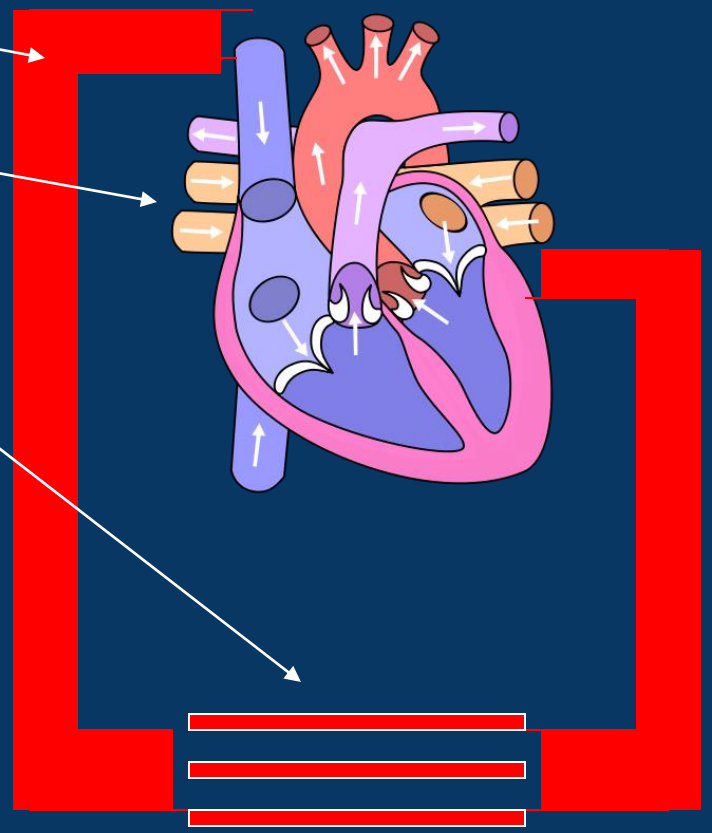
- Mortality from shock remains high:
  - cardiogenic shock from AMI - 60-90%
  - septic shock - 35-40%
  - hypovolemic shock - varies depending on disease state

Stages of shock



Key Elements of Blood Pressure

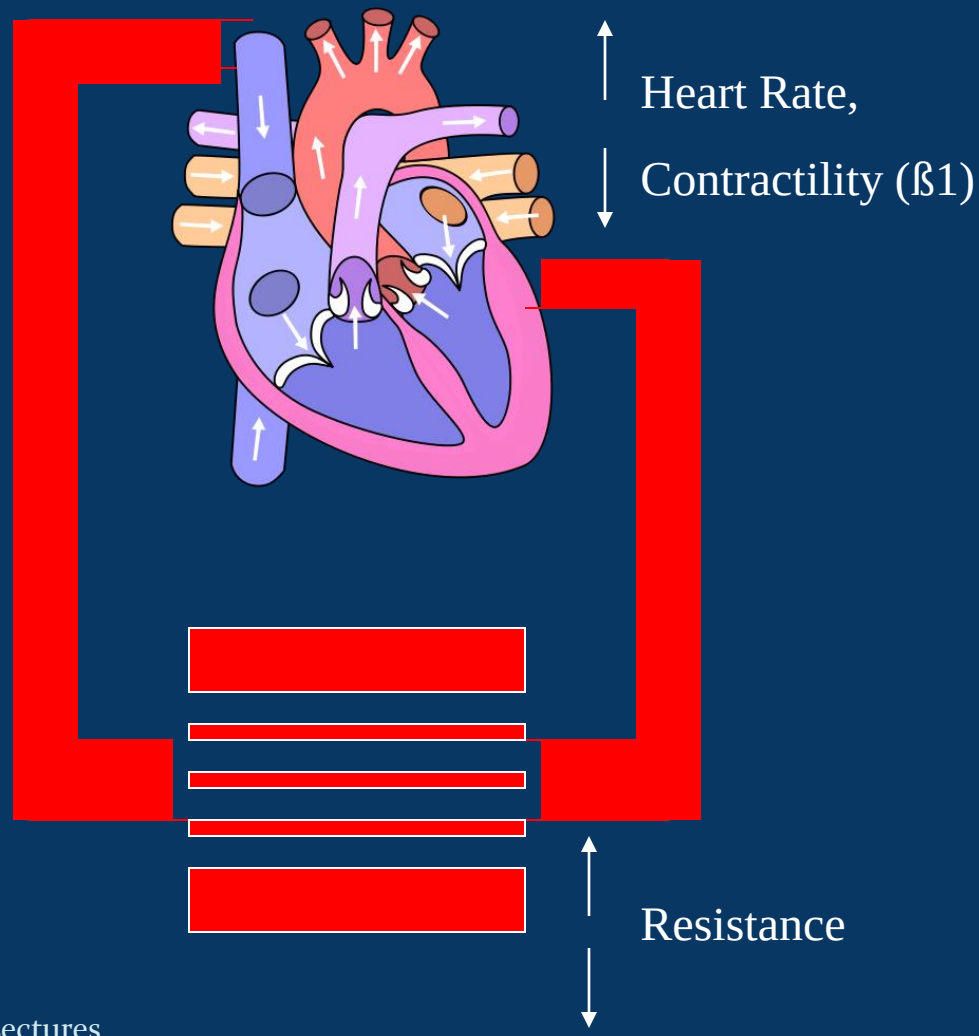
- Fluid
- Pump
- Pipes



Mean Arterial Pressure (MAP)

- MAP - CVP = Cardiac Output x SVR
- Cardiac Output (CO)= HR x Stroke Volume

MAP $_{-\ CVP}$ = (HR x SV) x SVR



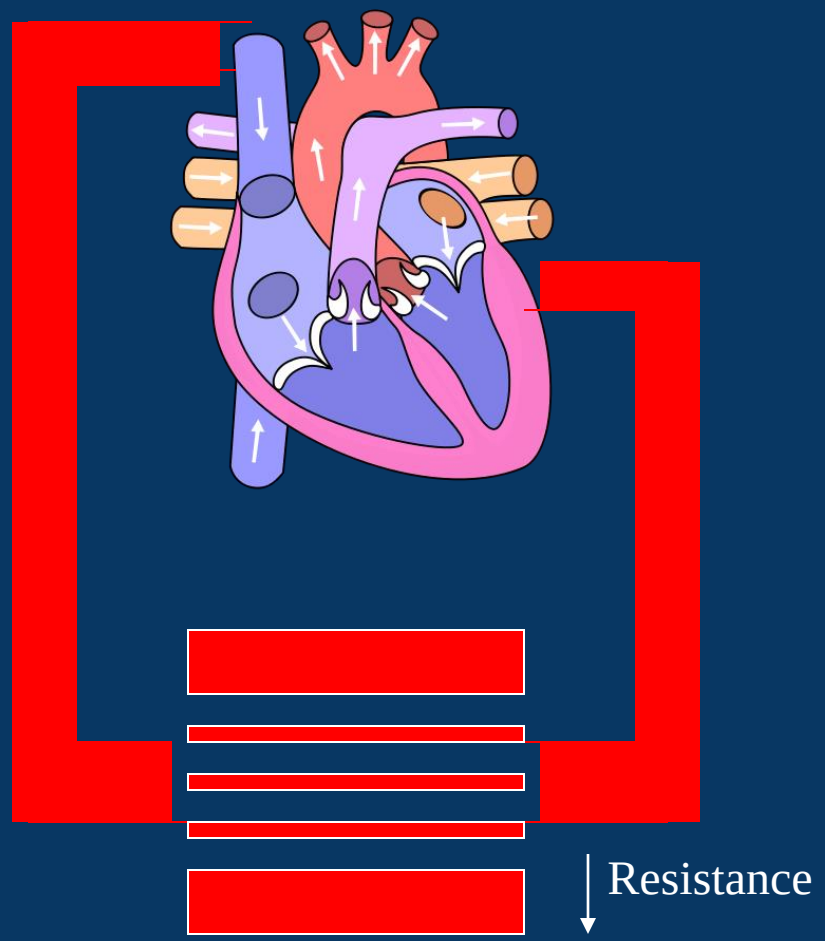
Etiologies of Shock(Distributive)

↓ MAP – CVP = (SV x HR) x SVR

- Low vascular resistance: **"Distributive"**

  Sepsis, anaphylaxis

  Other: adrenal insufficiency, myxedema coma, drug reaction, toxic shock syndrome, neurogenic



Etiologies of Shock (obstructive)

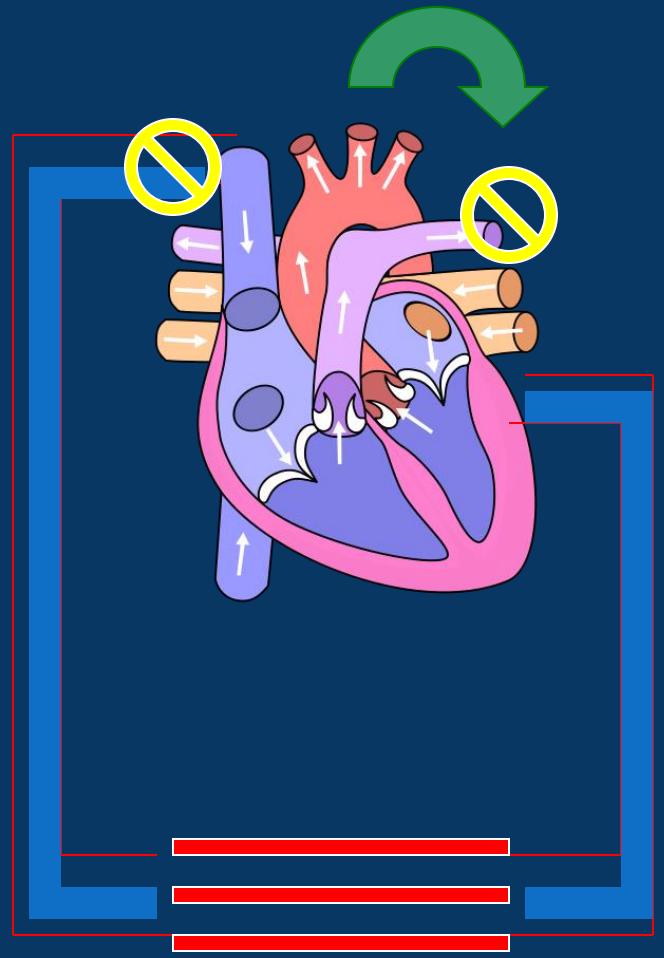
MAP – CVP = (SV x HR) x SVR

- Low Stroke Volume:

Venous return & Outflow obstruction

"Obstructive"

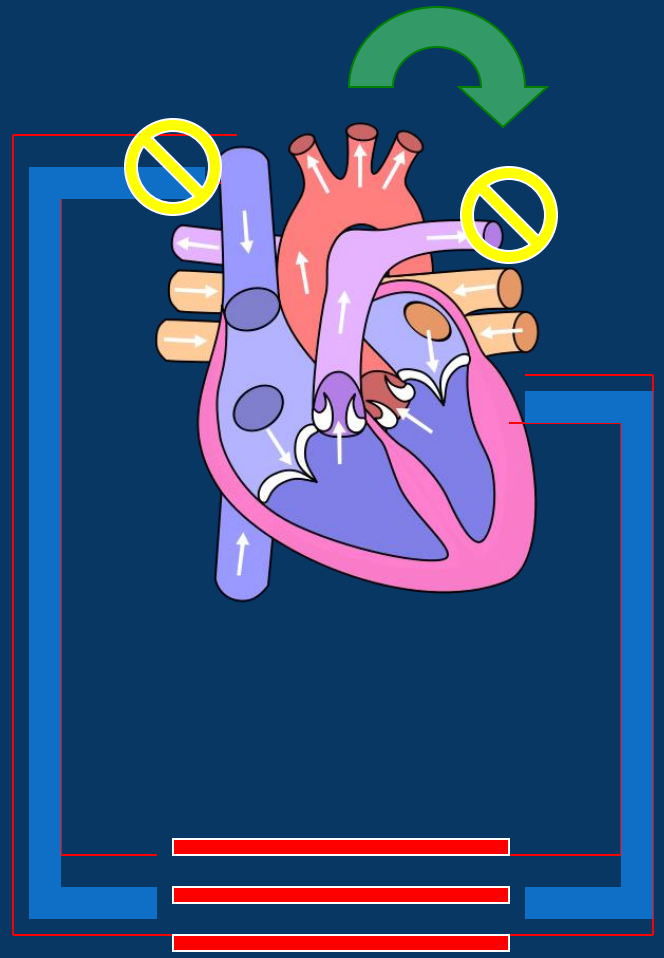
Tamponade, tension pneumothorax, PEEP, Pulmonary embolism



Etiologies of Shock (Hypovolemic)

MAP – CVP = (SV x HR) x SVR

- Low Stroke Volume:
  - Intravascular volume:
    "Hypovolemic"
    Dehydration, hemorrhage, 3rd space



Etiologies of Shock (Cardiogenic)

MAP – CVP = (SV x HR) x SVR

- Low Stroke Volume:

  Ejection: **"Cardiogenic**

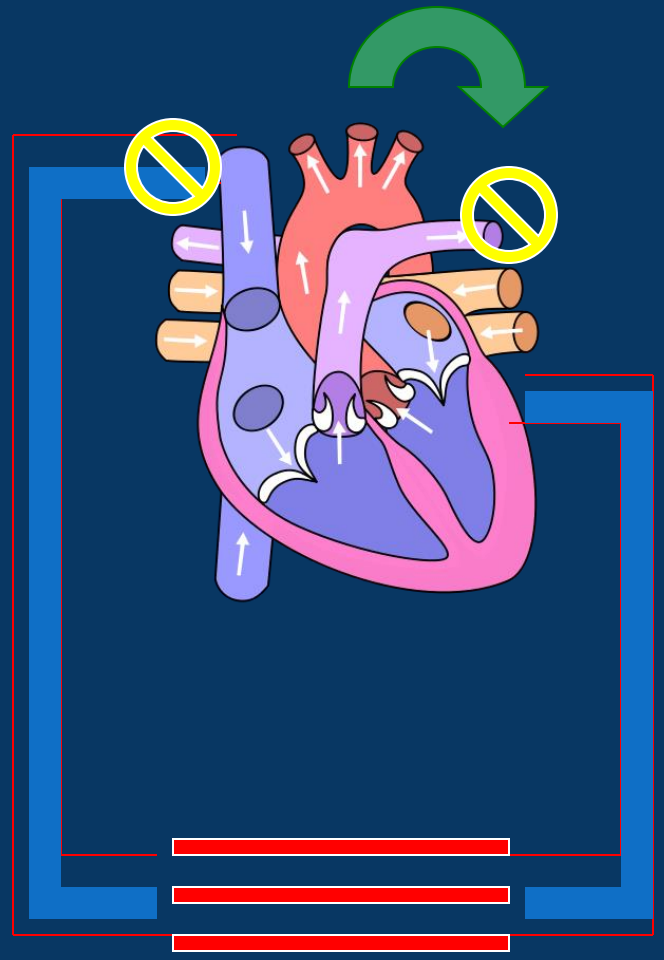
  Myocardial infarct, valvular defect

- Abnormal heart rate:

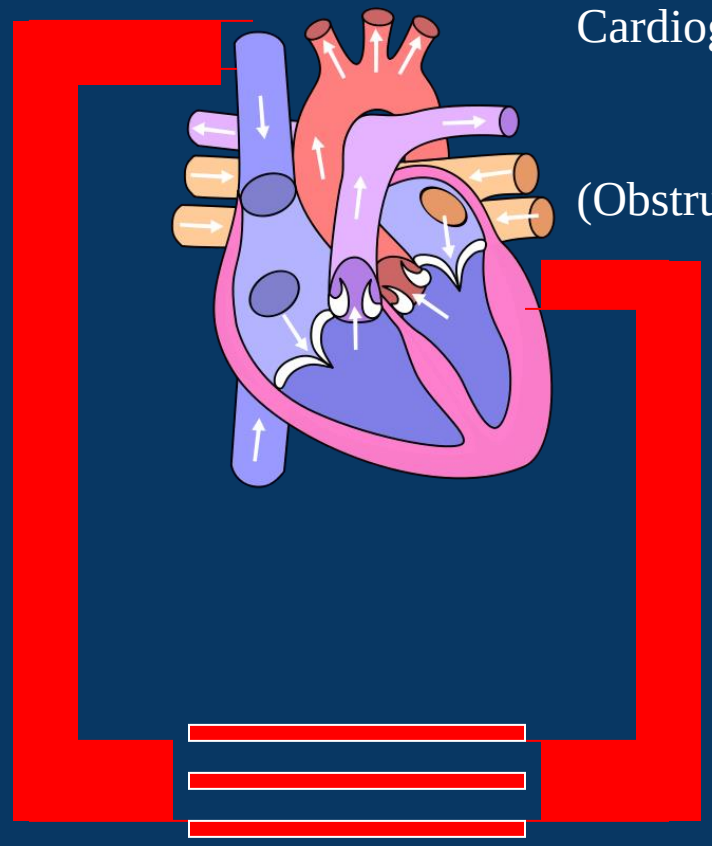
  "Cardiogenic"

  Tachycardia (short filling time)

  Bradycardia



Types of Shock



Cardiogenic

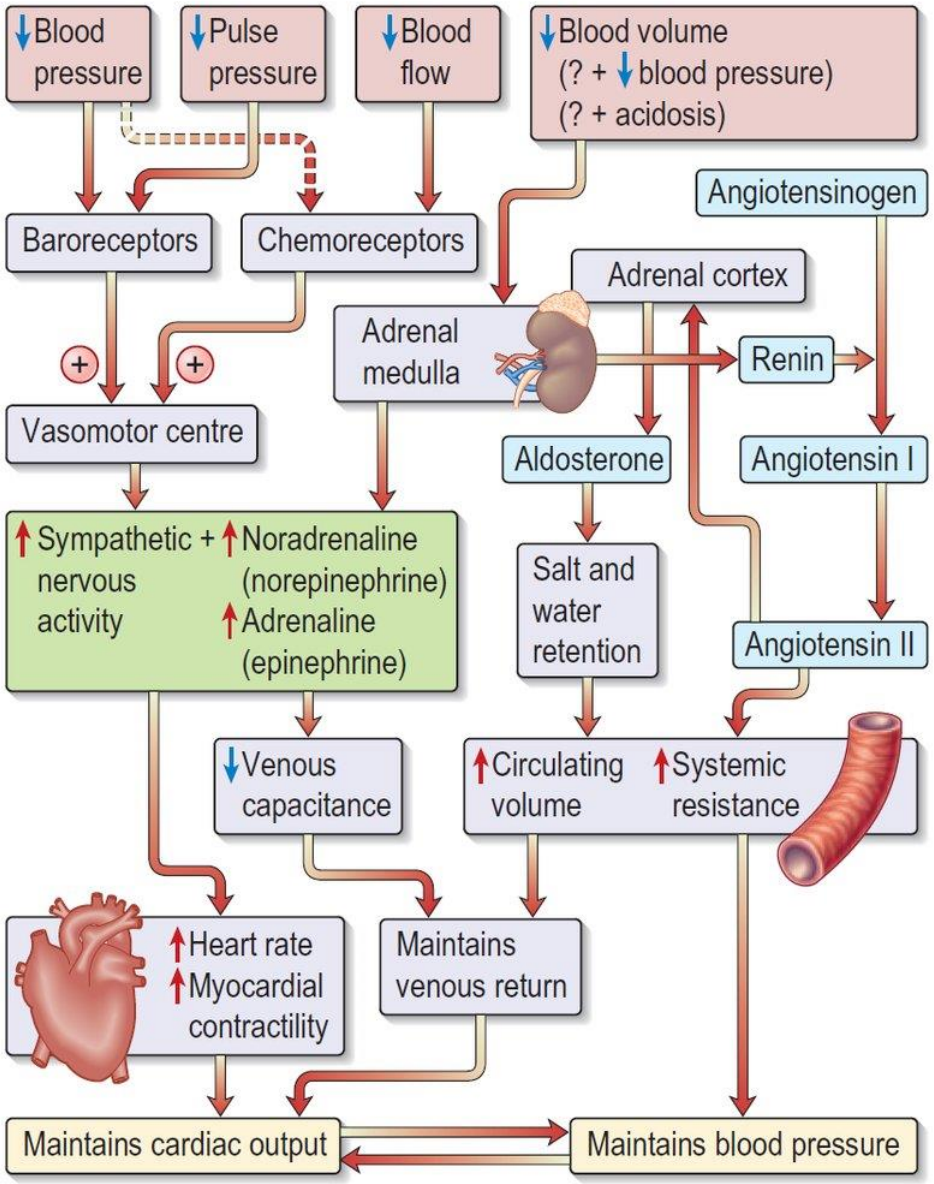
(Obstructive)

Hypovolemic

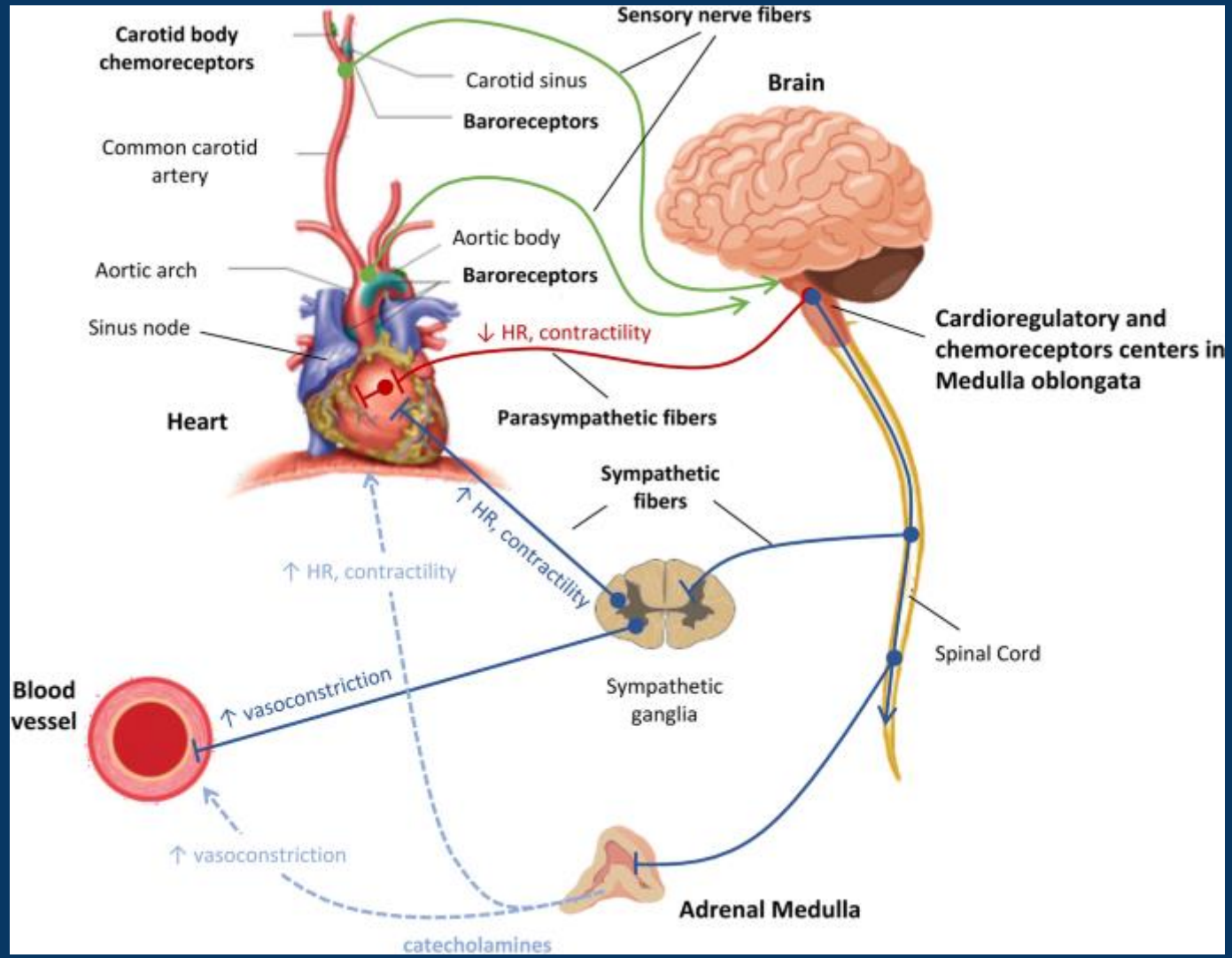
Distributive

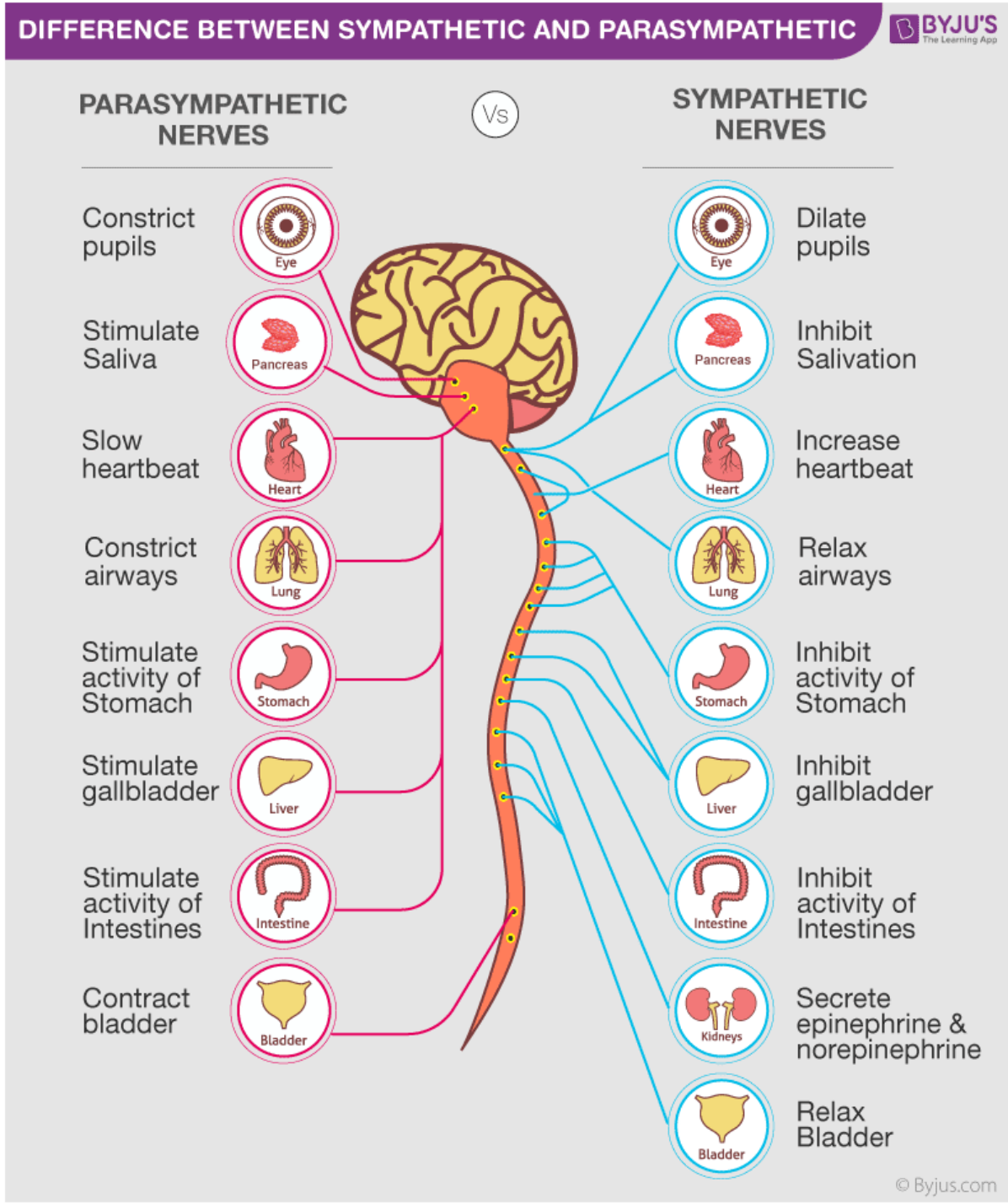
- The clinical manifestations of shock are the result of:

1- autonomic neuroendocrine responses
2- cardiovascular response
3- pulmonary response
4- renal response
5- cellular response
6- metabolic derangement
7- inflammatory response



The sympatho-adrenal response to shock showing the effect of increased catecholamines on the left of the diagram and the release of angiotensin and aldosterone on the right. Both mechanisms result in maintaining the cardiac output in shock.


Carotid body chemoreceptors
Sensory nerve fibers
Carotid sinus
Baroreceptors
Brain
Common carotid artery
Aortic body
Baroreceptors
Aortic arch
Sinus node
↓ HR, contractility
Cardioregulatory and chemoreceptors centers in Medulla oblongata
Heart
Parasympathetic fibers
Sympathetic fibers
↑ HR, contractility
↑ HR, contractility
Spinal Cord
Blood vessel
↑ vasoconstriction
Sympathetic ganglia
↑ vasoconstriction
Adrenal Medulla
catecholamines


DIFFERENCE BETWEEN SYMPATHETIC AND PARASYMPATHETIC
BYJU'S The Learning App
PARASYMPATHETIC NERVES
Vs
SYMPATHETIC NERVES
Constrict pupils
Eye
Stimulate Saliva
Pancreas
Slow heartbeat
Heart
Constrict airways
Lung
Stimulate activity of Stomach
Stomach
Stimulate gallbladder
Liver
Stimulate activity of Intestines
Intestine
Contract bladder
Bladder
Dilate pupils
Eye
Inhibit Salivation
Pancreas
Increase heartbeat
Heart
Relax airways
Lung
Inhibit activity of Stomach
Stomach
Inhibit gallbladder
Liver
Inhibit activity of Intestines
Intestine
Secrete epinephrine & norepinephrine
Kidneys
Relax Bladder
Bladder
© Byjus.com

The renin-angiotensin-aldosterone system increases blood volume and pressure

Renin → **Angiotensin** → **Angiotensin I** (ACE) → **Angiotensin II**

Direct effects:
- Causes arteries to constrict and increases cardiac output resulting in an increase in blood pressure and volume
- Decreases glomerular filtration rate resulting in water retention
- Increases thirst

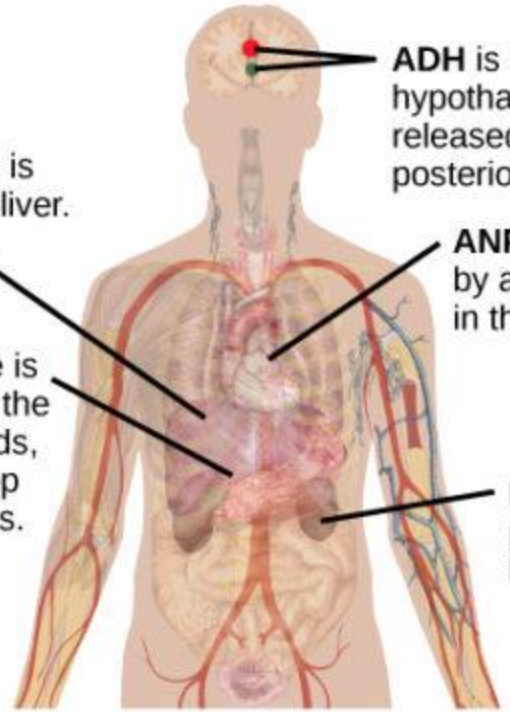
Angiotensin II triggers release of other hormones

Aldosterone

Causes nephron distal tubules to reabsorb more Na^+ and water, which increases blood volume

ADH

- Mediates insertion of aquaporins into nephron collecting duct cells; as a result, more water is reabsorbed into the blood
- Increases sodium reabsorption in the medulla of the kidney



ADH is made in the hypothalamus and released by the posterior pituitary.

Angiotensin is made by the liver.

ANP is made by atrial cells in the heart.

Aldosterone is produced by the adrenal glands, located on top of the kidneys.

Renin is produced by the kidney.

ANP is a hormone antagonistic to the angiotensin pathway.
ANP decreases blood voluume and pressure by:
- Increasing the glomular filtration rate
- Decreasing of reabsorption of Na^+ by nephrons
- Inhibiting the release of renin, aldosterone, and ADH

Neuroendocrine response

- Hypotension, and hypoxia are sensed by baroreceptors and chemoreceptors, which contribute to an autonomic response
- Release of norepinephrine induces arterial vasoconstriction (redistribution of blood flow from the skin, skeletal muscle, kidneys, and splanchnic viscera to heart and brain)
- Reduced vagal activity increases the heart rate and cardiac output
- Constriction of venous capacitance vessels, which augments venous return

- Renin-angiotensin-aldosterone axis activated
- Vasopressin increased and causes vasoconstriction and enhance water reabsorption

Renin Angiotensin System (RAS) regulation :

LIVER

ANGIOTENSINOGEN

KIDNEY

\+ RENIN

ANGIOTENSIN 1 (1-10)

ACE 2

ANGIOTENSIN (1-9)

ACE

LUNG

\+ ACE

ANGIOTENSIN 2 (1-8)

ACE 2

ANGIOTENSIN(1-7)

AT1 R

AT2 R

ALDOSTERONE secretion
HYPOKALEMIA
Sodium reabsorption
Vasopressin and ACTH secretion
Inflammation, cell proliferation
LUNG INJURY

ALDOSTERONE inhibition
HYPERKALEMIA
Sodium excretion
LUNG PROTECTION

ACE : Angiotensin converting enzym
ACE2 : Angiotensin converting enzym 2
AT1R : Angiotensin2 receptor1
AT2R: Angiotensin2 receptor2

The renin-angiotensin-aldosterone system increases blood volume and pressure

Angiotensin → (**Renin**) → **Angiotensin I** → (ACE) → **Angiotensin II**

Triggers release of other hormones

Direct effects:
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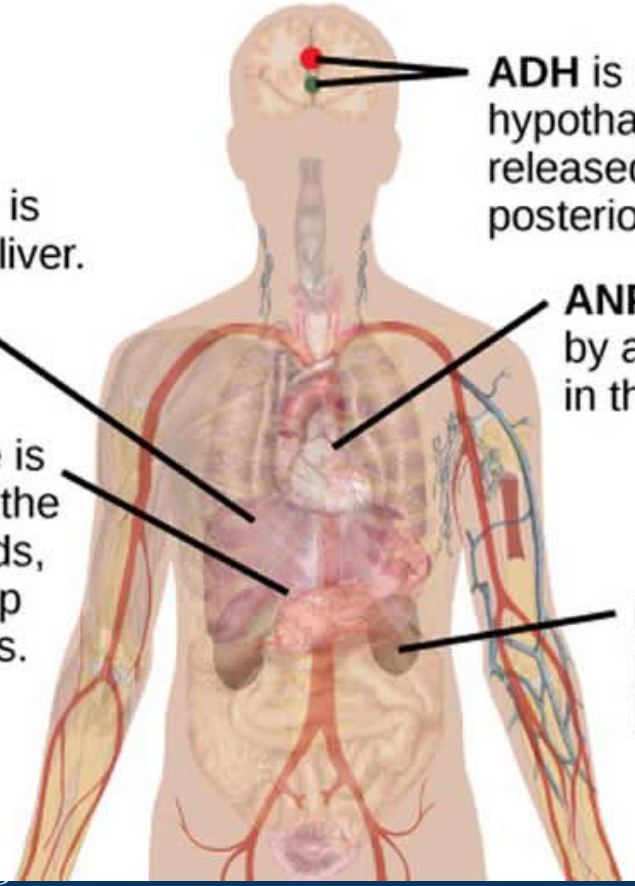

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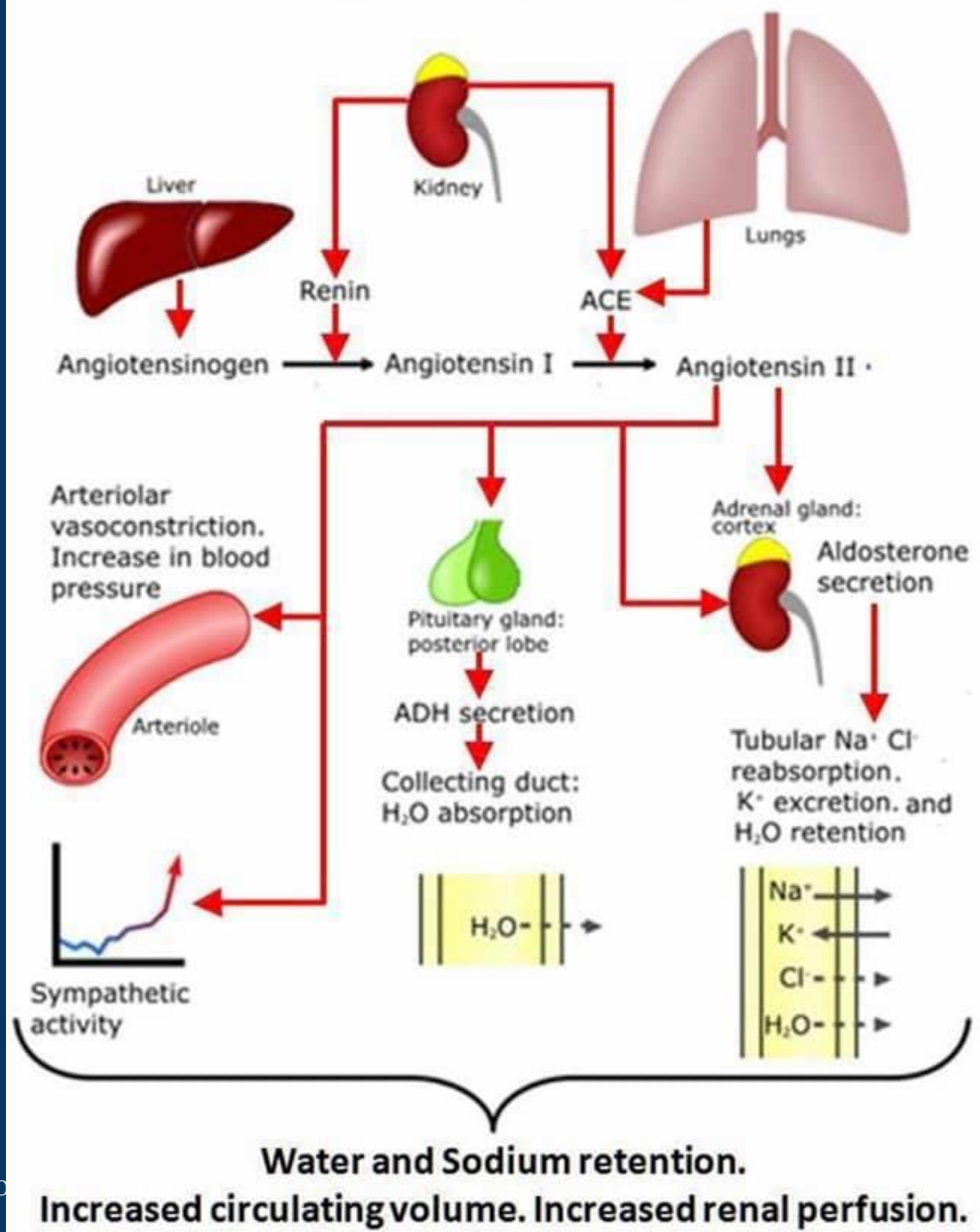
Renin-Angiotensin-Aldosterone System (RAAS)



Cardiovascular response

- An increase in heart rate is a useful but limited compensatory mechanism to maintain cardiac output
- Increased filling pressures of heart (cardiogenic , obstructive) stimulates release of BNP to secrete sodium and volume to relieve the pressure on the heart
- Prolonged hypotension , acidosis , sepsis, ischemia, trauma , hypothermia all impair myocardial contractility and reduce the SV and decrease CO (shock induced cardiomyopathy)

Pulmonary response

- Relative increase in PVR , particularly in septic shock
- Shock-induced tachypnea cause respiratory alkalosis and reduces tidal volume
- Acute lung injury and ARDS may complicate shock

Renal response

- The physiologic response of the kidney to hypoperfusion is to conserve salt and water (by decreasing GFR) which together with increased aldosterone and vasopressin is responsible for reduced urine amount

- This may leads to: acute renal failure , acute tubular necrosis , rhabdomyolysis

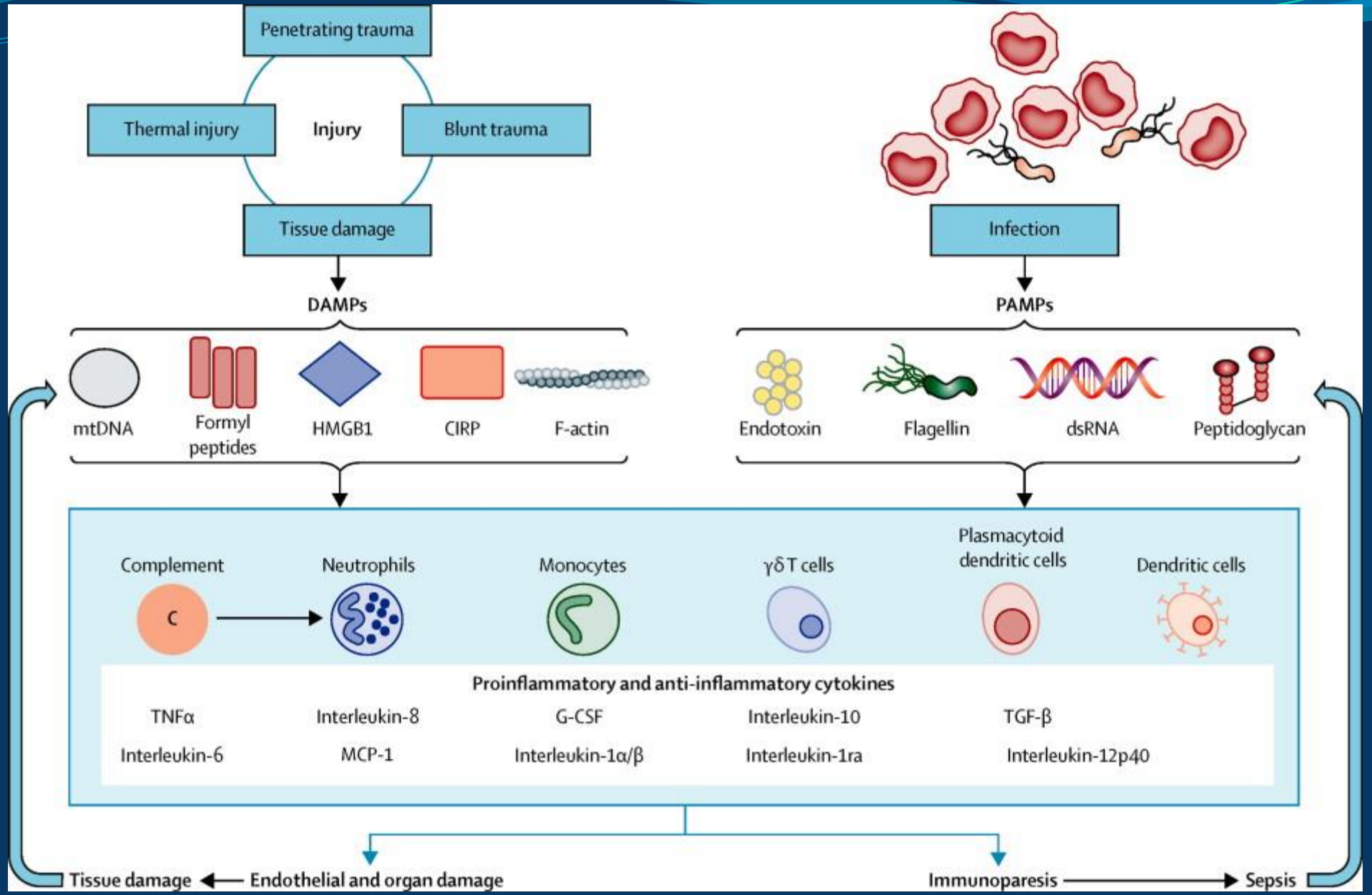
Cellular response

- Mitochondrial dysfunction leads to decrease in ATP and accumulation of hydrogen ions, lactate, and other products of anaerobic metabolism
- Dysfunction of cell membranes, leads to increase in intracellular sodium and water, leading to cell swelling, which interferes further with microvascular perfusion
- Cellular membrane receptors become poorly responsive to the stress hormones insulin, glucagon, cortisol, and catecholamines
- Homeostasis of calcium is lost with accumulation of calcium intracellularly and a concomitant extracellular hypocalcaemia

Metabolic derangement

- As shock progresses, lysosomal enzymes are released into the cells with subsequent hydrolysis of membranes, resulting in cellular death

- These pathologic events give rise to the metabolic features of hemoconcentration, hyperkalemia, hyponatremia, prerenal azotemia, hyper- or hypoglycemia, and lactic acidosis


Penetrating trauma
Thermal injury
Injury
Blunt trauma
Tissue damage
DAMPs
mtDNA
Formyl peptides
HMGB1
CIRP
F-actin
Infection
PAMPs
Endotoxin
Flagellin
dsRNA
Peptidoglycan
Complement
C
Neutrophils
Monocytes
γδT cells
Plasmacytoid dendritic cells
Dendritic cells
Proinflammatory and anti-inflammatory cytokines
TNFα
Interleukin-8
G-CSF
Interleukin-10
TGF-β
Interleukin-6
MCP-1
Interleukin-1α/β
Interleukin-1ra
Interleukin-12p40
Tissue damage
Endothelial and organ damage
Immunoparesis
Sepsis

Inflammatory response

- The **complement cascade**, activated through both the classical and alternative pathways, generates the anaphylatoxins C3a, C4a ,C5a

- Activation of the **coagulation cascade** causes microvascular thrombosis, with subsequent fibrinolysis leading to repeated episodes of ischemia and reperfusion

- Thrombin, potent proinflammatory can cause expression of adhesion molecules on endothelial cells and activation of neutrophils causing secondary injury because of the release of toxic oxygen radicals

- Platelet-activating factor causes pulmonary vasoconstriction, bronchoconstriction, systemic vasodilation, increased capillary permeability, and activates macrophages and neutrophils

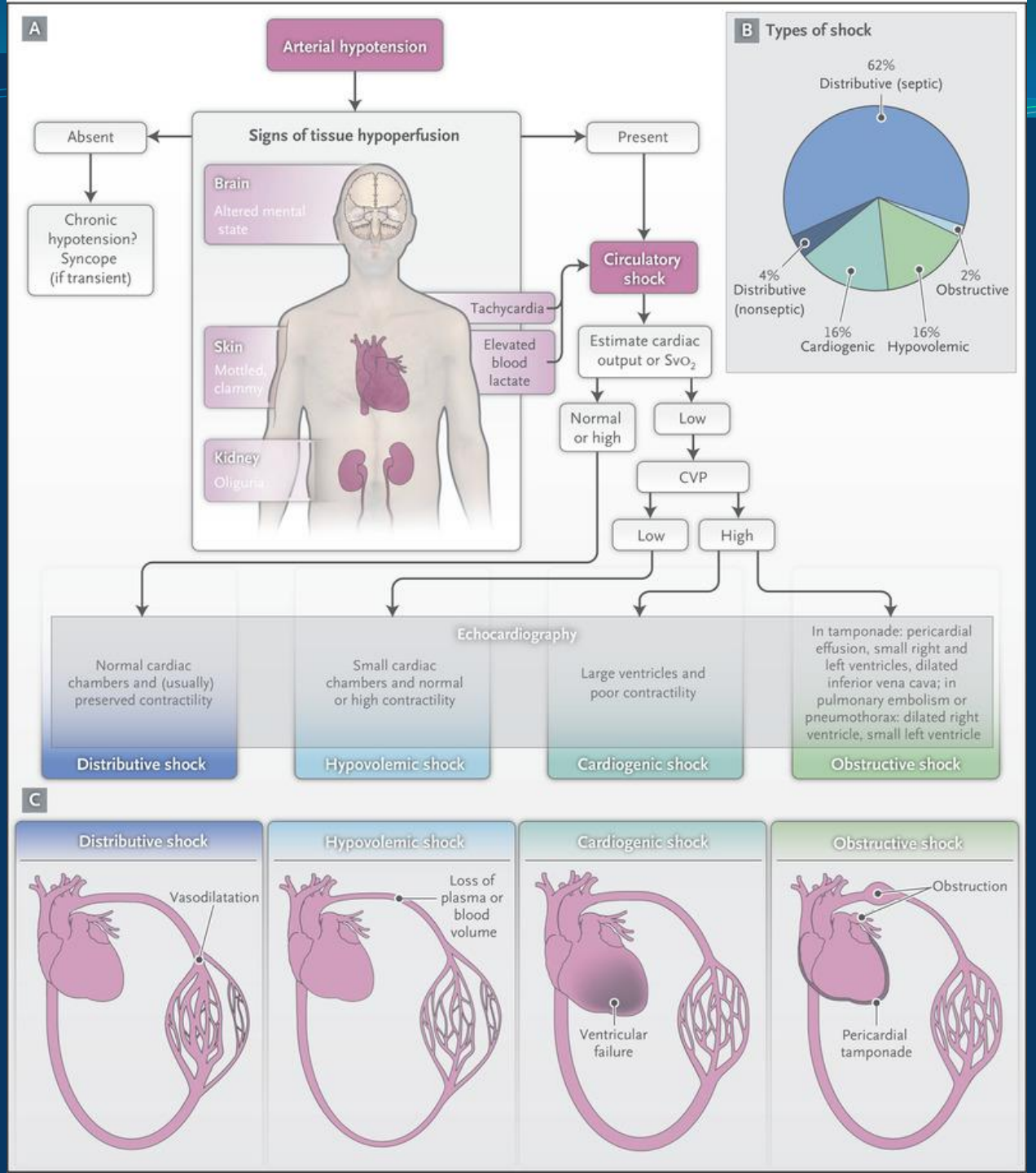
- TNF α produced by activated macrophages causes hypotension, lactic acidosis, and respiratory failure

- IL-6, also produced predominantly by the macrophage, is the best predictor of prolonged recovery and development of multiple organ failure after shock

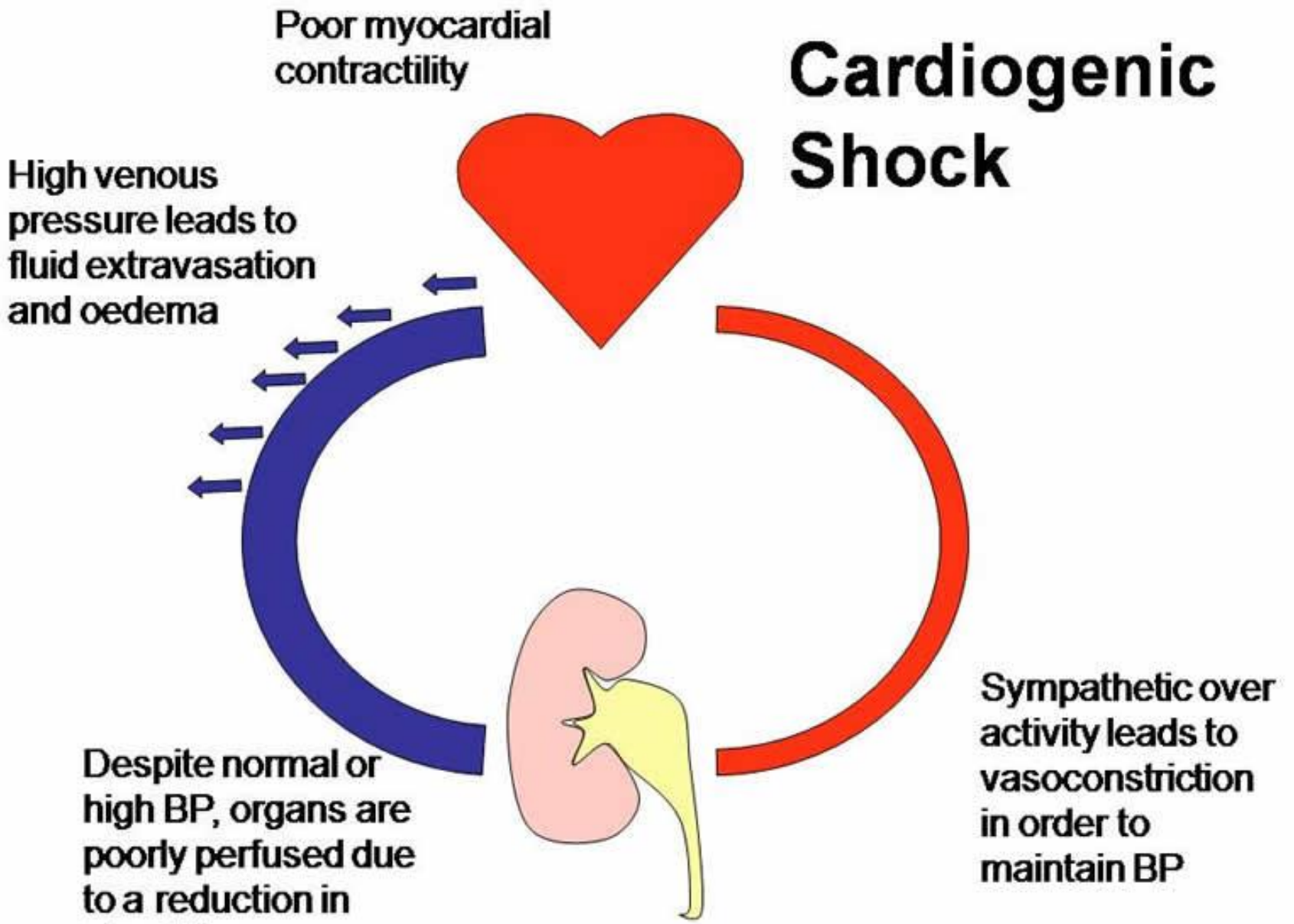
- Although the endothelium normally produces NO, the inflammatory response stimulates the inducible isoform of NO synthase (iNOS), which is overexpressed and produces toxic free radicals that contribute to the hyperdynamic cardiovascular response in sepsis

Classification of Shock

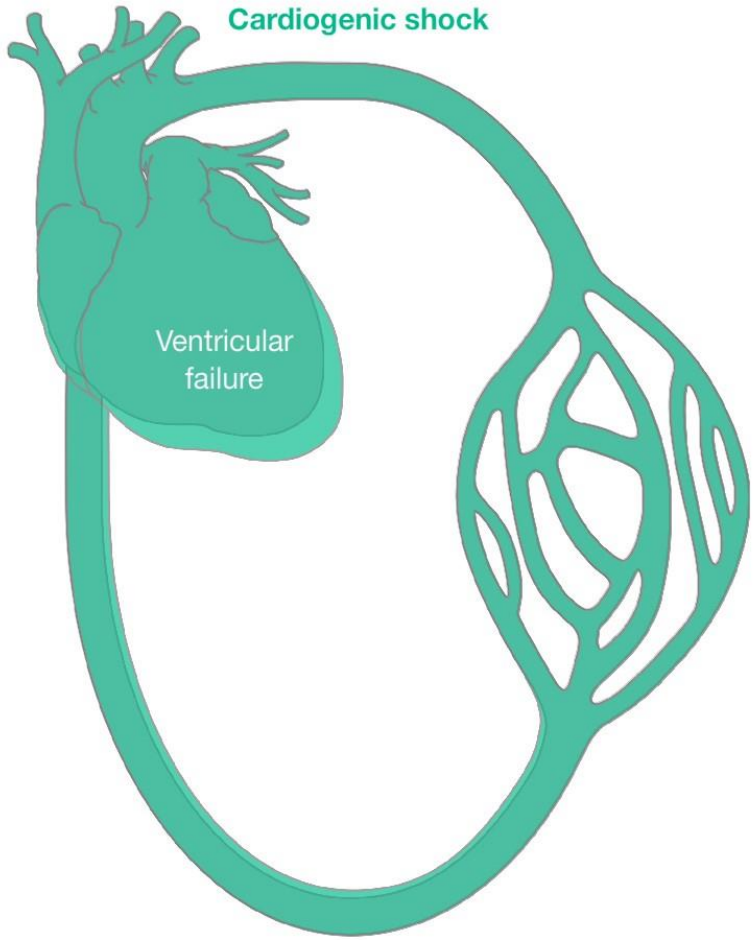
- Hypovolemic
- Cardiogenic
- Distributive (vasodilatory)
- Obstructive


A
Arterial hypotension
Absent
Chronic hypotension? Syncope (if transient)
Signs of tissue hypoperfusion
Brain
Altered mental state
Skin
Mottled, clammy
Kidney
Oliguria
Present
Tachycardia
Elevated blood lactate
Circulatory shock
Estimate cardiac output or SvO_2
Normal or high
Low
CVP
Low
High
Echocardiography
Normal cardiac chambers and (usually) preserved contractility
Distributive shock
Small cardiac chambers and normal or high contractility
Hypovolemic shock
Large ventricles and poor contractility
Cardiogenic shock
In tamponade: pericardial effusion, small right and left ventricles, dilated inferior vena cava; in pulmonary embolism or pneumothorax: dilated right ventricle, small left ventricle
Obstructive shock
B Types of shock
62% Distributive (septic)
4% Distributive (nonseptic)
2% Obstructive
16% Cardiogenic
16% Hypovolemic
C
Distributive shock
Vasodilatation
Hypovolemic shock
Loss of plasma or blood volume
Cardiogenic shock
Ventricular failure
Obstructive shock
Obstruction
Pericardial tamponade

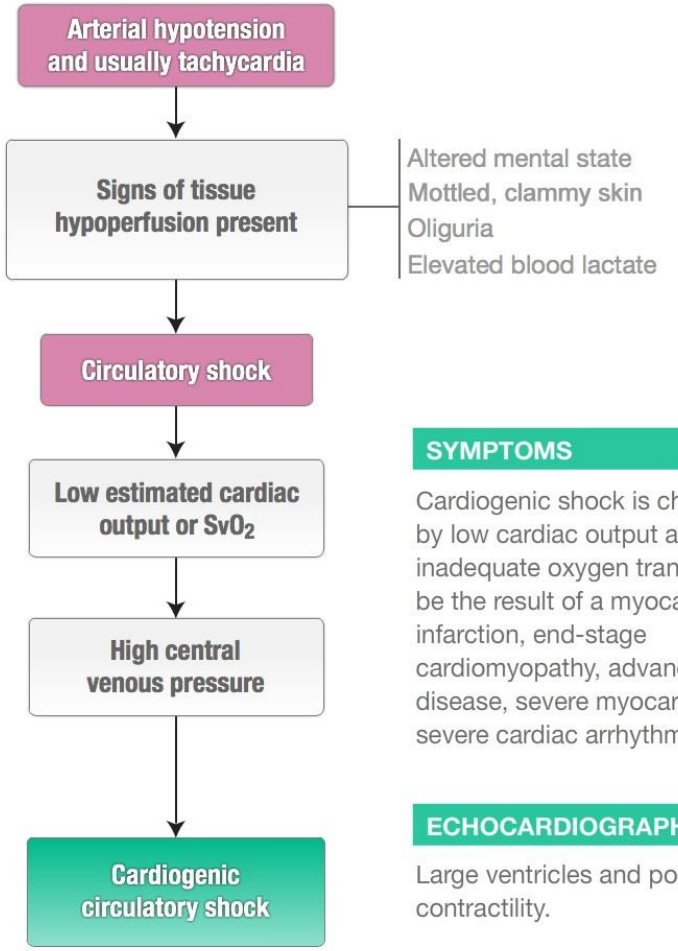
Cardiogenic Shock



DIAGRAM



SIGNS OF CIRCULATORY SHOCK PATHWAY



SYMPTOMS

Cardiogenic shock is characterized by low cardiac output and inadequate oxygen transport. It can be the result of a myocardial infarction, end-stage cardiomyopathy, advanced valvular disease, severe myocarditis, or severe cardiac arrhythmias.

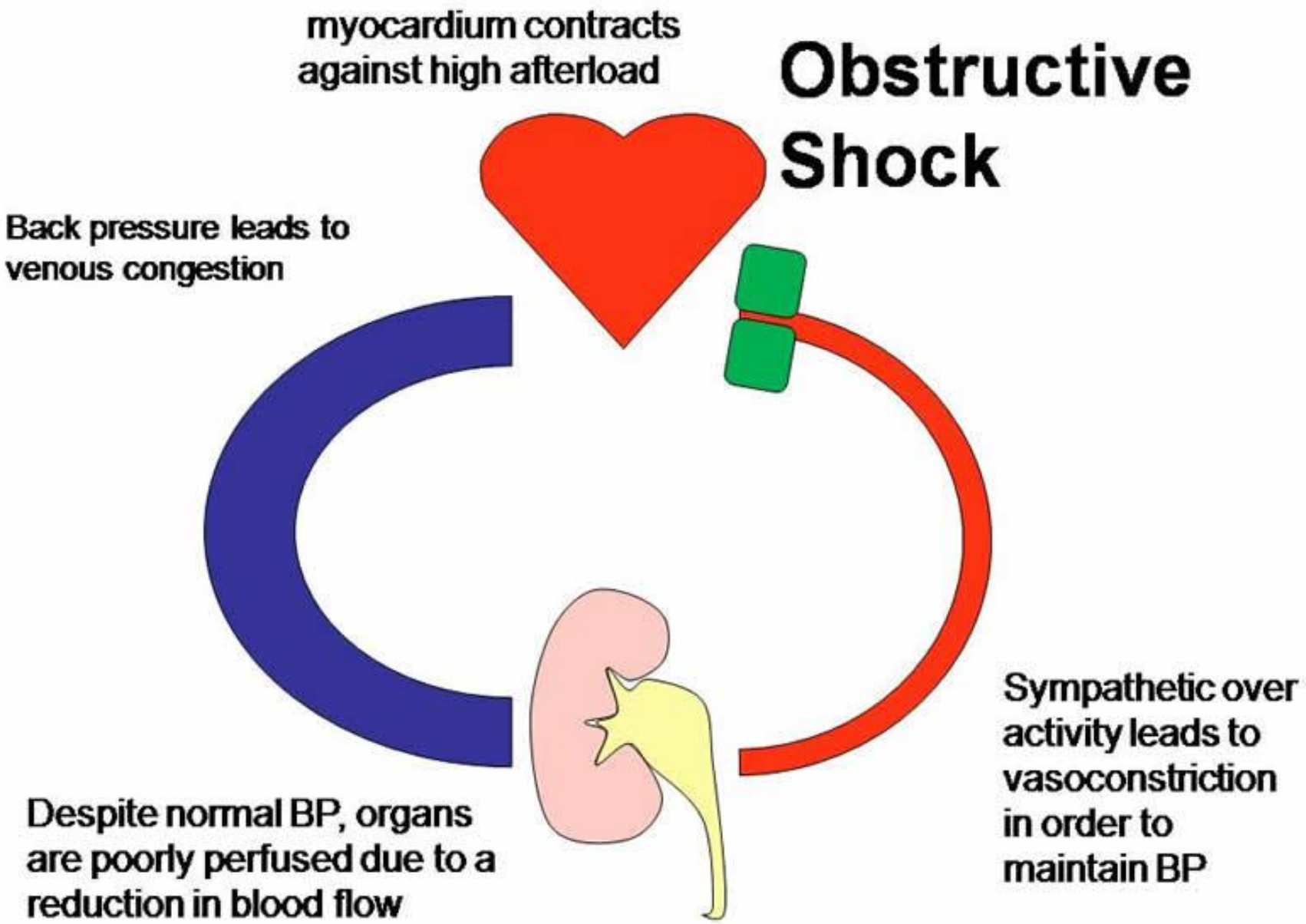
ECHOCARDIOGRAPHIC SIGNS

Large ventricles and poor contractility.

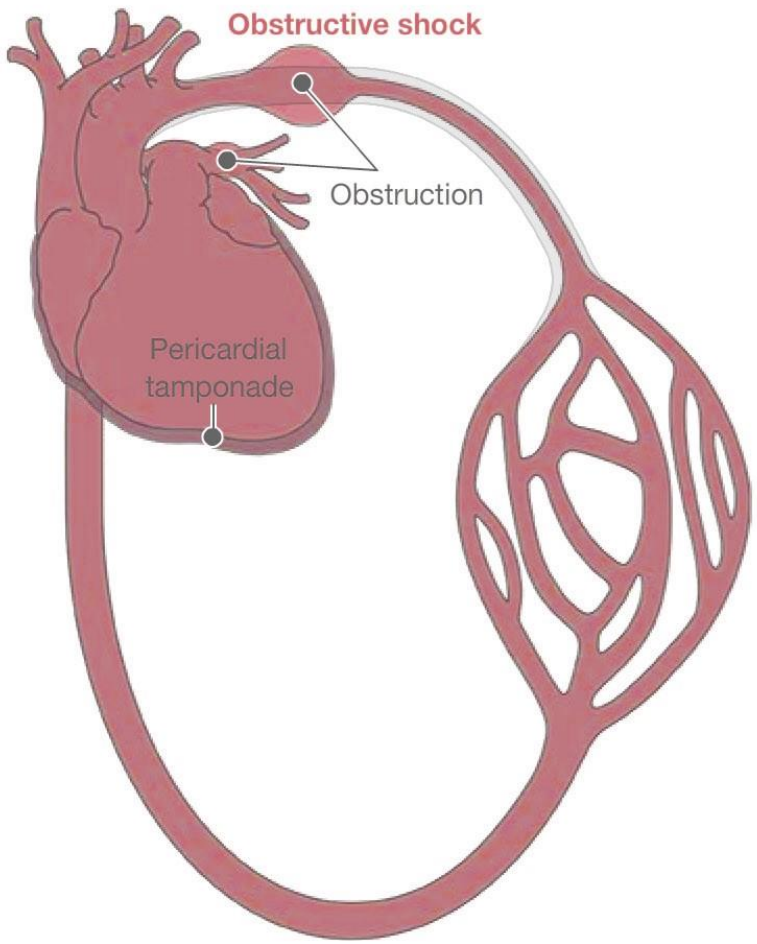
Cardiogenic

- Myocardial infarction
- Myocardial contusion
- Myocarditis
- Acute valvular failure
- Arrhythmia
- Acute ventricular septal wall defect

Obstructive Shock



DIAGRAM



SIGNS OF CIRCULATORY SHOCK PATHWAY

Arterial hypotension and usually tachycardia

↓

Signs of tissue hypoperfusion present

- Altered mental state
- Mottled, clammy skin
- Oliguria
- Elevated blood lactate

↓

Circulatory shock

↓

Low estimated cardiac output or SvO_2

↓

High central venous pressure

↓

Obstructive circulatory shock

SYMPTOMS

Obstructive shock is characterized by a blockage in blood flow caused by a massive pericardial effusion, cardiac tamponade, or tension pneumothorax.

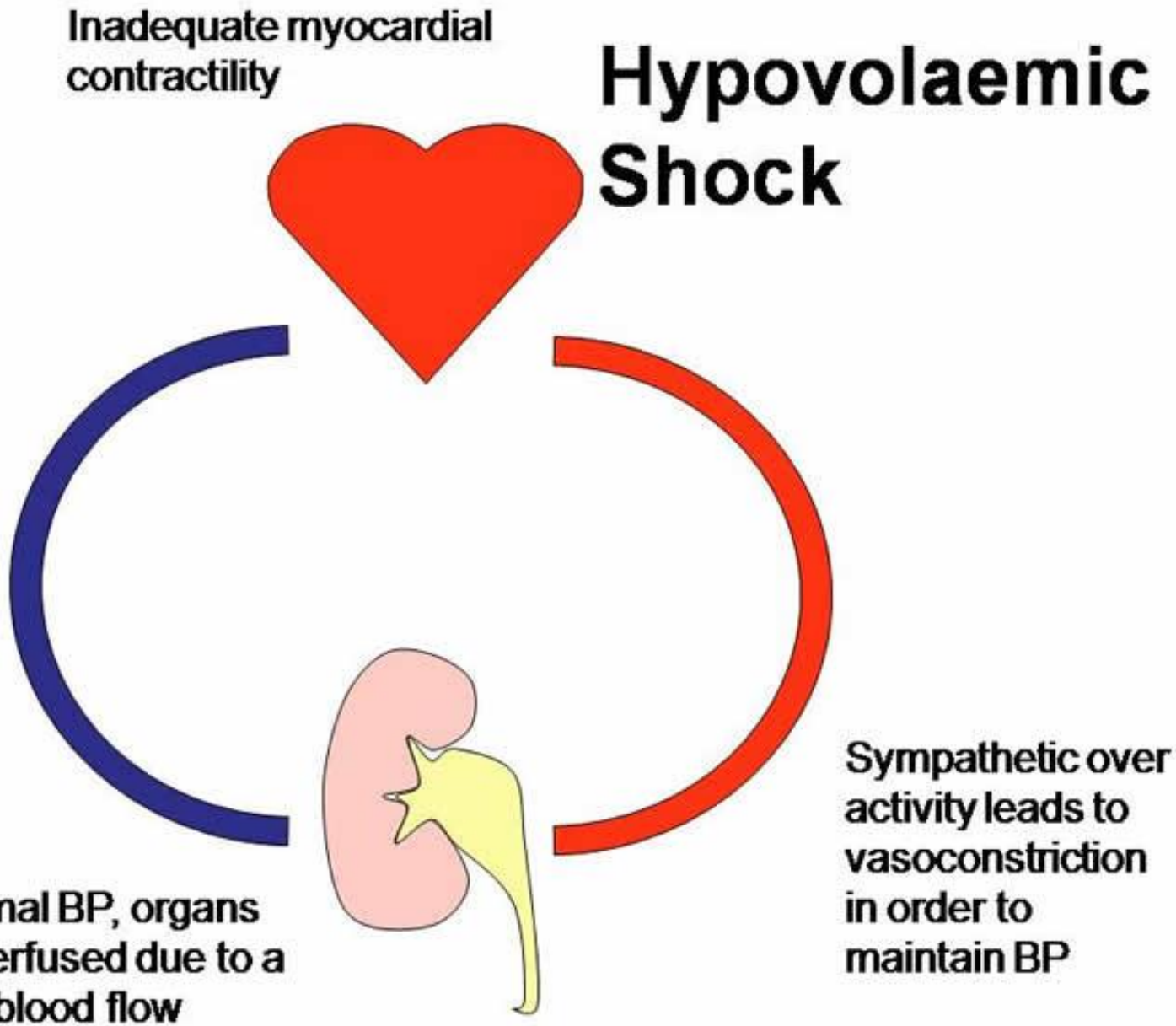
ECHOCARDIOGRAPHIC SIGNS

Depends on the cause. Pulmonary embolism or pneumothorax: dilated right ventricle, small left ventricle. Tamponade: pericardial effusion, small left and right ventricles, dilated inferior vena cava.

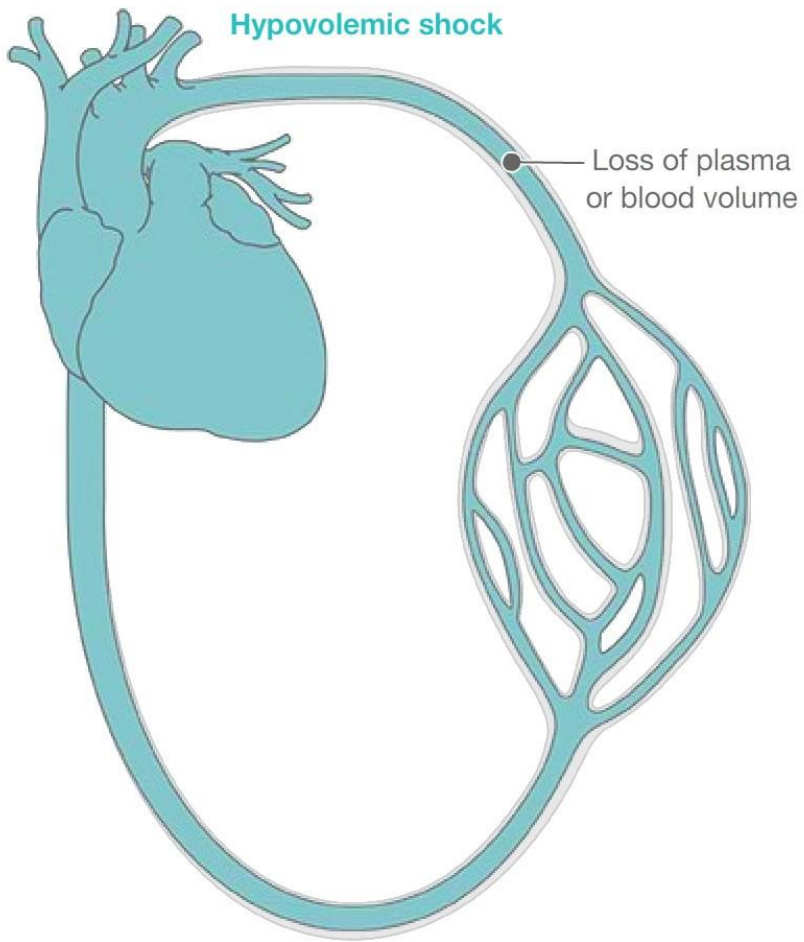
Obstructive

- Pulmonary embolus
- Cardiac tamponade
- Tension pneumothorax

Hypovolaemic Shock



DIAGRAM



SIGNS OF CIRCULATORY SHOCK PATHWAY

Arterial hypotension and usually tachycardia

↓

Signs of tissue hypoperfusion present

- Altered mental state
- Mottled, clammy skin
- Oliguria
- Elevated blood lactate

↓

Circulatory shock

↓

Low estimated cardiac output or SvO_2

↓

Low central venous pressure

↓

Hypovolemic circulatory shock

SYMPTOMS

Hypovolemic shock is characterized by internal or external fluid loss leading to organ failure.

ECHOCARDIOGRAPHIC SIGNS

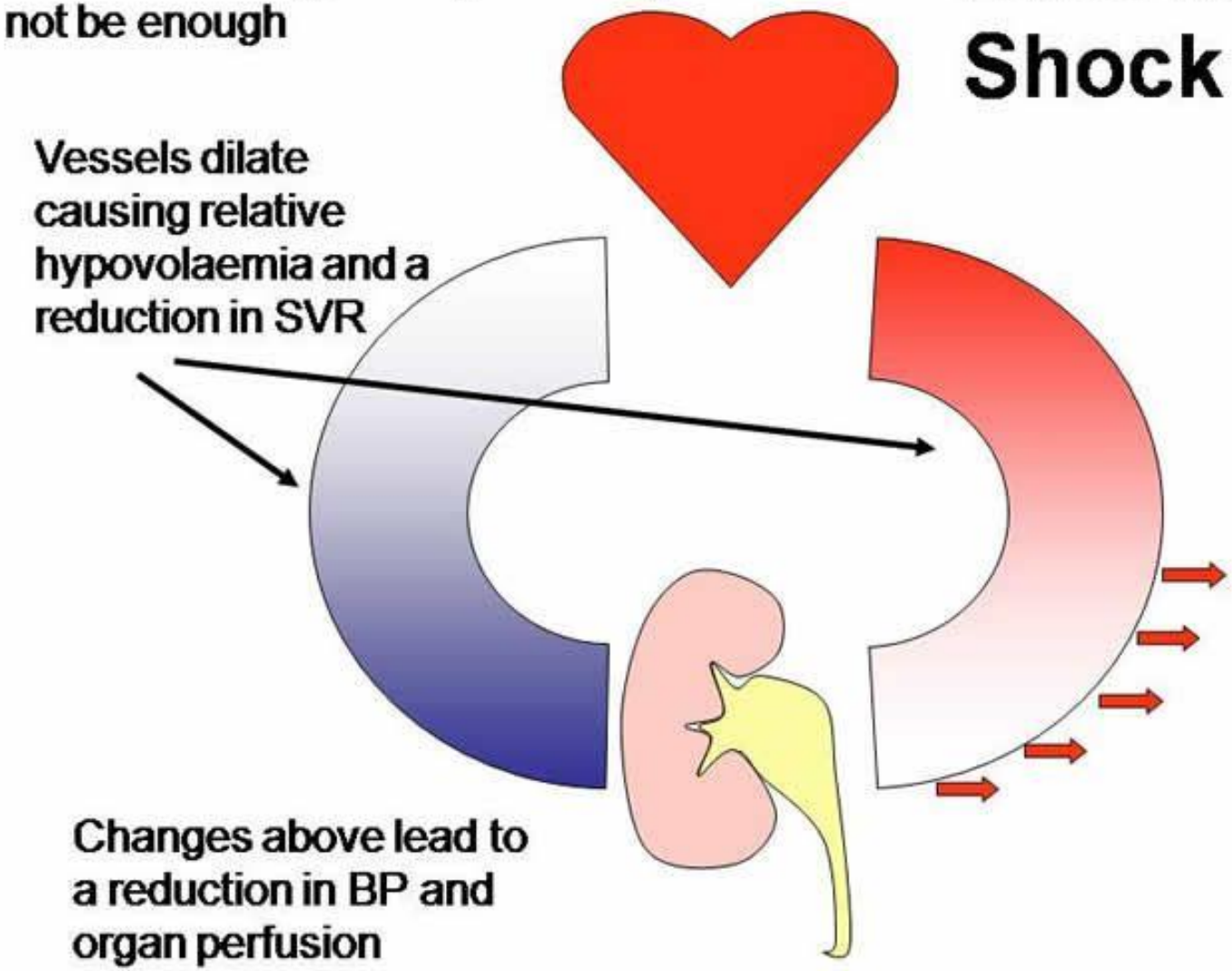
Small cardiac chambers and normal or high contractility.

Hypovolaemic

- Fluid depletion
  - Vomiting and diarrhoea
  - Burns
  - Polyuria
- Haemorrhagic
- Trauma
- Gastrointestinal
- Retroperitoneal

Distributive Shock

With adequate fluid therapy, the heart usually compensates by increase rate and contractility, although this might not be enough



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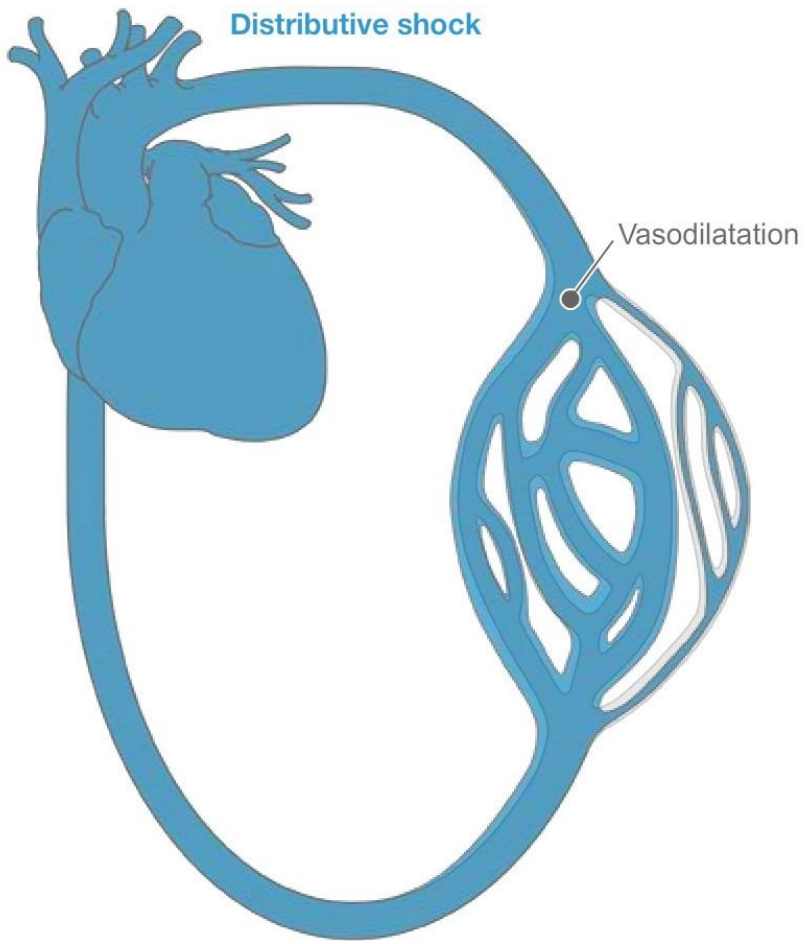

SIGNS OF CIRCULATORY SHOCK PATHWAY

Arterial hypotension and usually tachycardia

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- Altered mental state
- Mottled, clammy skin
- Oliguria
- Elevated blood lactate

↓

Circulatory shock

↓

Normal or high cardiac output or SvO_2

↓

Distributive circulatory shock

SYMPTOMS

Distributive shock is characterized by hypovolemia and hypotension. It is the result of vasodilatation and release of inflammatory mediators.

ECHOCARDIOGRAPHIC SIGNS

Normal cardiac chambers and (usually) preserved contractility.

Distributive

- Sepsis
- Neurogenic
- Anaphylaxis

Stages of Shock

- **Stage I Compensated (Nonprogressive)**
  - Maintains end organ perfusion
  - BP is maintained usually by ↑ HR
- **Stage II Uncompensated (progressive)**
  - Decreases micro-vascular perfusion
  - Sign/symptoms of end organ dysfunction
  - Hypotensive
- **Stage III Irreversible**
  - Progressive end-organ dysfunction
  - Cellular acidosis results in cell death

Key Issues

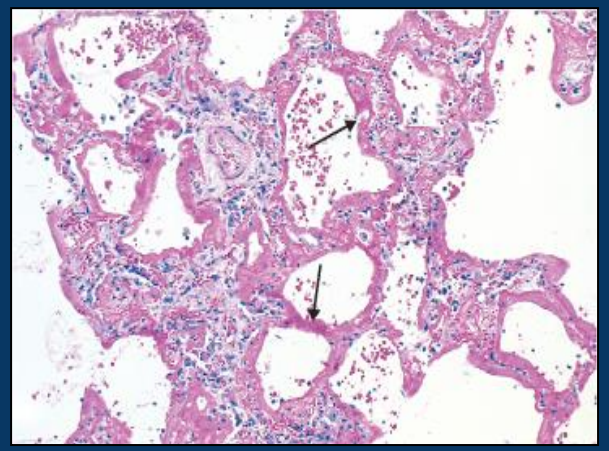
Recognize & **Treat** during compensatory shock phase

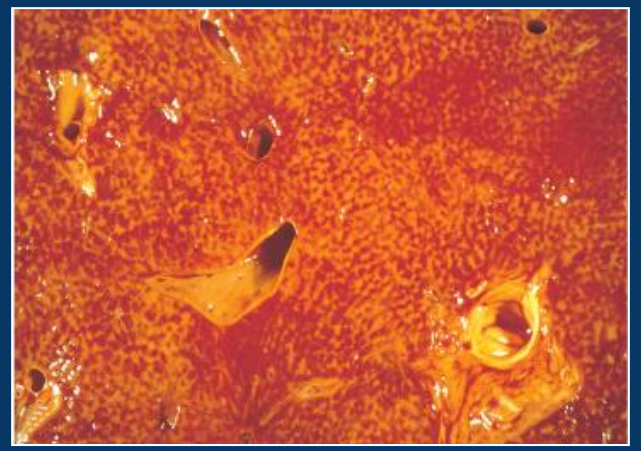
Mortality
increase 2-fold for every hour
in treatment delay.

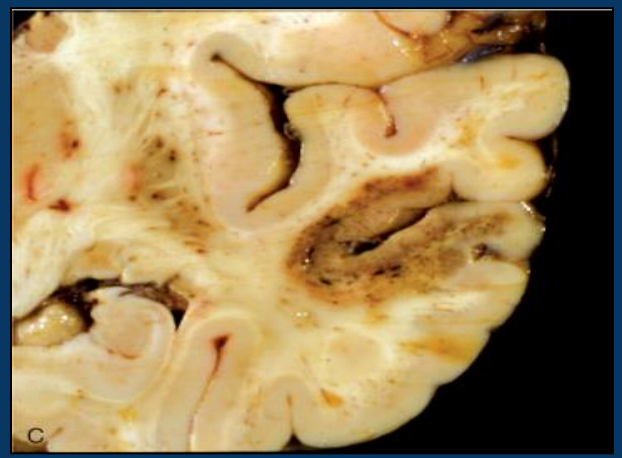
Han, Carcillo. Pediatrics 2003;112:793-799

Multisystem effect of shock

- Resp: Resp failure, ARDS
- Renal: ATN, acute renal failure
- CNS: infarcts & bleeding
- Liver: centrilobular necrosis
- GIT: bleeds, necrosis, ileus, bacterial translocation
- Haemat: DIC, vasculopathy, capillary leak







Robbins & Cotran Pathologic Basis of Disease: 2005

Common Features of Shock

- Cool, clammy skin
- Pale or ashen skin
- Bluish tinge to lips or fingernails (or gray in the case of dark complexions)
- Rapid pulse
- Rapid breathing
- Nausea or vomiting
- Enlarged pupils
- Weakness or fatigue
- Dizziness or fainting
- Changes in mental status or behavior, such as anxiousness or agitation

SHOCK

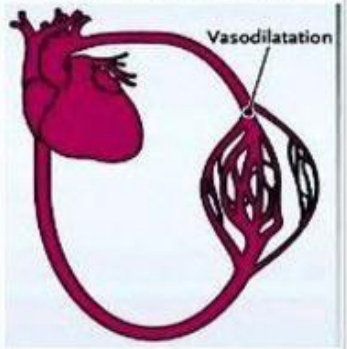
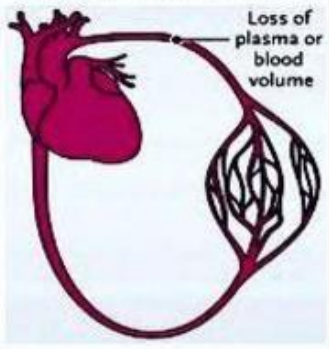
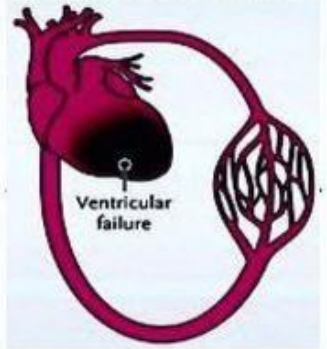
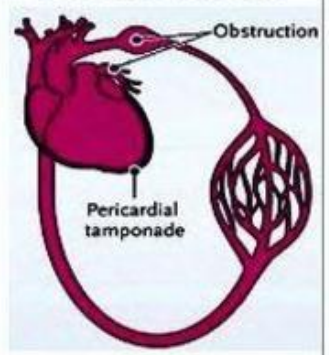
Signs of ↑ CO: ↑ pulse pressure, warm extremities, normal cap refill

↑ CO

@MDHealthTips

↓ CO

Signs of ↓ CO: AMS, cold extremities, slow cap refill

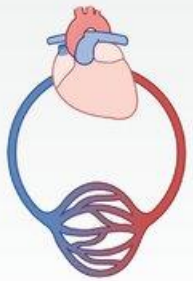
ETIOLOGY	DISTRIBUTIVE 66%	HYPOVOLEMIC 16%	CARDIOGENIC 16%	OBSTRUCTIVE 2%
				
PHYSIO	Decreased systemic vascular resistance and altered oxygen extraction	Low cardiac output and therefore inadequate oxygen transport		
EXAMPLE	**Sepsis/SIRS, anaphylaxis, adrenal insufficiency**, liver failure, toxins, spinal/neurogenic	**Bleed (GIB, RP bleed), third spacing (pancreatitis)**, GI losses, overdiuresis	**MI, CHF**	**PE, tension PTX, tamponade**
EXT	Warm and dry	Cold and dry	Cold and wet	Cold and dry
CVP (JVP)	↓	↓	↑	↑
CO (SvO_2)	↑ **or normal**	↓↓	↓↓	↓↓
SVR	↓↓	↑	↑	↑
BASIC TX	All causes: IVF, pressors Sepsis: source control, abx Adrenal: steroids Anaphylaxis: epi 0.3mg IM	Ensure adequate access! Most cases: Crystalloid HRS/SBP: Albumin Hemorrhage: pRBCs	Based on etiology consider diuresis, pressors, inotrope / inodilators, +/- PA line	PE: Heparin/lysis PTX: needle decompression Tamponade: pericardiocentesis

Classification of Shock

Volume

Shift — Distributive shock

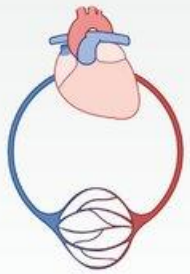
Septic	Capillary leakage
Anaphylactic Anaphylactoid Neurogenic	Vascular tone dysregulation



Vasodilation

Loss — Hypovolemic shock

Hemorrhagic (traumatic or nontraumatic)	Blood (whole)
Nonhemorrhagic (nontraumatic)	Body fluids (e.g., GI loss)
Nonhemorrhagic (traumatic)	Plasma (e.g., from burns)

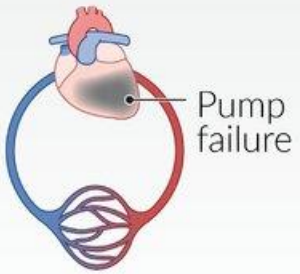


Hypovolemia

Output

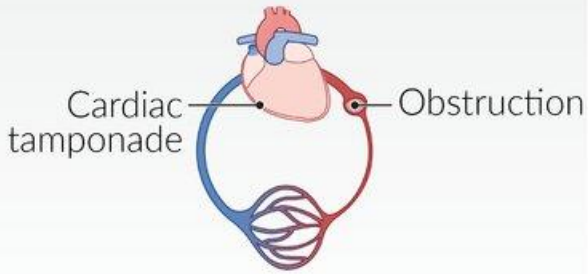
Cardiac — Cardiogenic shock

Myocardial causes	Myocardium
Arrhythmias	Conduction system
Valvular heart disease	



Extracardiac — Obstructive shock

Impaired diastolic filling	E.g., cardiac tamponade
↑ Ventricular afterload	E.g., massive PE
Obstruction of venous return	E.g., tension pneumothorax



Hemodynamics in Shock

Physiologic variable	Preload (R)	Preload (L)	Pump function	Afterload	Tissue perfusion
Clinical measurement	**RAP/CVP**	**PCWP/LVEDP**	**Cardiac output/ index**	**SVR/TPR**	**MvO_2**
Hypovolemic · Hemorrhagic · Burns · Pancreatitis (3rd spacing)	↓	↓↓	↓	↑	↓
Distributive · Sepsis · Anaphylaxis · Addisonian crisis	↓	↓	↑	↓	↑
Cardiogenic					
LV Dysfunction · MI (LAD) · Acute myocarditis	↑	↑	↓	↑	↓
RVMI · RCA occlusion · Inferior and RV MI · Isolated RV dysfunction	↑	↓	↓	↑	↓
Obstructive					
Pulmonary Vascular · PE · Severe PH	↑	↓	↓	↑	↓
Mechanical · Pericardial tamponade · Tension pneumothorax · Constrictive pericarditis · Restrictive cardiomyopathy	↑	↑	↓	↑	↓

RAP/CVP: right atrial pressure/central venous pressure
PCWP/LVEDP: pulmonary capillary wedge pressure/left ventricular end diastolic pressure
SVR/TPR: systemic vascular resistance/total peripheral resistance
MvO_2: mixed venous oxygen content
LAD: left anterior descending artery
RVMI: right ventricular myocardial infarction
RCA: right coronary artery
SV: stroke volume
PE: pulmonary embolism
PH: pulmonary hypertension

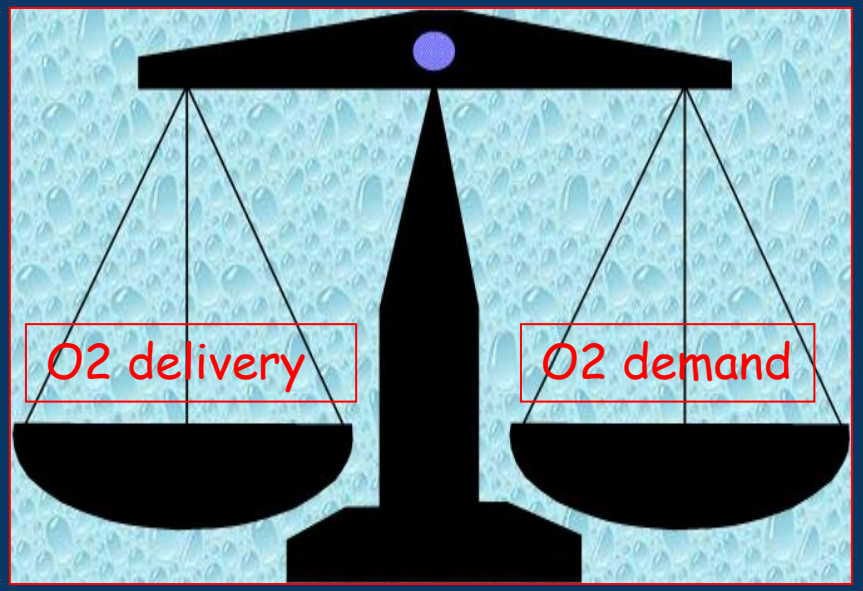
Shock states coexist

Changing hemodynamics

Individualize treatment

Treatment principles

1. Increase O2 delivery
2. Reduce O2 demand
   - Fever
   - Tachycardia
   - Tachypnea
   - Anxiety & restlessness
   - Pain
   - Seizures & shivering



ABCDE

Resuscitation Priorities

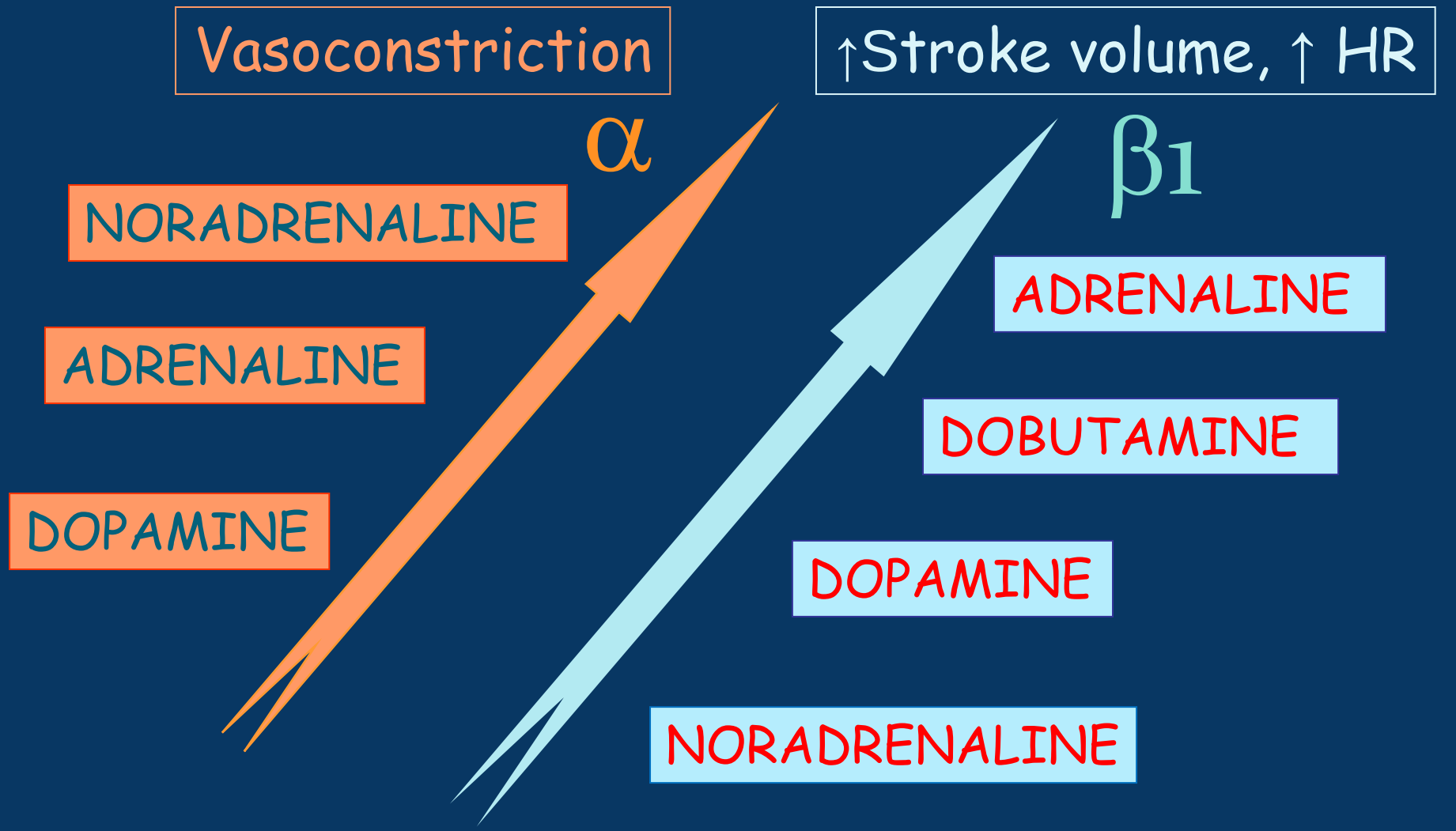
Increase O2 delivery

- V: Ventilate & Oxygenate.
- I: Infuse:
  - Fluids, fluids, fluids
  - Electrolytes
  - Blood- Hb >10
- P: ↑Pump Function:
  - Inotropes
  - Rhythm control
  - Electrolytes & glucose
- E: Etiology: - Treat the cause.

FLUID, FLUID, FLUID

- Regardless of etiology - fluid bolus x3
  - 5ml/kg cardiac
  - 10ml/kg trauma
  - 20ml/kg sepsis
- Delayed fluid resuscitation ↑ mortality.
  - *Rivers NEJM 2001, Han Pediatrics 2003*
- Reassess liver & lungs.
- Septic shock may need up to 200ml/kg.
- No evidence one is fluid superior.
  - *Finfer NEJM 2004*

Inotropes in fluid resistance



Pediatric Cardiac Intensive Care . Chang & Wernovsky

Resuscitation endpoints

- No difference between peripheral & central pulses
- Warm skin, CFT < 2sec
- Normal BP for age
- Decreasing lactate & BE
- Improving mental state
- UO >1ml/kg/h

Trend of improvement

Peters ICM 2008;34

- Thank you for your Attention