BLOOD PRESSURE
IN SMALL ANIMAL PRACTICE

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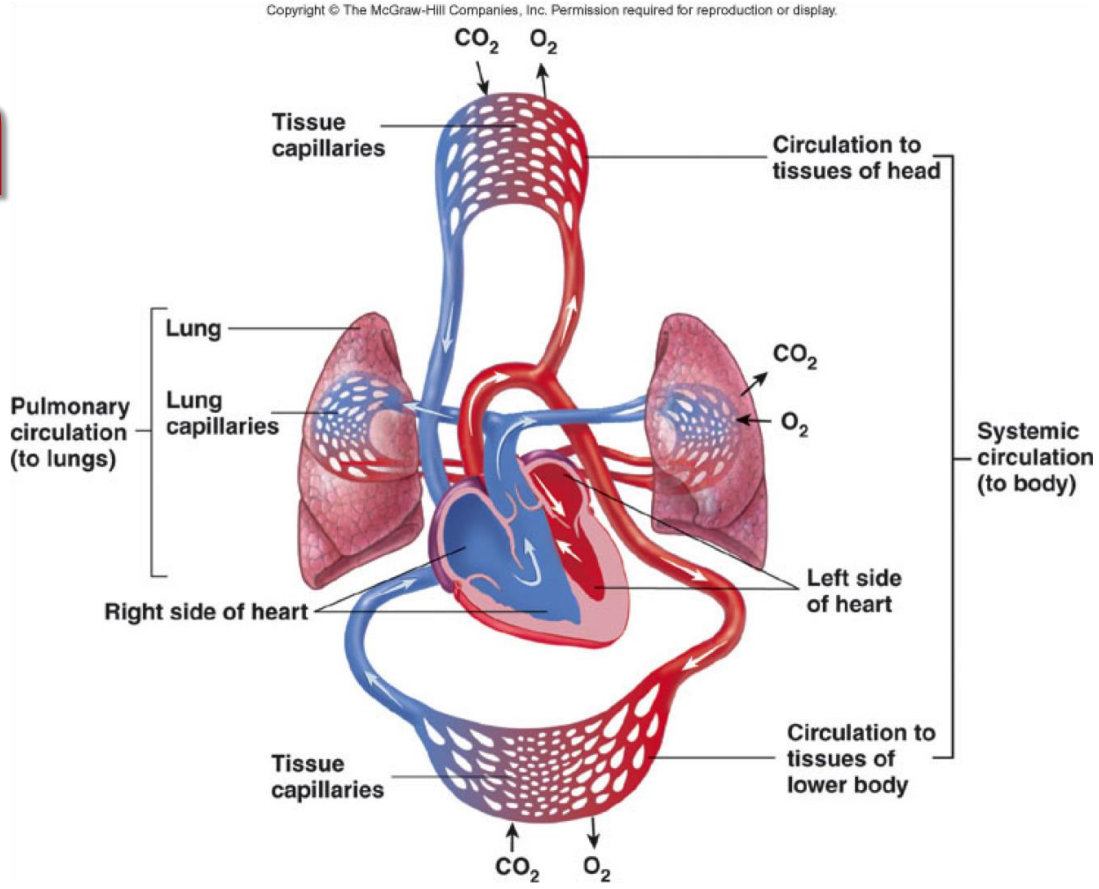
CONTENTS

- Physiology of blood pressure
- Blood pressure measurements
- Systemic Hypertension
- Pulmonary Hypertension
- Systemic Hypotension

PHYSIOLOGY OF BLOOD PRESSURE

Circulatory system

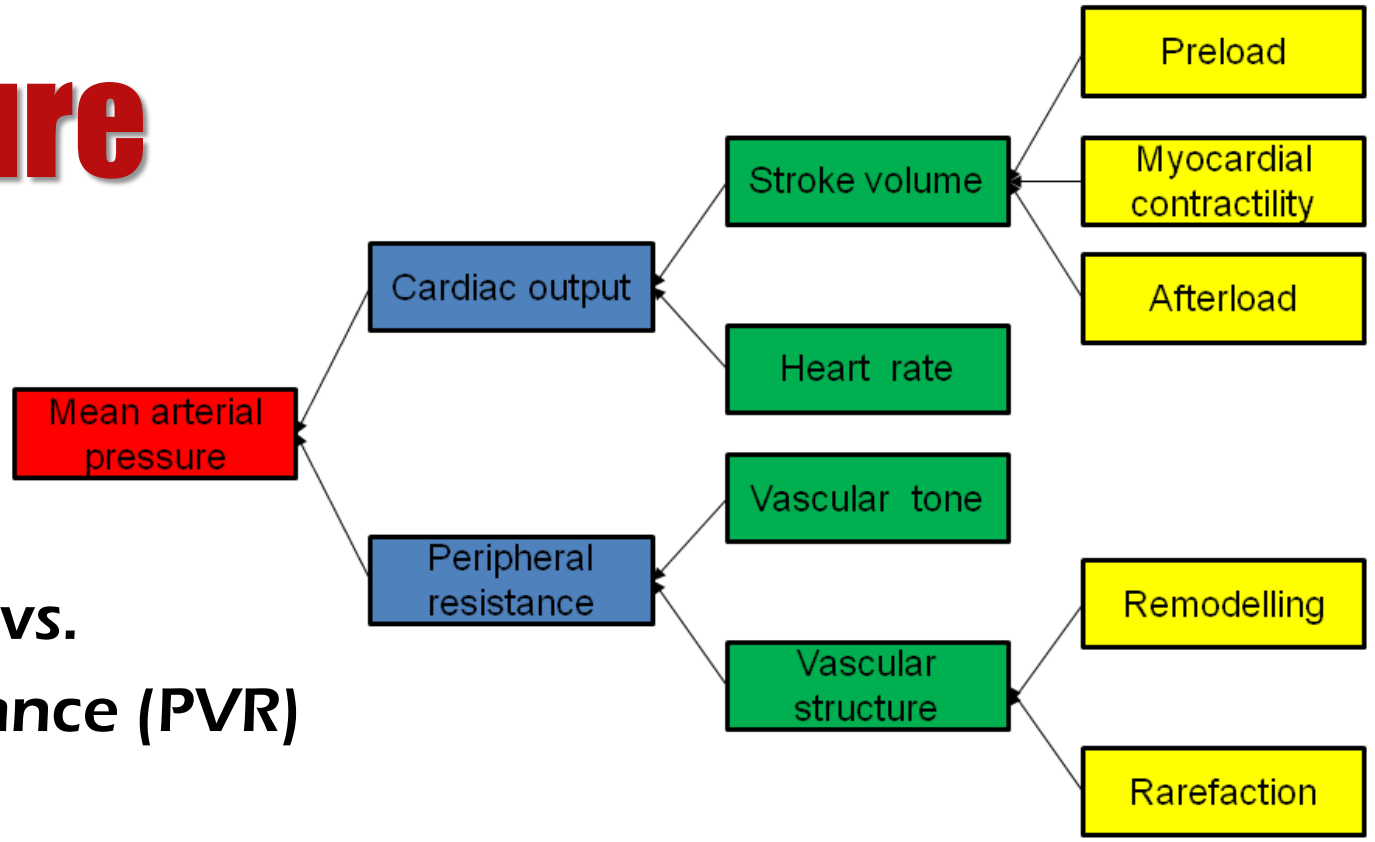
- Systemic circulation
  - From aorta to Venae cavae
- Central circulation
  - Right heart, pulmonary circuit, left heart



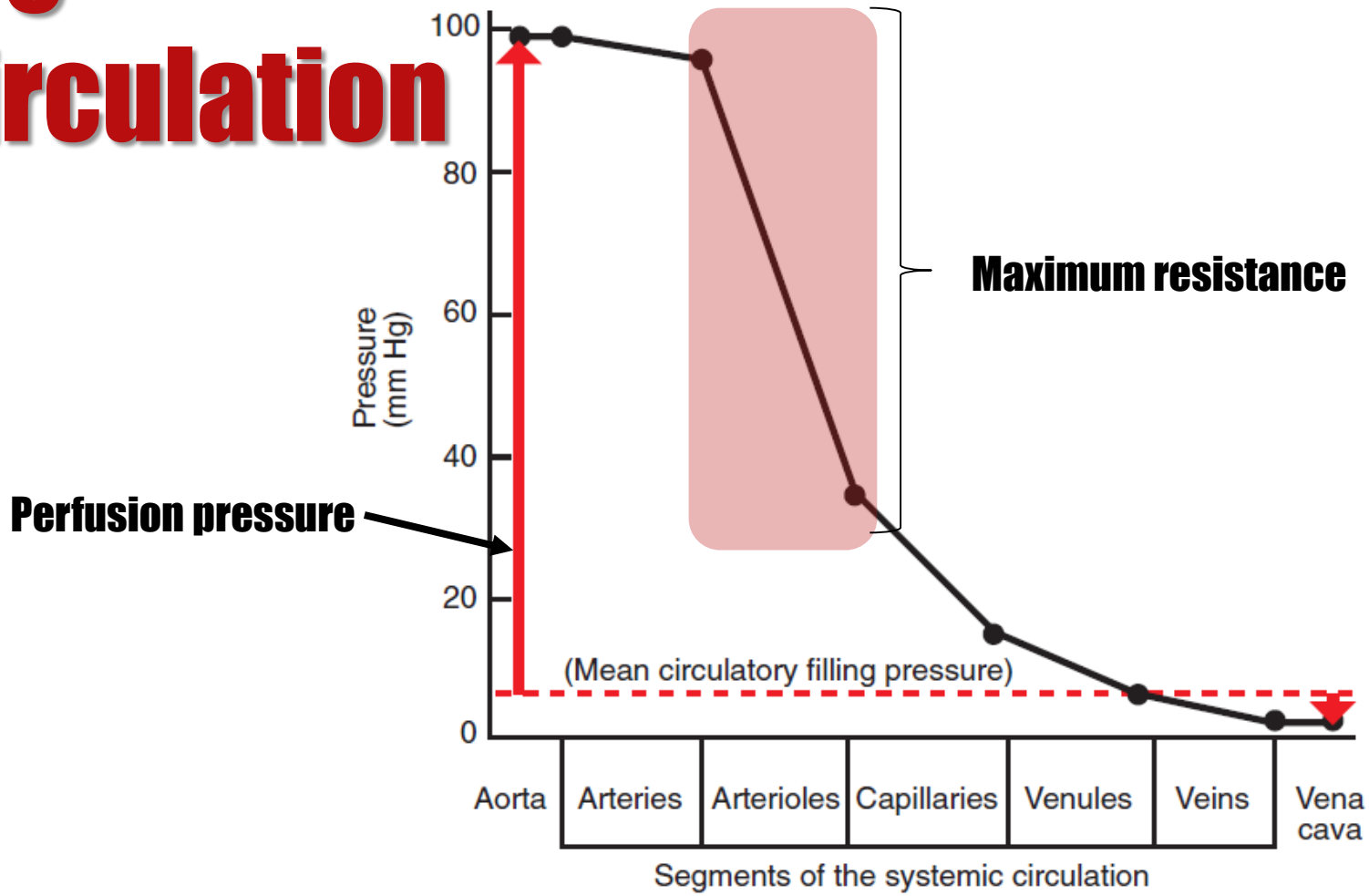
Blood Pressure

- **Definition:**

Energy that moves blood vs. peripheral vascular resistance (PVR)

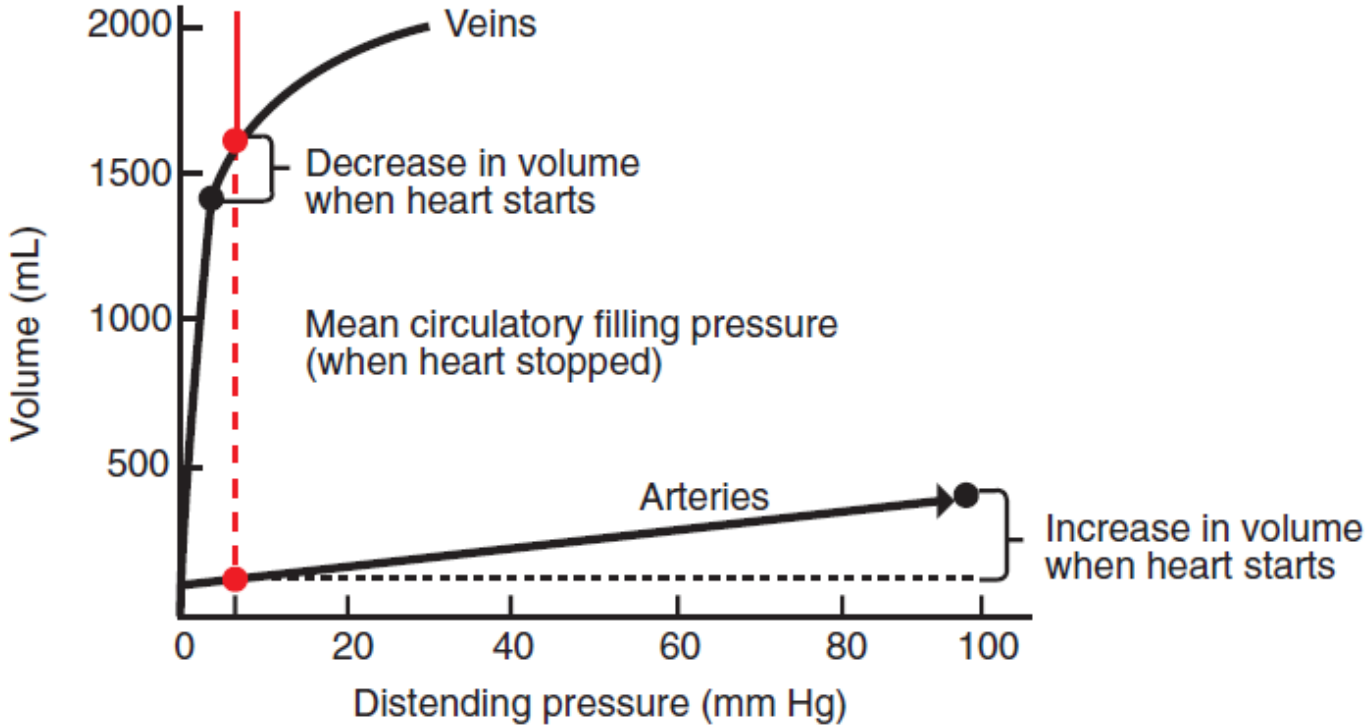


Blood Pressure in Systemic circulation



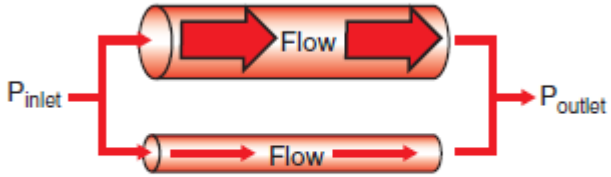
Vascular Compliance

$$\text{Compliance} = \frac{\Delta\text{Volume}}{\Delta\text{Transmural pressure}}$$



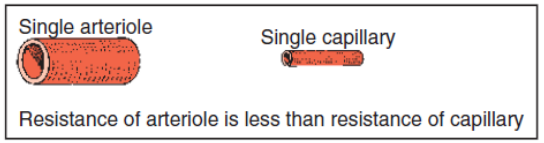
Vascular Resistance

$$\text{Resistance} = \frac{\Delta\text{Pressure}}{\text{Flow}}$$

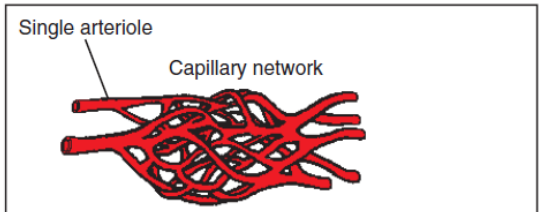


Δ Pressure = ($P_{inlet} - P_{outlet}$)

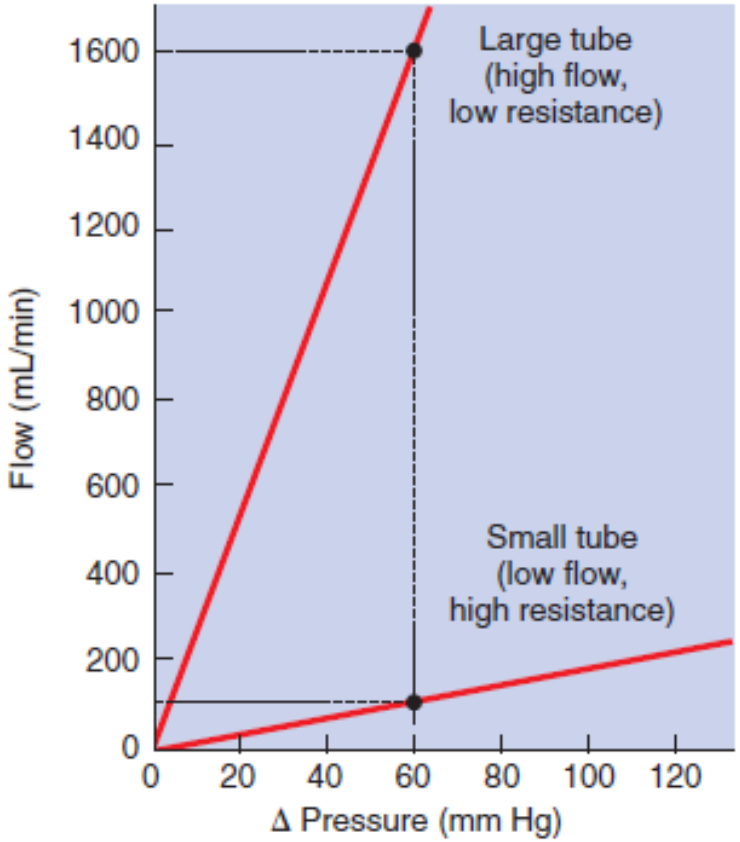
$$\text{Resistance of a tube} \cong \frac{8\eta l}{\pi r^4}$$



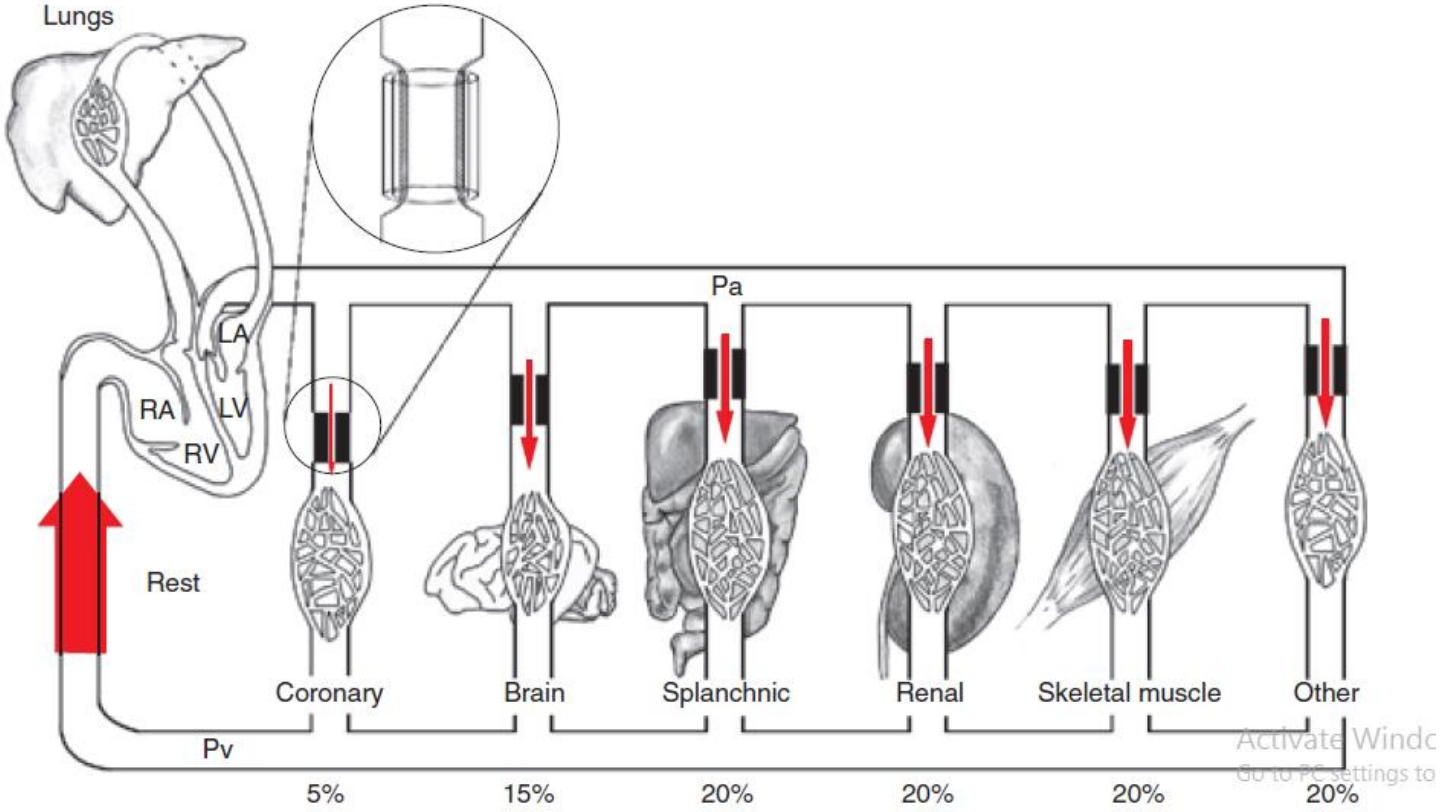
Resistance of arteriole is less than resistance of capillary



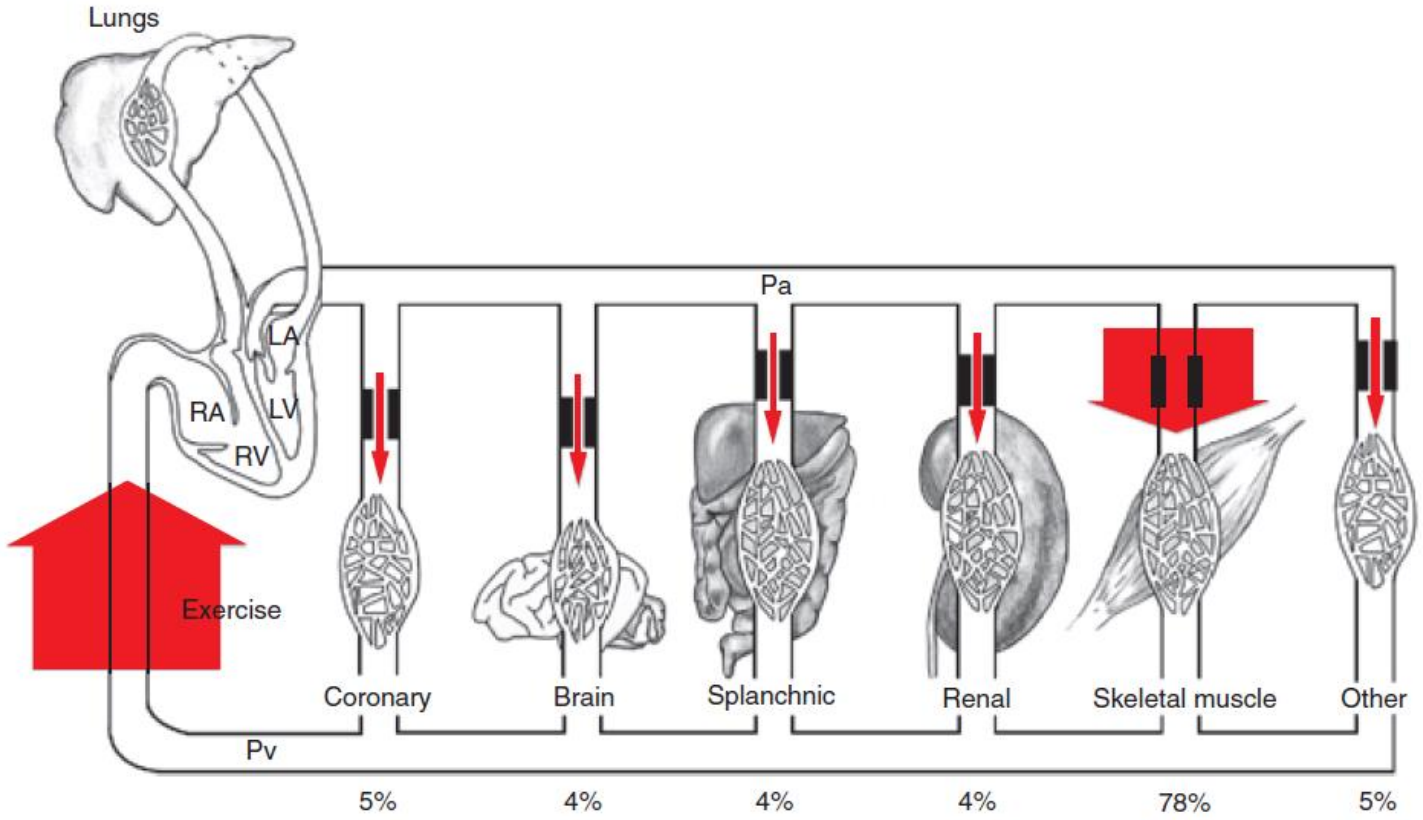
Resistance of arteriole is greater than resistance of capillary network



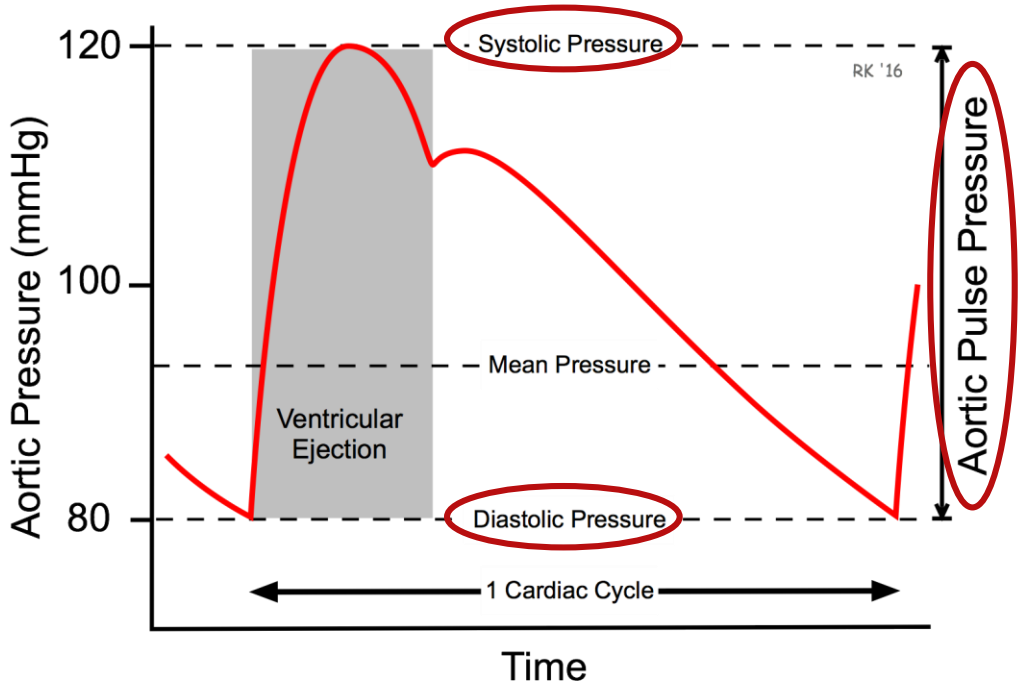
Cardiac output during rest



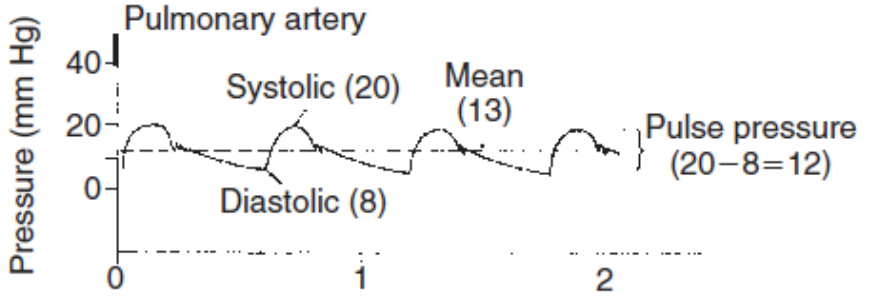
Cardiac output during exercise

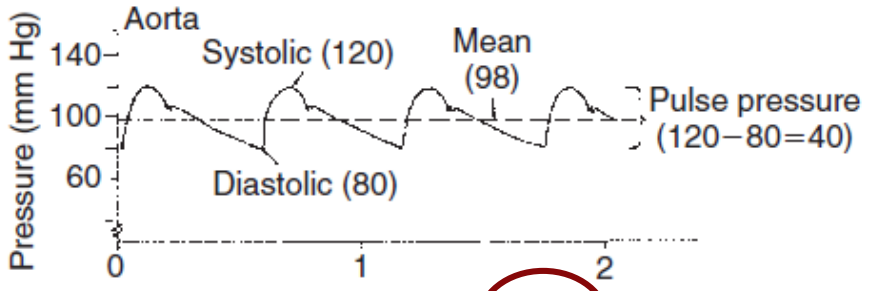


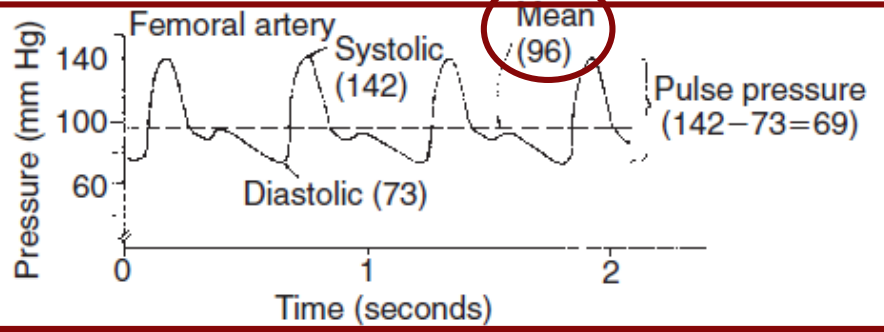
Systolic, Diastolic and MAP



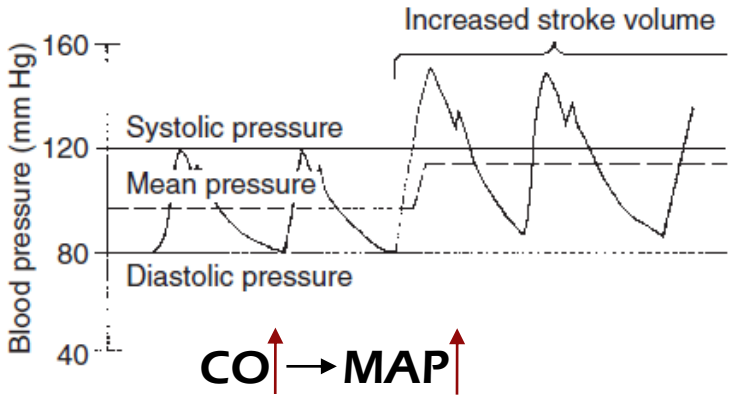
MAP= Dia + [(Sys – Dia)/3]



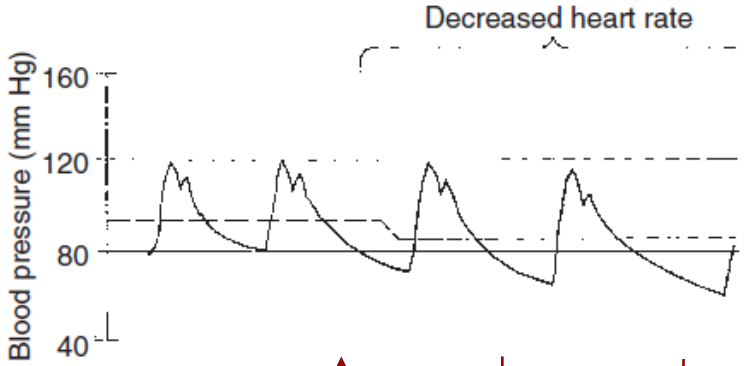




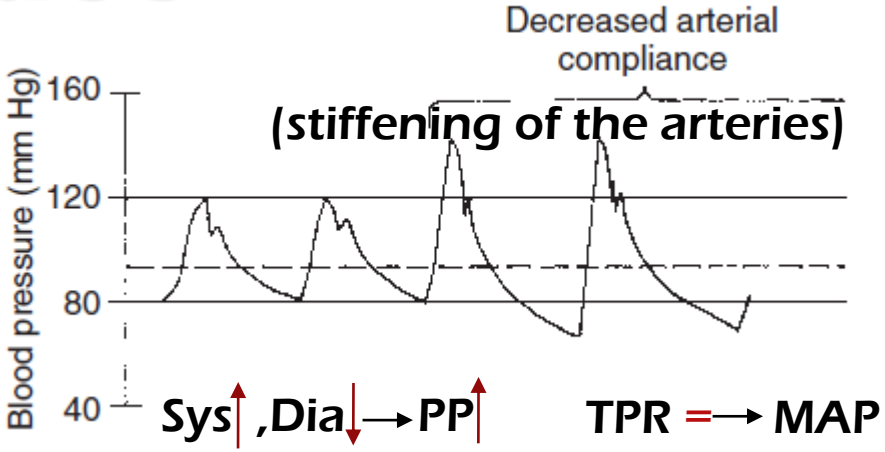
Pulse Pressure Increase



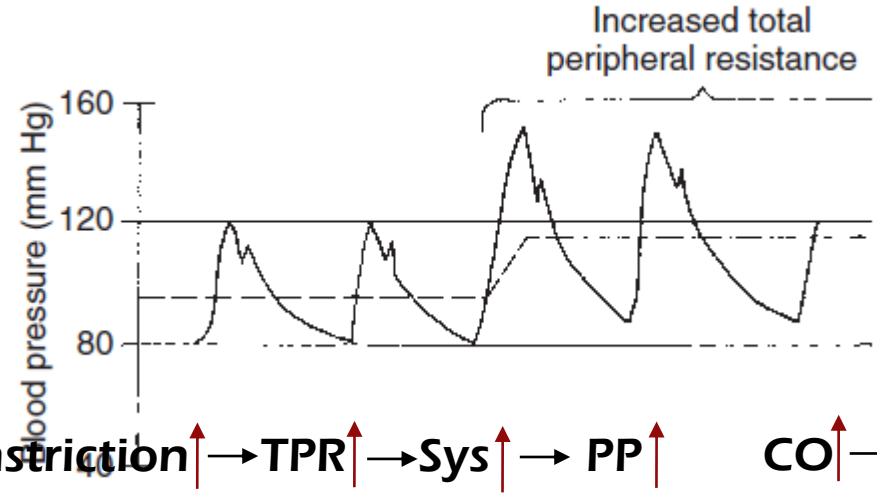
CO↑ → MAP↑



Dia↓ → PP↑ CO↓ → MAP↓

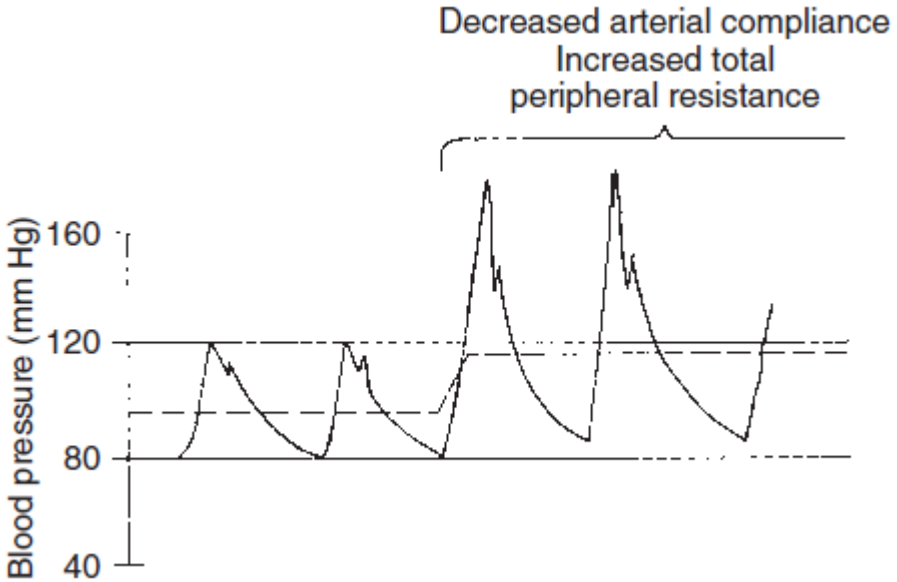


Sys↑ ,Dia↓ → PP↑ TPR = → MAP =

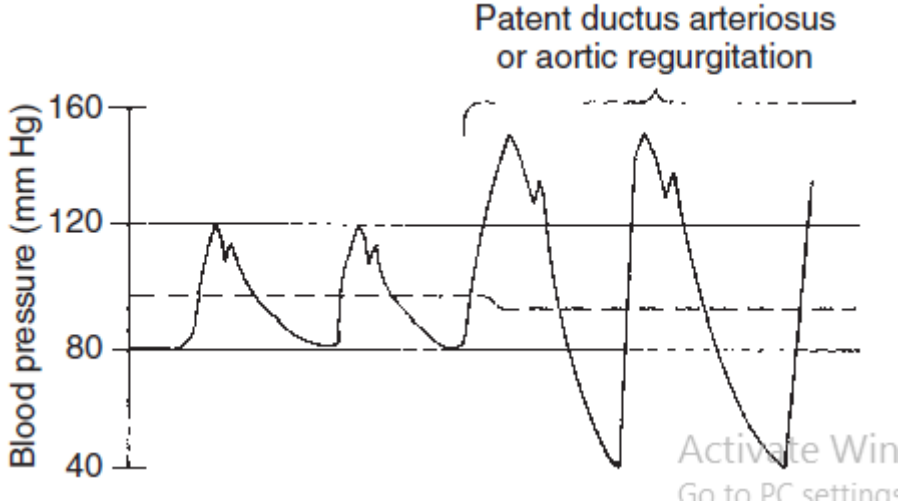


Vasoconstriction↑ → TPR↑ → Sys↑ → PP↑ CO↑ → MAP↑

Pulse Pressure Increase



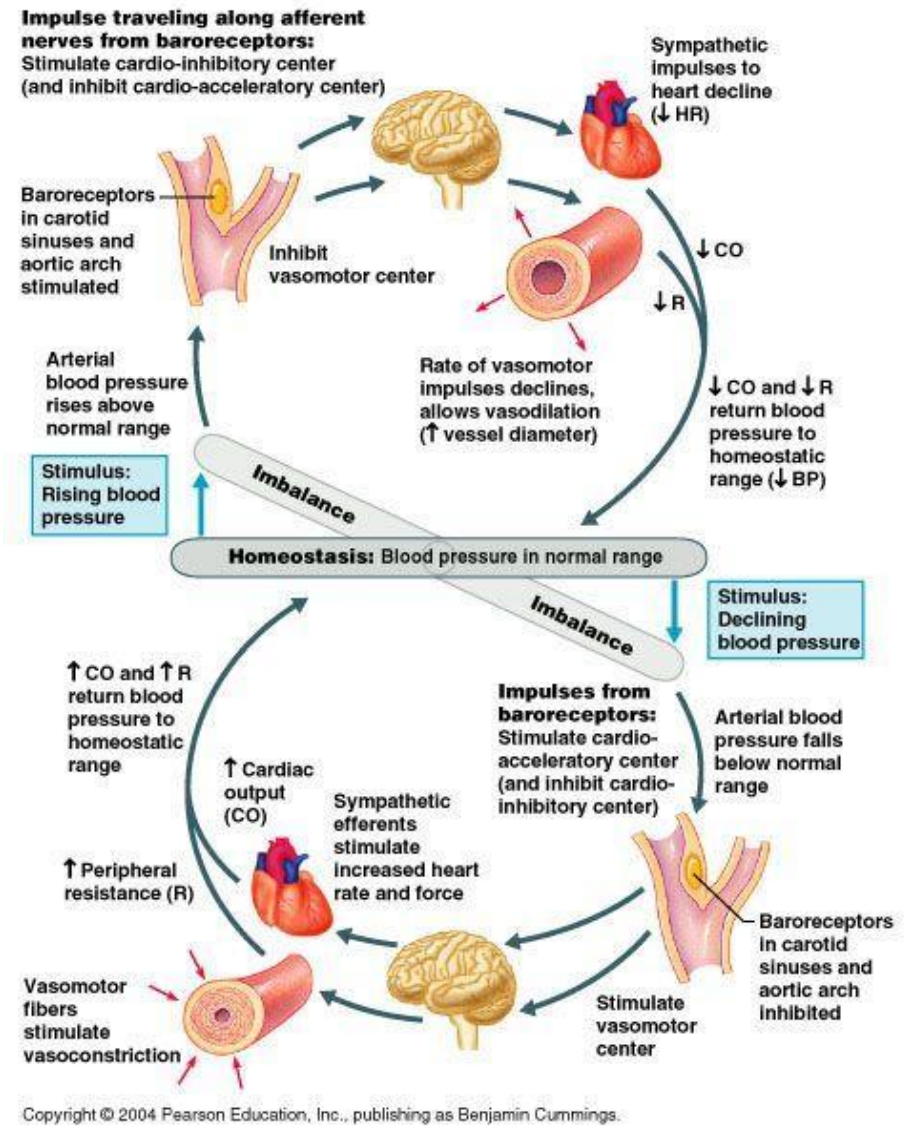
Aging process ⟶ stiffening of arteries
TPR ⟶ Essential hypertension
(common in human not in animals)
} PP↑



PDA & AoReg↑ ⟶ LVSV↑ ⟶ Sys↑
In PDA: blood ⟶ ductus and aorta Dia
In AoReg: blood ⟶ aorta and LV Dia
} PP↑

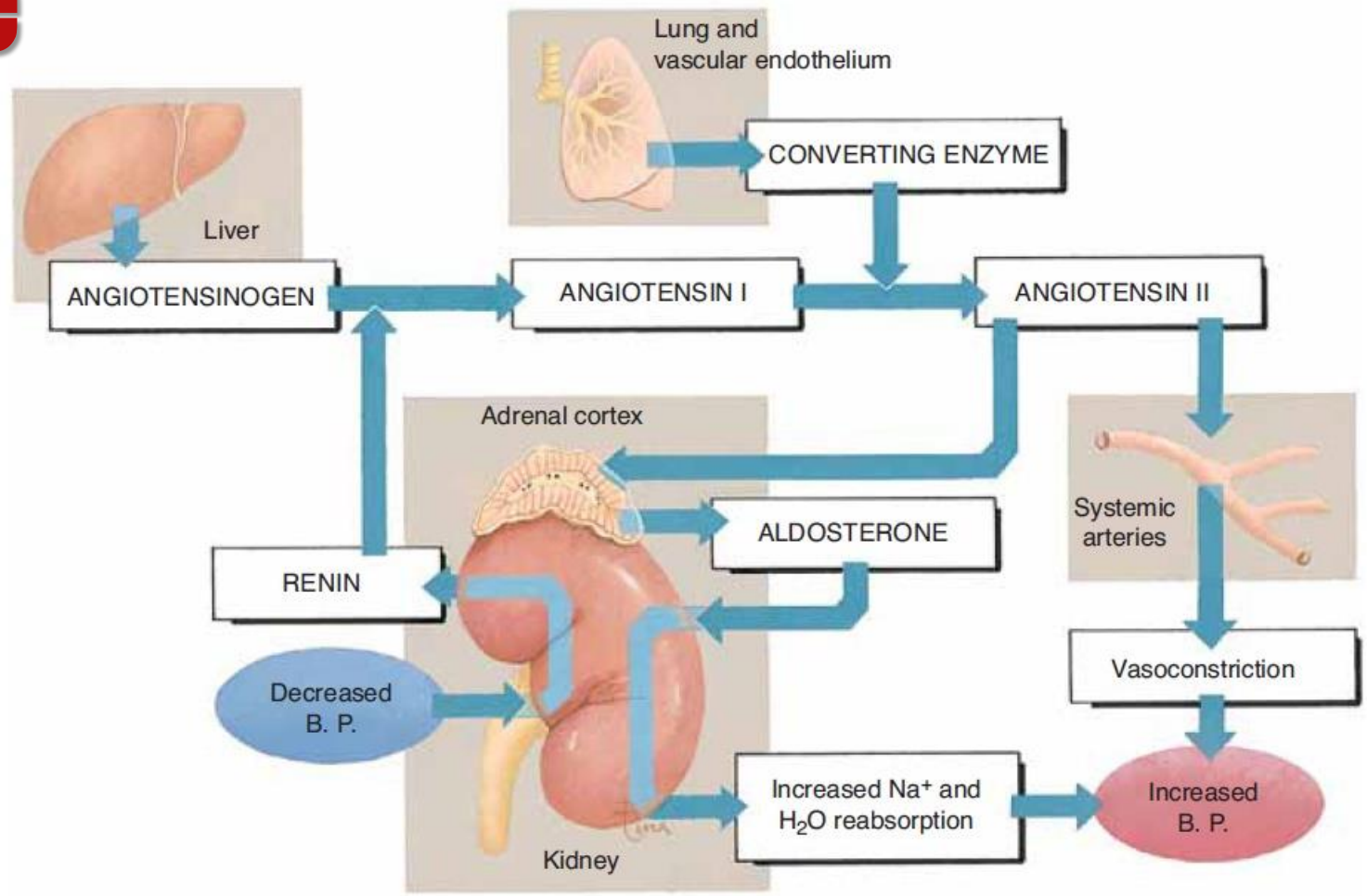
Blood Pressure Regulation

- SHORT-TERM MECHANISMS



Blood Pressure Regulation

- LONG-TERM MECHANISMS



Normal Ranges of Blood Pressure

Blood Pressure Values	Dogs	Cats
Systolic arterial pressure	90-140 mmHg	80-140 mmHg
Diastolic arterial pressure	50-80 mmHg	55-75 mmHg
Mean arterial pressure	60-100 mmHg	60-100 mmHg

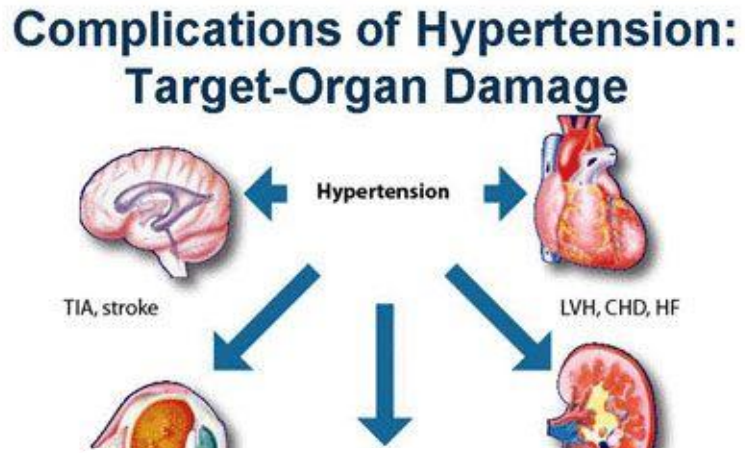
Normal Arterial Blood Pressure Values in Adult Dogs & Cats

BLOOD PRESSURE MEASUREMENT

- Arterial Catheterization
- Oscillometric or HDO method
- Doppler sphygmomanometric method

Indications for BP Assessment

- Cats:
  - Ophthalmic abnormalities (The most common)
    - Retinal detachment
    - Intraocular hemorrhage
  - Neurologic signs
    - Dull mentation
    - Focal facial seizures
  - Renal insufficiency
  - Thyrotoxicosis
  - Cardiac abnormalities
    - Gallop heart sound
    - Left-sided systolic murmurs



Primary hypertension

About 20% of diagnosed cases are classified as idiopathic hypertension, with no specific cause identified.[3]

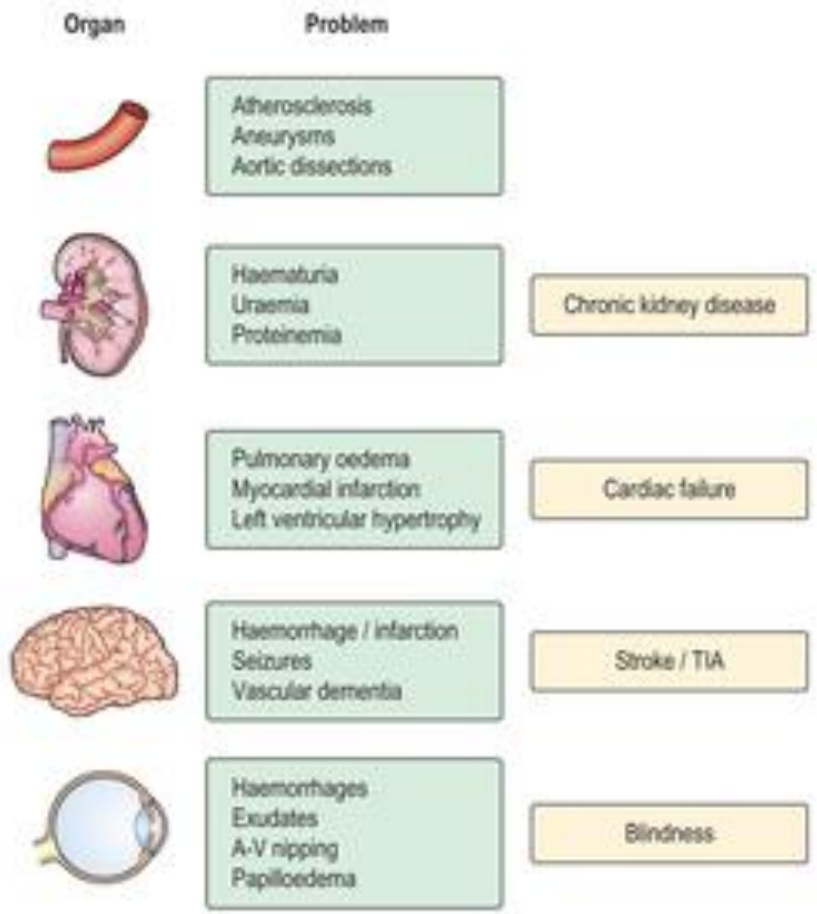
Secondary hypertension

Up to 74% of hypertensive cats have CKD[5,6]

Up to 65% of cats with CKD are hypertensive[7–9]

Indications for BP Assessment

- Dogs:
  - Renal dysfunctions
    - Protein losing renal disease
    - Acute or chronic renal failure
  - Ophthalmic abnormalities
    - Retinal hemorrhage and detachment
    - Hyphema
  - Hyperadrenocorticism
  - Diabetes mellitus
  - Pheochromocytoma
  - Cardiac dysfunctions
    - Left ventricular thickening



Choosing BP measurement technic

- It is often preferable to measure BP acutely (During clinical examination or diagnostic evaluation
- Considerations:
  - Availability of equipment
  - Availability of "normal" values to use for comparison
  - Experience of operator
  - Animal's conditions (Size, Obesity, Temperament)
- A well-performed study using normal animals may be used to develop normal values for non-invasive methods
- The technique used in a specific study must be accurately reproduced in the clinic for suggested "normal values" to be valid

Choosing BP measurement technic

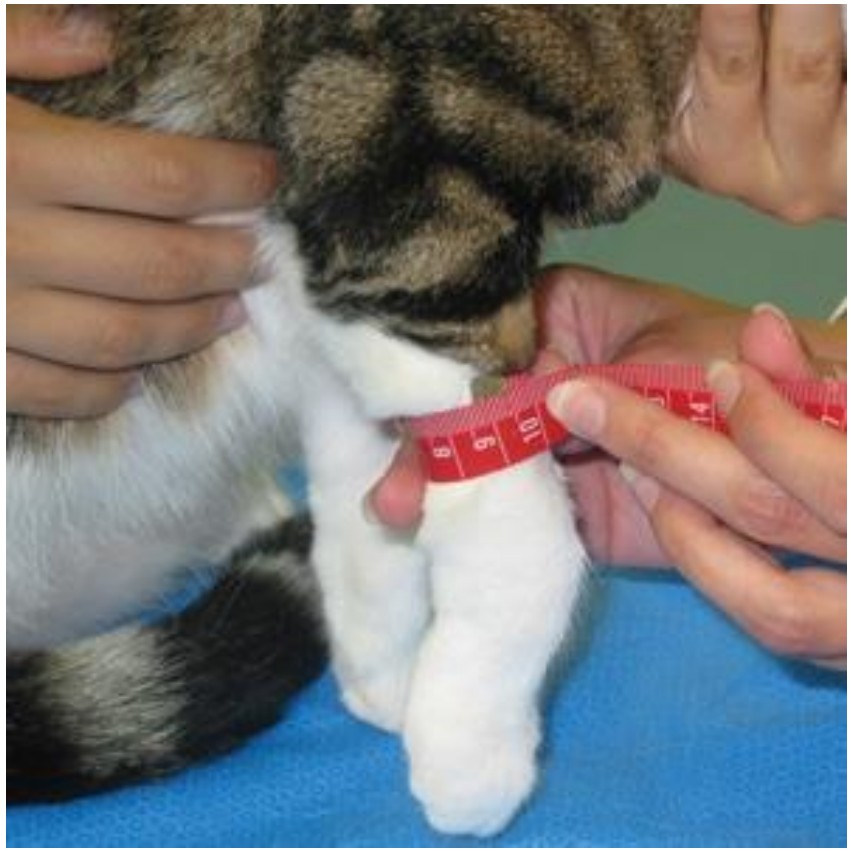
- Conscious Patients:
  - Arterial catheterization method (continuous measurement)
    - Accurate, no animal move disturbances, results are objective and repeatable
    - Invasive, technique skill, expensive equipment
  - Oscillometric method (automatic measurement)
  - Doppler sphygmomanometric method (manual measurement)
    - Technically simple, repeatable recordings
    - Inaccurate with animal movement, poor pulse pressure, arrhythmias, inconsistent technic

- When repeated BP measurement for monitoring are obtained, "animal posture", "limb position", "cuff size" and "cuff position" should be identical.

Choosing BP measurement technic

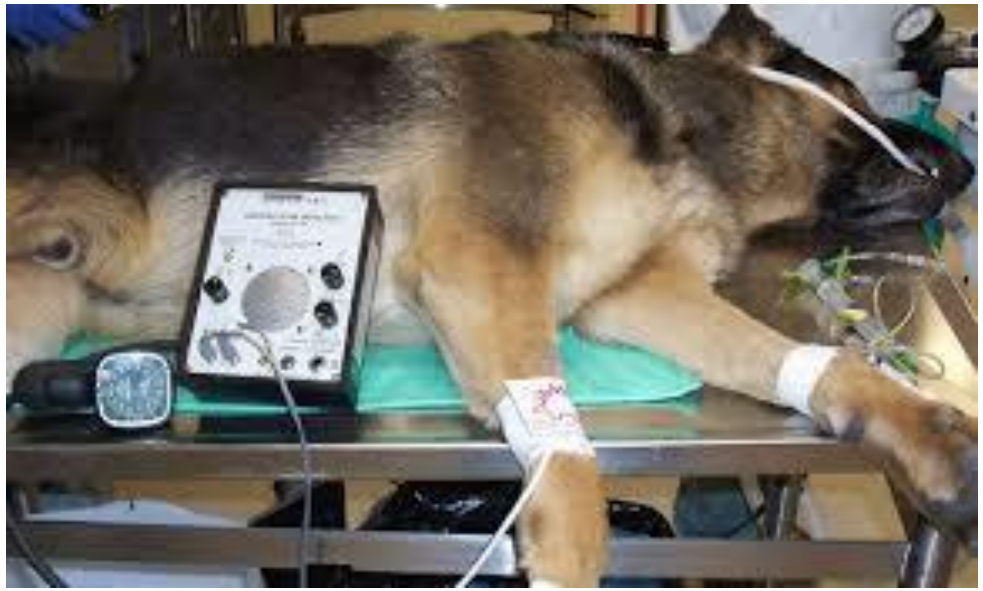
Cuff choice and placement:

- The width of the chosen cuff should be 30% to 40% of the circumference of the measurement site.
- Oversized cuffs give a falsely low value and cuffs that are markedly < 30% of circumference will yield a falsely elevated value for blood pressure.
- Most cuffs have an artery arrow imprinted on them, which should overlie the anatomic site of the vessel in the extremity



Choosing BP measurement technic

- Anesthetized patients:
  - All methods are accurate and repeatable (due to not moving patient)
  - Non-invasive vs. invasive methods often underestimate true BP



Arterial Cannulation (Invasive Method)

- Placing a catheter in femoral artery
- Usually needs general or local anesthesia
- Uses for critical patients
- Mostly in dogs, Seldom in cats

Oscillometric Technique

1. A cuff wraps around a limb or tail over an artery
2. Cuff inflates automatically, Causes occlusion of the artery, then slowly deflates
3. The pressure at which oscillations are maximal, records as MAP
4. The monitor uses algorithms to calculate Systolic and Diastolic pressures

- This technic uses data from many cardiac cycles so is unsuitable for animals with rapidly changing BP
- More accurate in dogs than in cats (small arteries in cats)
- Needs patient to be motionless
- The cuff should be at the level of the heart
- At least five readings with 1 min intervals

Blood Pressure

Measurement

David LISS, RVT

Training. Educating. Empowering.

Doppler-Ultrasonic Method

1. Doppler ultrasonic piezoelectric crystal detects flow in a peripheral artery
2. Hair clip site for ultrasonic probe placement:
   - Forelimb measurement: prox. to the palmar metacarpal pad
   - Hindlimb measurement: over the dorsal pedal artery
   - Tail measurement: ventral aspect of the tail

3. A cuff is placed proximal to the clipped site
4. After hearing an audible sound, the cuff is inflated no less than 40mmHg above the cut-off point of the signal
5. The cuff then slowly deflated, first audible sound represents Sys. Pressure, and when the sound becomes muffled, is considers as Dia. Pressure (which is not so reliable!)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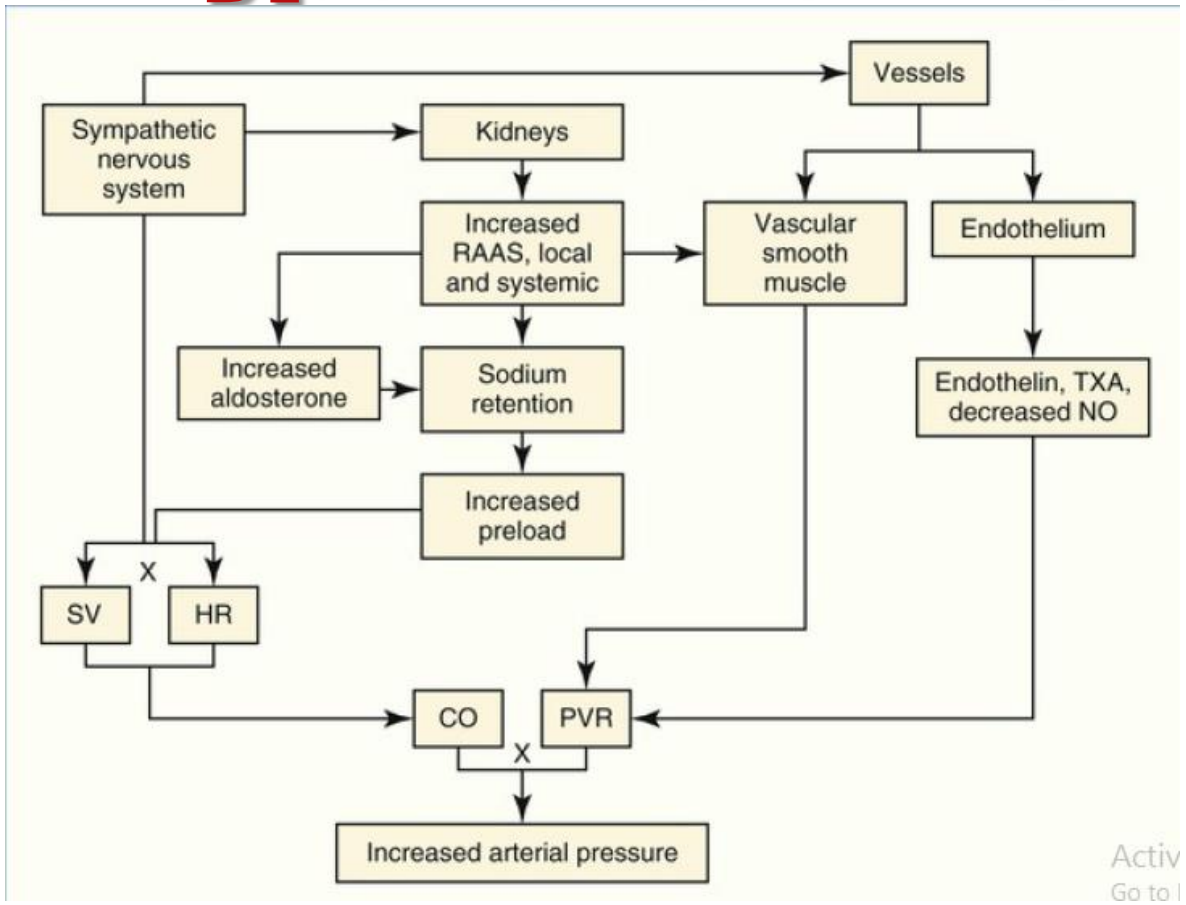
SYSTEMIC HYPERTENSION

Systemic Hypertension (SH)



Potential mechanisms for the development of systemic hypertension

Conditions associated with SH

- Older **male** dogs > **female** dogs
- Increased **age** in cats w/o CKD → higher SH and higher HR
- **Obesity**: unlike human, there is small or no correlation b/w SH and obesity
- **Kidney disease**: the most common cause of SH in dogs and cats
- **Hyperadrenocorticism**: 59-86% of these dogs have SH too. But no corr. found yet
- **Hyperthyroidism**: recent studies show lower prevalence of HT and SH together
- **Diabetes Mellitus**: SH is recognized in 35-46% of acute DM, but no association b/w SH, proteinuria and retinopathy with DM have been found
- **Hyperaldosteronism**
- **Pheochromocytoma**
- **White-coat effect**

Target-organ Damage

- Patients with hypertension (HT) are often subclinical or demonstrate clinical signs corresponding to another underlying disease process
- Chronically sustained HT can damage the eyes, kidneys, brain, and cardiovascular system; injuries referred to as target-organ damage

Table 1. Target-Organ Damage Caused by Systemic Hypertension

Target Organ	Target-Organ Damage	Appropriate Assessment Tests
Brain	• Depression • Seizures	Complete neurologic examination
Eyes	• Retinal detachment • Hemorrhage • Vessel tortuosity	Complete ocular examination (See **Ten Tips to Improve Your Ophthalmology Skills**, July/August 2011)
Heart & blood vessels	• Left ventricular hypertrophy • Congestive heart failure	Auscultation, ECG, thoracic radiographs, cardiac ultrasound
Kidney	• Renal azotemia • Proteinuria	Blood creatinine, urine protein:creatinine ratio

ECG = electrocardiogram

Treatment of Hypertension

The initial assessment of an animal suspected to have HT should include:

- Recognizing conditions that may be contributing to an increase in BP
- Identifying and characterizing target-organ damage
- Determining if there are any concurrent conditions that may complicate antihypertensive therapy (e.g. heart or kidney disease)

- A decision to use antihypertensive drugs should be based on the BP stage (Table 2)
- The ultimate goal of therapy is to minimize target-organ damage while providing a good quality of life

Treatment of Hypertension

Table 2. International Renal Interest Society Staging: Risk for Future Target-Organ Damage*

Blood Pressure Substage	Systolic Blood Pressure	Diastolic Blood Pressure	Risk for Target-Organ Damage
AP0	< 150	< 95	None or minimal
AP1	150 – 159	95 – 99	Low
AP2	160 – 179	100 – 119	Moderate
AP3	≥ 180	≥ 120	High

**The patient's BP stage should be selected as the higher of the 2 assessments if reliable measurements provide different risk assessments based on the patient's systolic and diastolic BPs.*

Treatment of Hypertension

Which Patients to Treat?

- The general consensus is to institute therapy in a patient with evidence of target-organ damage (Table 1)
- if reliable measurements of BP indicate that systolic BP (SBP) exceeds 160 and/or diastolic BP (DBP) exceeds 100 mm Hg (AP2 or AP3) (Table 2)
- the ideal goal of therapy would be to reduce the risk of future target-organ damage to substage AP0 (SBP < 150 and/or DBP < 95 mm Hg)
- The response to effective antihypertensive therapy is typically a 25 to 50 mm Hg decline in BP

Dogs with Hypertension

For hyperaldosteronism

for pheochromocytoma

Initial choice

If partially effective, Add

If nephrotic syndrome also presents

Table 3. Oral Agents for Antihypertensive Therapy for Dogs and Cats

Class	Drug	Usual Oral Dosage	
		Dogs	Cats
Aldosterone antagonist	Spironolactone	1–2 mg/kg Q 12–24 H	1–2 mg/kg Q 12–24 H
Alpha-1 blocker	Prazosin	0.5–2 mg/kg Q 8–12 H	0.25–0.5 mg/cat Q 24 H
	Phenoxybenzamine	0.25 mg/kg Q 8–12 H or 0.5 mg/kg Q 24 H	2.5 mg/cat Q 8–12 H or 5 mg/cat Q 24 H
Angiotensin-converting enzyme inhibitor (ACEI)	Benazepril, enalapril	0.5–2 mg/kg Q 12 H	0.5–2 mg/kg Q 24 H
Angiotensin-receptor blocker	Losartan, irbesartan	0.5–1 mg/kg/D 1–5 mg/kg Q 12–24 H	Unknown
Beta-blocker	Atenolol	0.25–1 mg/kg Q 12 H	6.25–12.5 mg/cat Q 12 H
Calcium channel blocker (CCB)	Amlodipine	0.1-0.75 mg/kg Q 24 H	0.1-0.75 mg/kg Q 24 H
Direct vasodilator	Hydralazine	0.5–2 mg/kg Q 12 H (start at 0.5 mg/kg)	2.5 mg/cat Q 12–24 H
	Acepromazine	0.5–2 mg/kg Q 8 H	0.5–2 mg/kg Q 8 H
Thiazide diuretic	Hydrochlorothiazide	2–4 mg/kg Q 12–24 H	2–4 mg/kg Q 12–24 H

Cats with hypertension

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Angiotensin-receptor blocker	Losartan, irbesartan	0.5–1 mg/kg/D 1–5 mg/kg Q 12–24 H	Unknown
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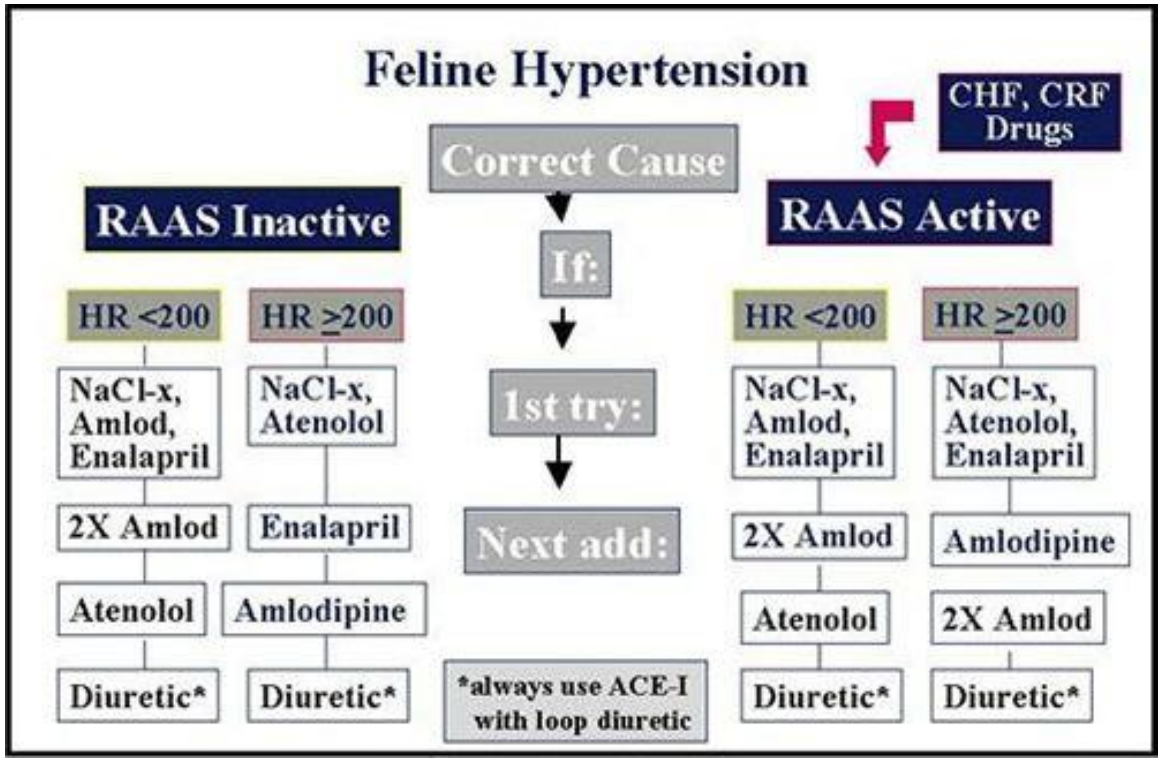
	Acepromazine	0.5–2 mg/kg Q 8 H	0.5–2 mg/kg Q 8 H
Thiazide diuretic	Hydrochlorothiazide	2–4 mg/kg Q 12–24 H	2–4 mg/kg Q 12–24 H

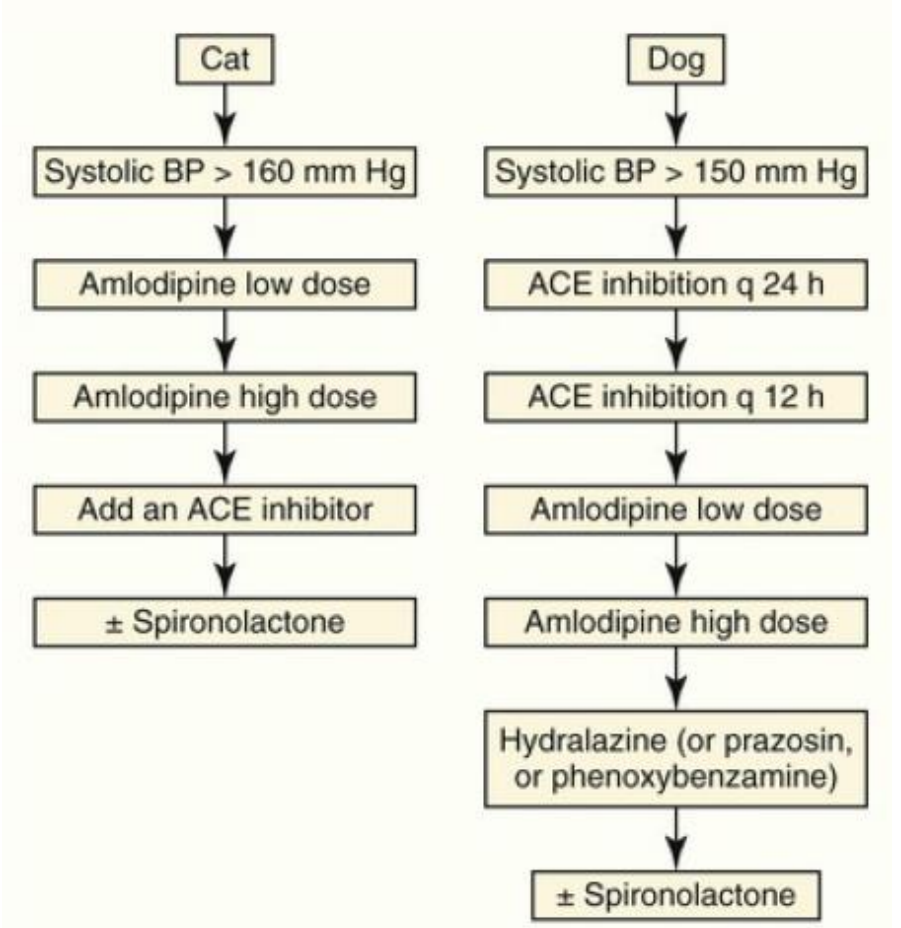
2nd choice esp. in Proteinuric cats

For hyperthyroid cats (combined with CCB)

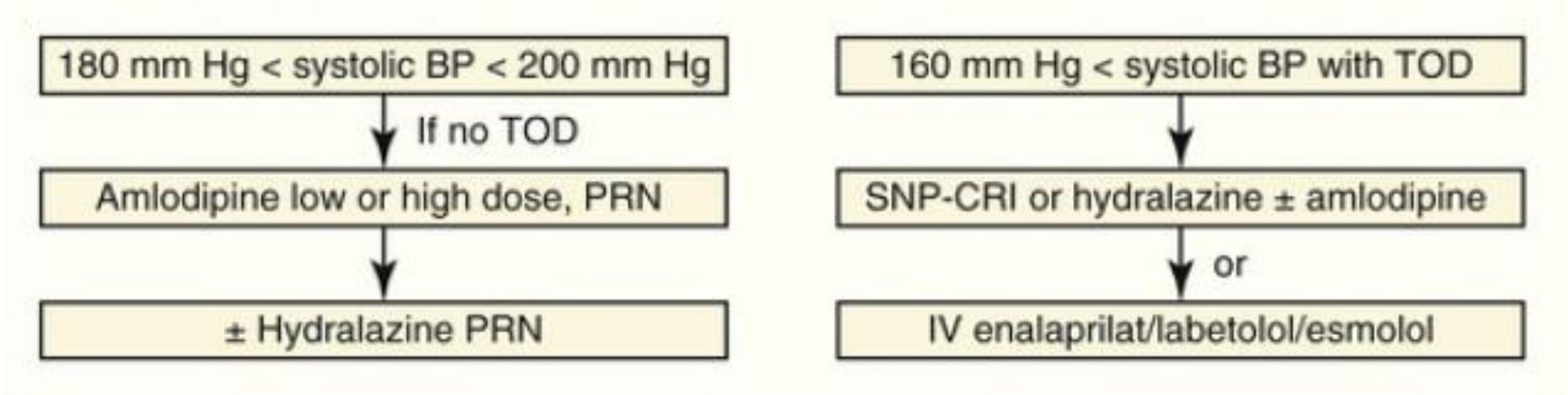
Initial choice

Treatment of Hypertension





Emergency Treatment for Hypertension



- The goal of emergency treatment in either species is to reduce BP within hours to slow rapidly progressing ocular or neural target-organ damage, adjusting dosages within that time frame as necessary.

Treatment of Hypertension

- Dietary Considerations
  - available evidence suggests sodium restriction alone generally does not reduce BP
  - high salt intake may produce adverse consequences in treating HT.
  - Therefore, low-salt diets are recommended for hypertensive patients.
- Monitoring Antihypertensive Therapy
  - In not emergent cases: 3 to 4 weeks interval dose adjustments
  - In Chronic kidney disease (CKD) patients: 3 to 14 days after any change in therapy
  - In hypertensive emergencies and hospitalized patients: daily or several times daily depending on severity of crisis

Further Evaluation

- Re-evaluation is appropriate at 1 to 4 month intervals, depending on stability (more frequent if BP or other conditions are unstable) and degree of hypertension (more frequent if BP remains > 180 mm Hg)
- Follow-up includes:
  - Assessment of BP
  - Blood creatinine concentration
  - Urinalysis with quantitative assessment of proteinuria
  - Funduscopic examination
  - Any other specific evaluations depending on circumstances (eg, target-organ damage, causes of secondary hypertension, concurrent conditions)

Further Evaluation

- A key predictive indicator of antihypertensive efficacy is its effect on proteinuria: a benefit is predicted if the antihypertensive regimen is antiproteinuric (eg, normalizes the urine protein:creatinine ratio to < 0.2 or reduces the ratio by at least 50%).

- The frequency and nature of re-evaluations will vary depending on:
  - BP stage
  - Stability of BP
  - Other aspects of the health of the patient
  - Frequency of dosage adjustment to antihypertensive therapy

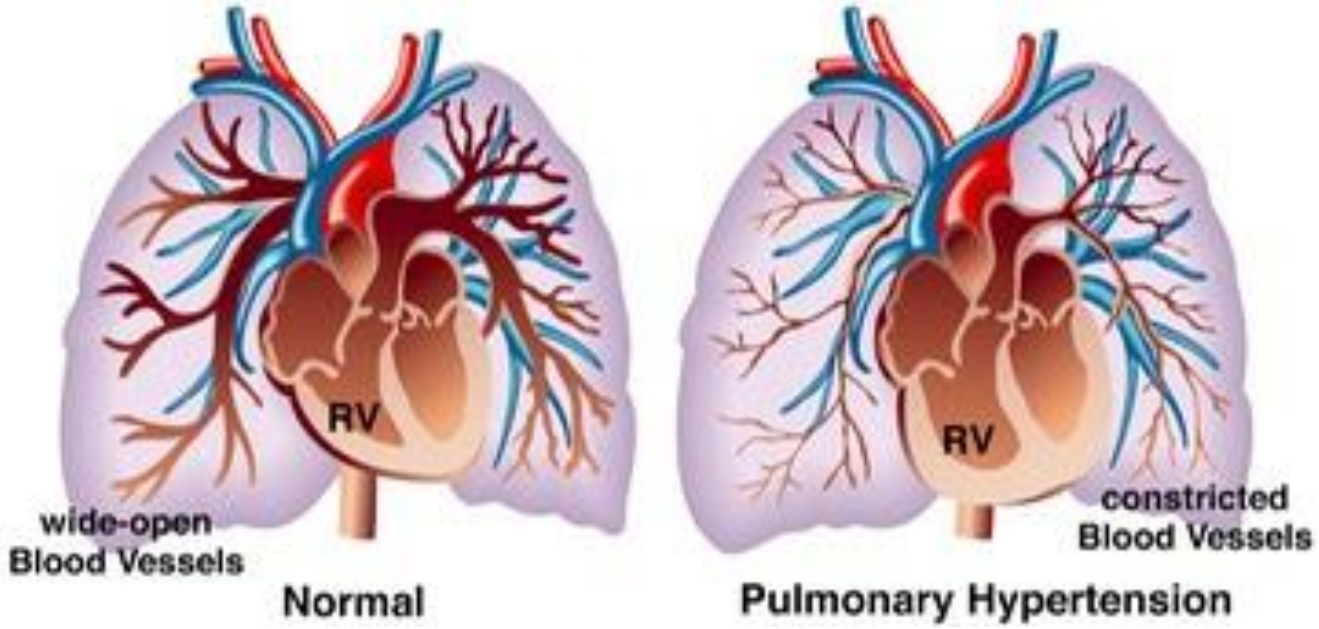
PULMONARY HYPERTENSION

Definition

- Pulmonary arterial systolic pressure > 30 mmHg and/or diastolic pressure > 19 mmHg
- Estimated by echocardiographic measurements of pulmonic or tricuspid regurgitation gradients
- Normal mean pulmonary arterial pressure: 14mmHg

Pathophysiology of PH

- Imbalance between PA vasoconstriction, vasodilation, platelet activation and smooth muscle cell proliferation → Pulmonary Hypertension



Classification of PH

Box 243-1

Classification of Pulmonary Hypertension[1-5,15,17-19,21,30-33,35-37,39-50,53,60,62,71,89-96]

I. Pulmonary arterial hypertension (PAH) due to pulmonary arteriolar vascular disease
- Pulmonary vascular parasitic disease
  - *Angiostrongylus vasorum* (French heartworm)
  - *Dirofilaria immitis* (heartworm disease)
- Congenital systemic-to-pulmonary shunts
  - Atrial septal defect (ASD)
  - Patent ductus arteriosus (PDA)
  - Ventricular septal defect (VSD)
- Necrotizing vasculitis/arteritis
- Idiopathic

II. Pulmonary hypertension with left heart disease (pulmonary venous hypertension)
- Mitral valve disease
- Myocardial disease
- Miscellaneous left-sided heart disease

Classification of PH

III. Pulmonary hypertension with pulmonary disease/hypoxemia
- Chronic obstructive pulmonary disease
- High-altitude disease
- Interstitial pulmonary fibrosis
- Neoplasia
- Reactive pulmonary artery vasoconstriction (from pulmonary edema and hypoxemia)
- Tracheobronchial disease

IV. Pulmonary hypertension due to thrombotic and/or embolic disease
- Thromboembolism
  - Cardiac disease
  - Corticosteroid administration
  - Disseminated intravascular coagulation
  - Endocarditis (pulmonic/tricuspid valve)
  - Hyperadrenocorticism
  - Immune-mediated hemolytic anemia
  - Indwelling venous catheters
  - Neoplasia
  - Pancreatitis
  - Protein-losing disease (nephropathy or enteropathy)
  - Sepsis
  - Surgery
  - Trauma
- *Dirofilaria immitis* (heartworm disease)

V. Miscellaneous
- Compressive mass lesions (neoplasia, granuloma)

Signalment

- Most canine patients are small breed and middle- to older-age.
- Predisposing etiology:
  - Degenerative mitral valve disease
  - Chronic pulmonary disease
  - Interstitial pulmonary fibrosis (usually terriers)

Clinical Signs & Physical Examination

Canine patients:

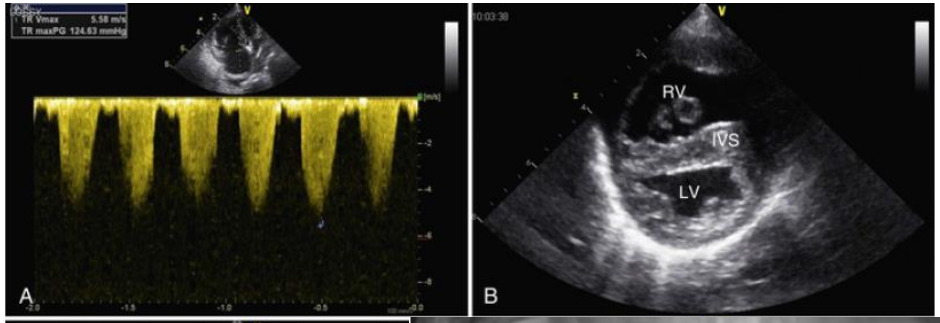
- Exercise intolerance
- Cough
- Dyspnea
- Syncope
- Abnormal lung sounds
- Cyanosis
- +/- Ascites
- Pulmonary crackles/wheezes/harsh sounds

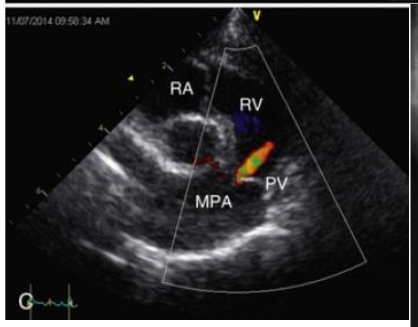
Feline patients:

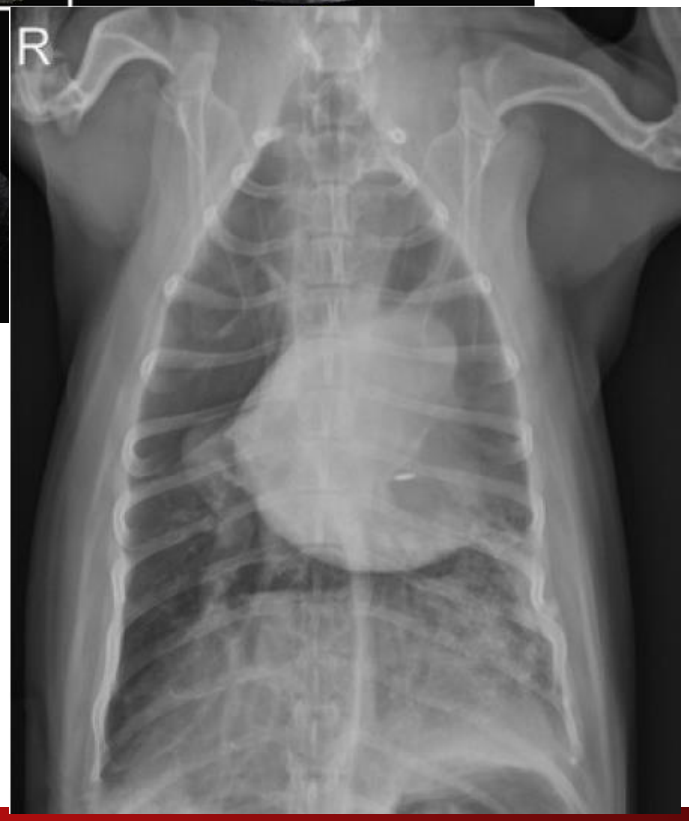
- Dyspnea
- Jugular venous distention
- Right-sided systolic heart murmur

Diagnosis

- Echocardiography





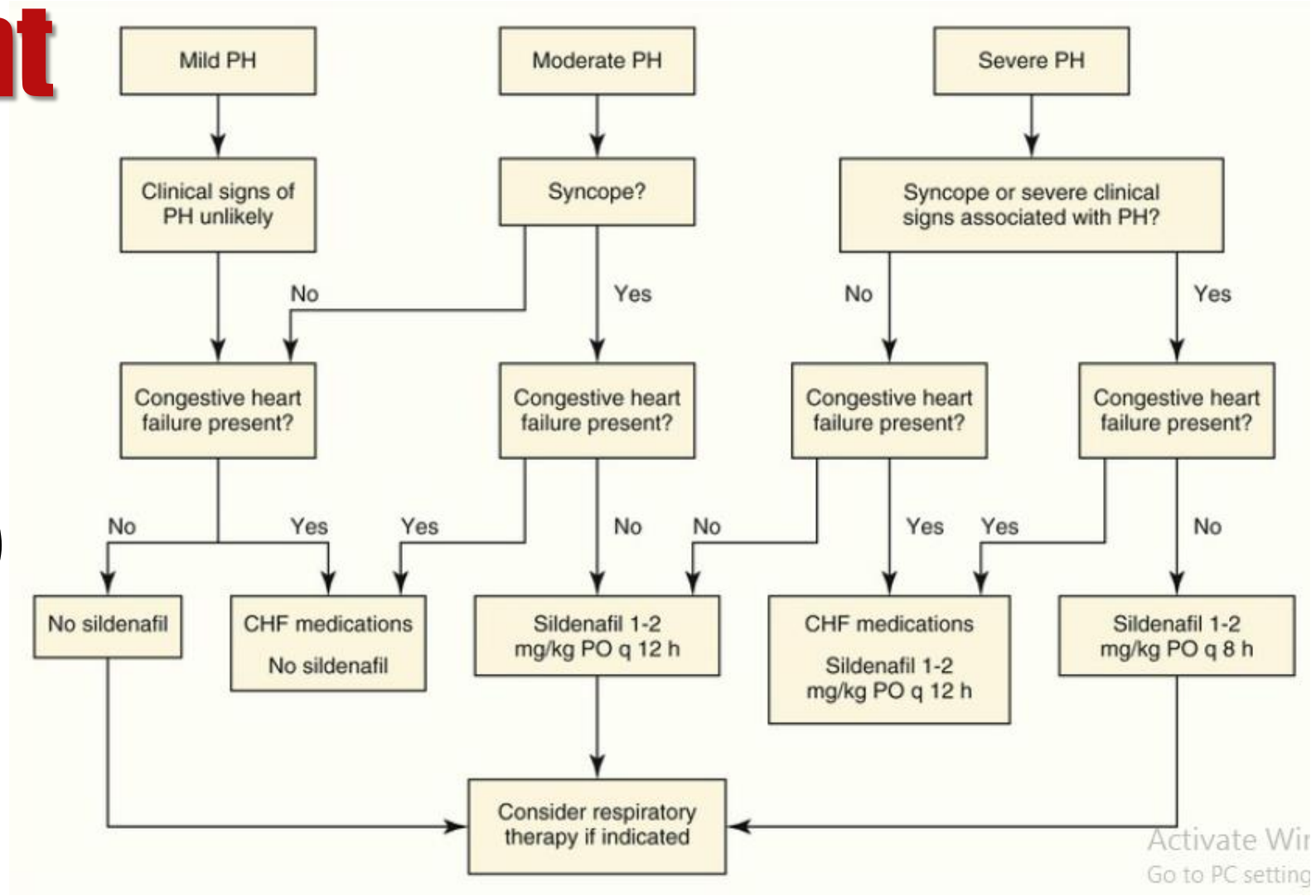


- Thoracic X-Ray
  - (not specific, maybe supportive)
- NT-proBNP
  - Useful for ddx. Between cardiac and respiratory dz.

Treatment

PDE5-I medications:

- Sildenafil (Viagra)
- Tadalafil (Cialis)
- Vardanafil (Levitra)



SYSTEMIC HYPOTENSION

Definition

- Systole < 80 mmHg or MAP < 60 mmHg in either dog or cat
  - Decreased preload to the heart
  - Cardiac dysfunction
  - Decreased vascular tone

- Untreated hypotension
  - Inadequate tissue perfusion
  - Inadequate oxygen delivery
  - Shock

Clinical manifestations

- Sinus tachycardia with weak pulses
- Pale mucus membrane
- CRT > 2 sec.
- Mental dullness
- Weakness
- In case of sepsis in dogs: not pale mucus membrane, CRT < 2 sec.
- In case of sepsis or SIRS in cats: bradycardia, pale mucus membrane

classification

Causes of Systemic Hypotension

Decreased Preload

Hypovolemia

Blood loss
Gastrointestinal losses
Polyuria
Hypoadrenocorticism
Effusions or other third spacing of fluid
Burns
Heatstroke

Decreased Venous Return

Cardiac tamponade
Constrictive pericarditis
Severe pneumothorax
Positive pressure ventilation

classification

Gastric dilation and volvulus
Heartworm disease (caval syndrome)

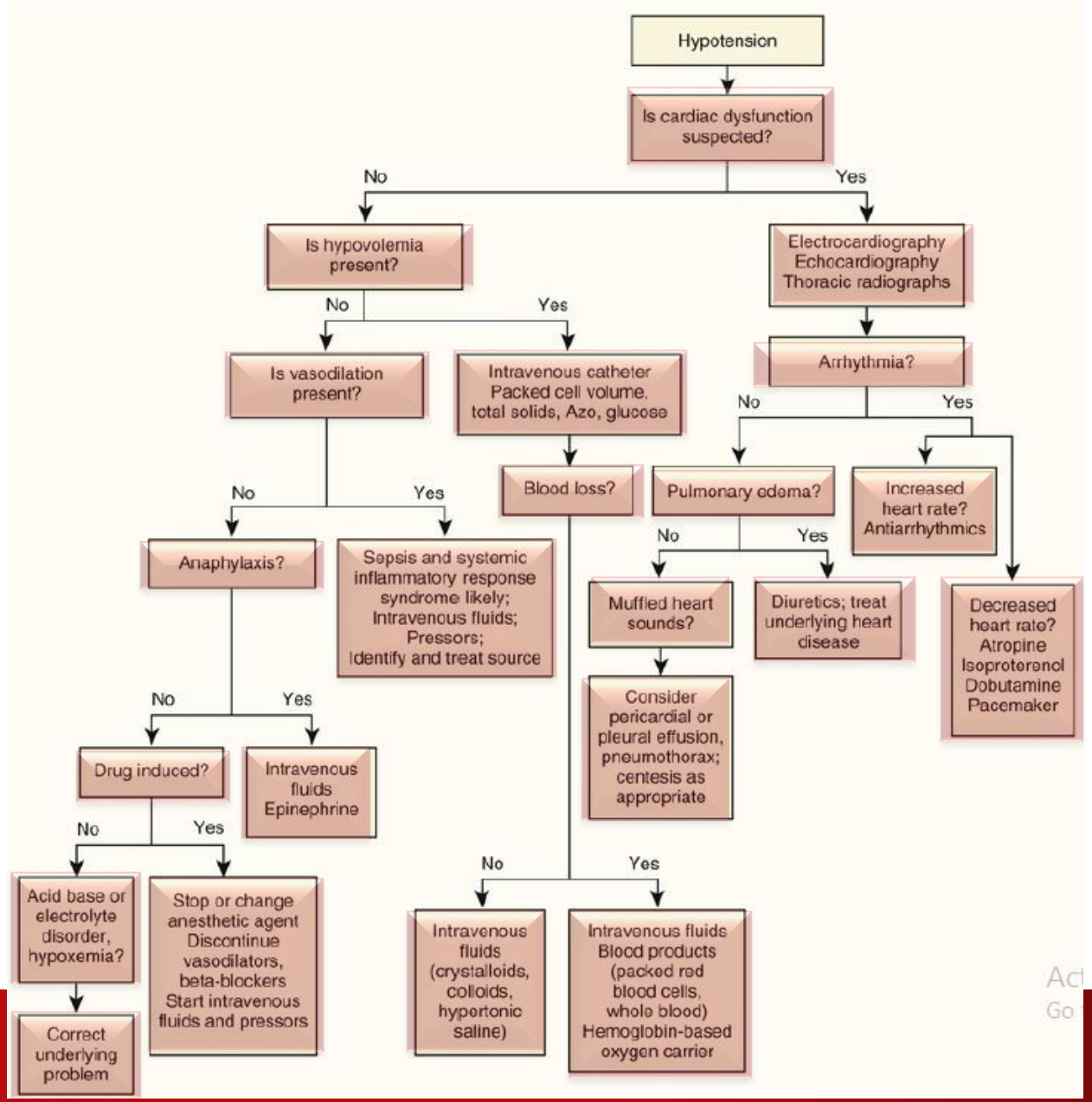
Decreased Cardiac Function

Cardiomyopathy
Adult-onset valvular disease
Congenital heart disease
Bradyarrhythmias
Tachyarrhythmias
Serum electrolyte abnormalities
Acid-base disturbances
Severe hypoxemia
Sepsis/systemic inflammatory response syndrome (SIRS)

Decreased Vascular Tone

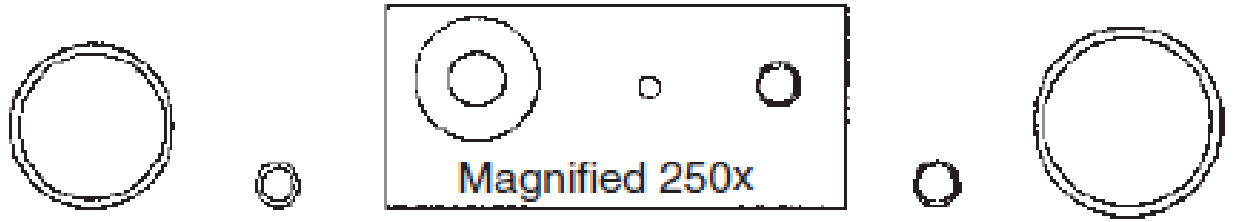
Sepsis/SIRS
Anaphylaxis
Neurogenic
Drug-induced (anesthetic agent, vasodilators [e.g., beta-blockers, calcium channel blockers])
Electrolyte abnormalities
Acid-base disturbances
Severe hypoxemia

Evaluation and Treatment



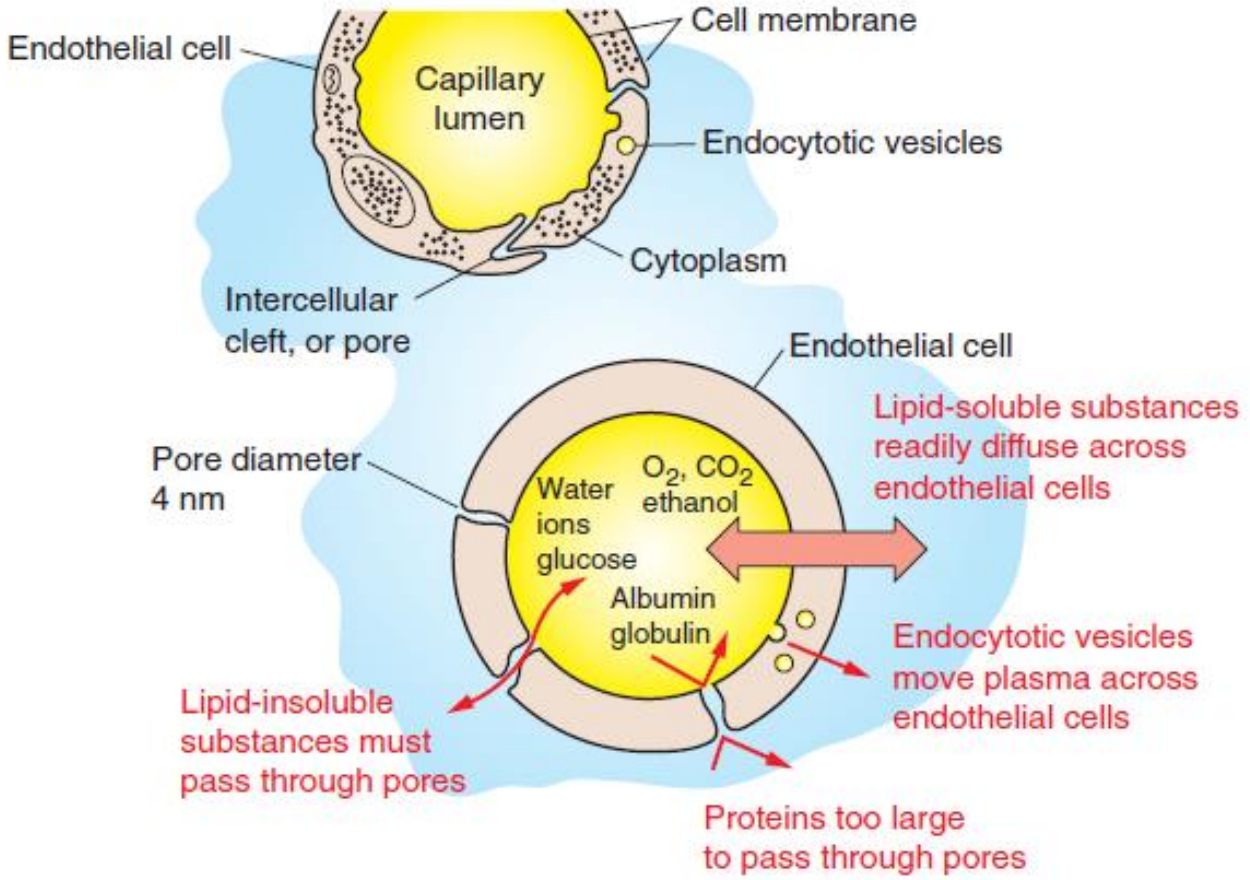
Capillaries and fluid exchange

Types of blood vessels

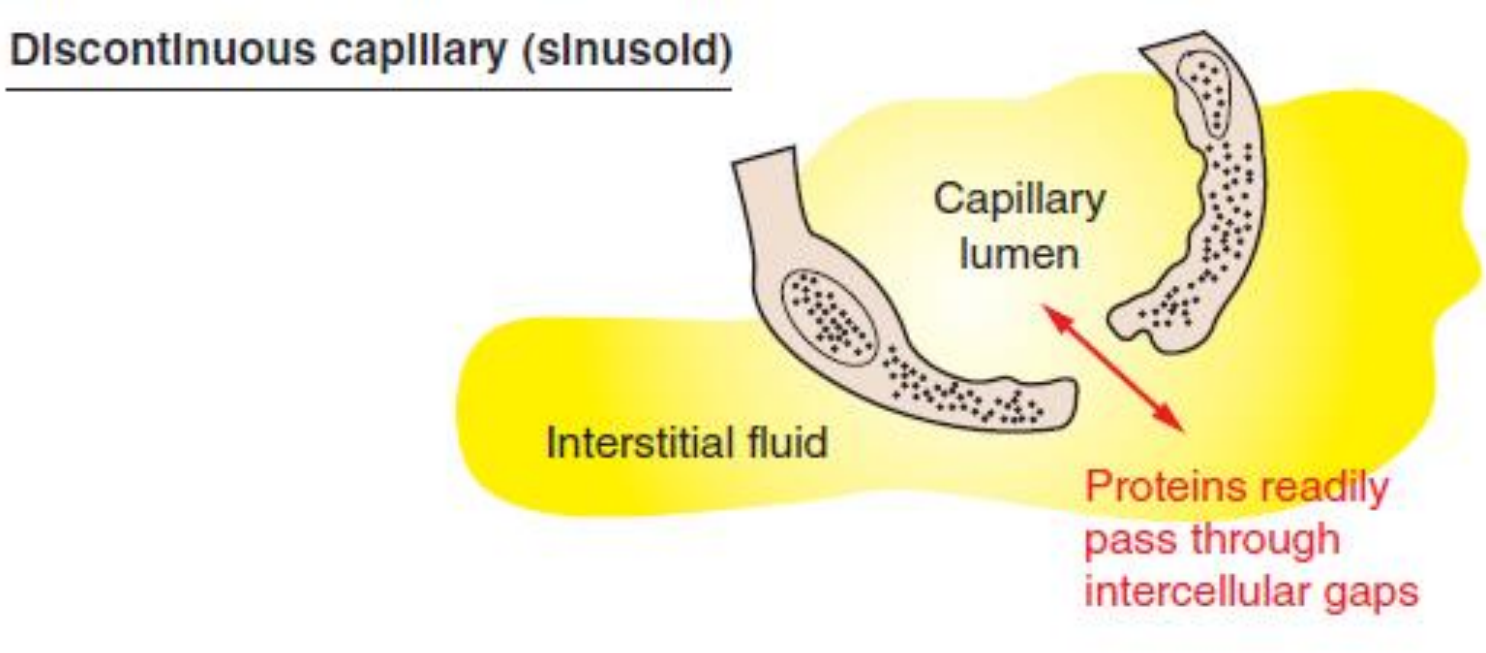


	Aorta	Artery	Arteriole	Capillary	Venule	Vein	Vena cava
Inside diameter	25 mm	4 mm	30 μm	8 μm	20 μm	5 mm	30 mm
Wall thickness	2 mm	1 mm	20 μm	1 μm	2 μm	0.5 mm	1.5 mm
Wall features							
Endothelium							
Smooth muscle							
Elastic tissue							

Typical continuous capillary



Discontinuous capillary



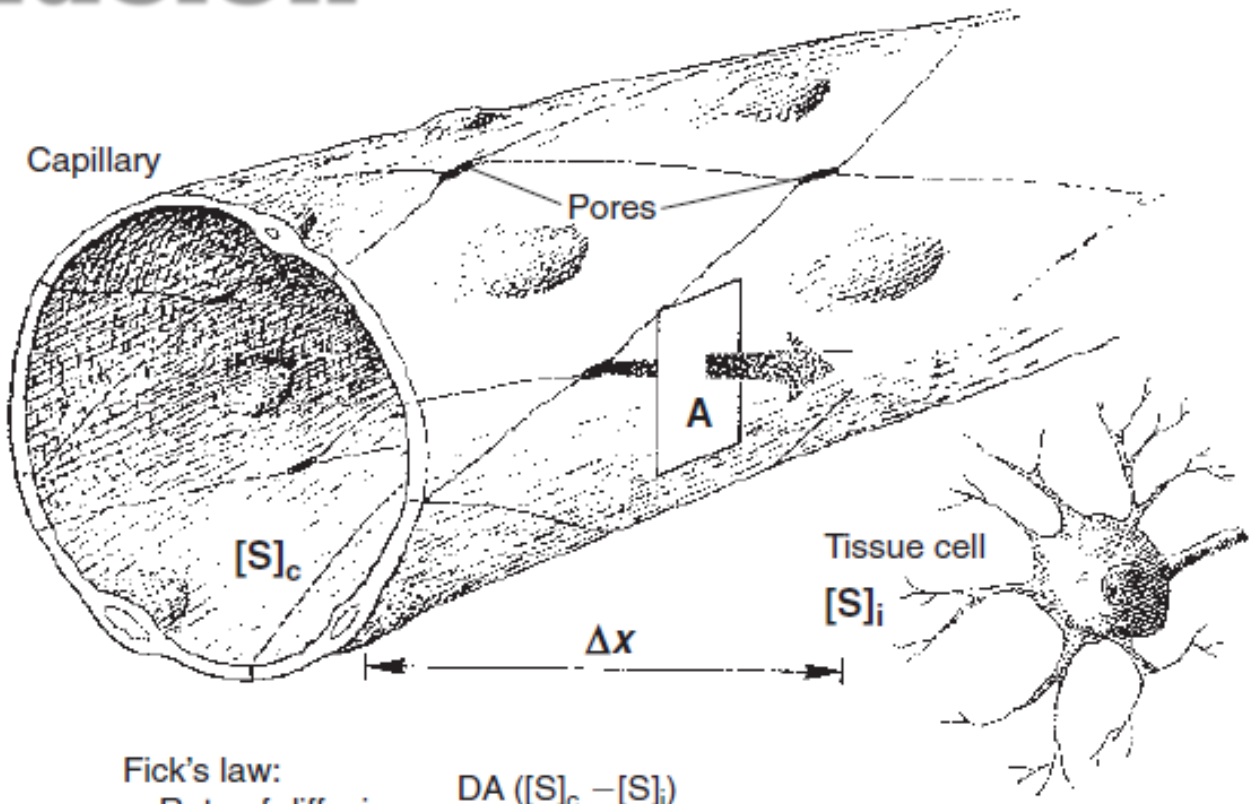
Fick's Law of Diffusion

$[S]_c - [S]_i$, the concentration difference between the capillary plasma and interstitial fluid;

A, area available for diffusion;

Δx, distance involved;

D, diffusion coefficient for the substance.



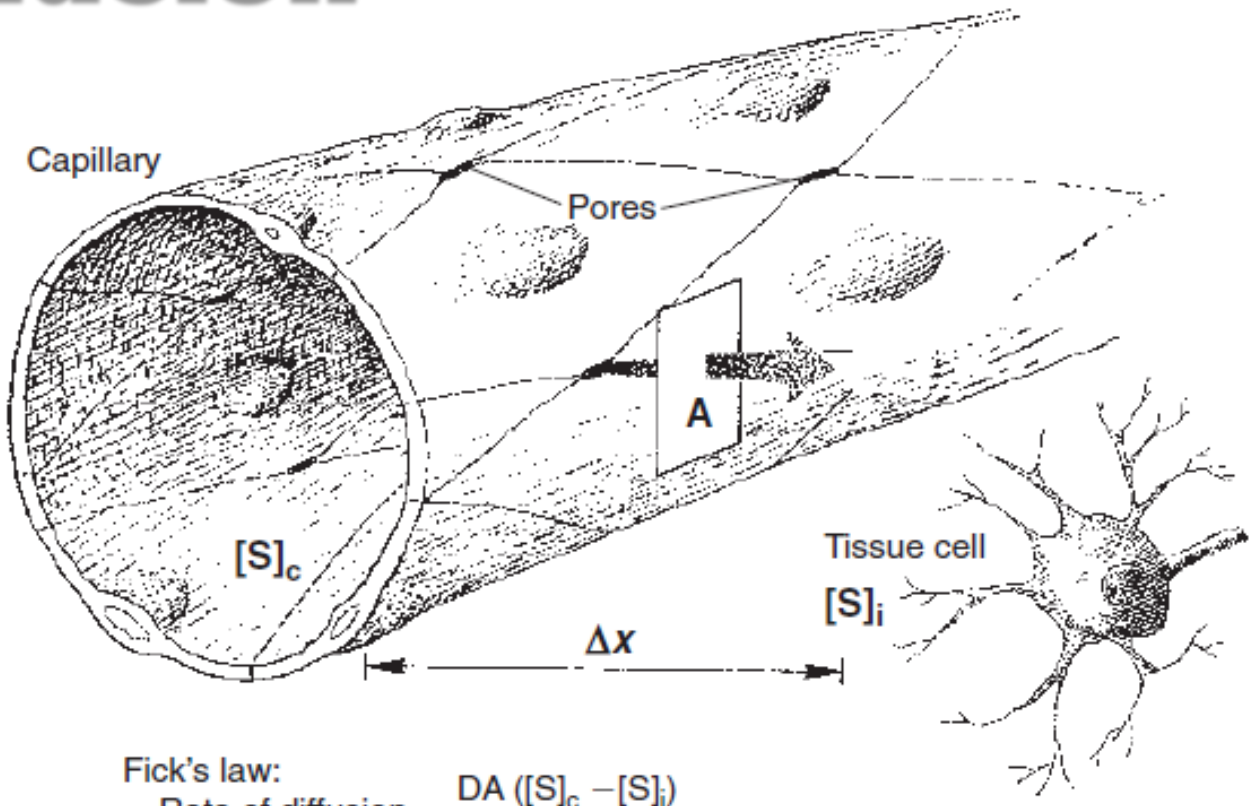
Fick's law:

$$\text{Rate of diffusion} = \frac{DA([S]_c - [S]_i)}{\Delta x}$$

Fick's Law of Diffusion

Diffusion coefficient:

- Temperature
  - Increase random (Brownian) motion
  - Increase velocity
- Molecular weight
- Solubility



Fick's law:

$$\text{Rate of diffusion} = \frac{DA([S]_c - [S]_i)}{\Delta x}$$

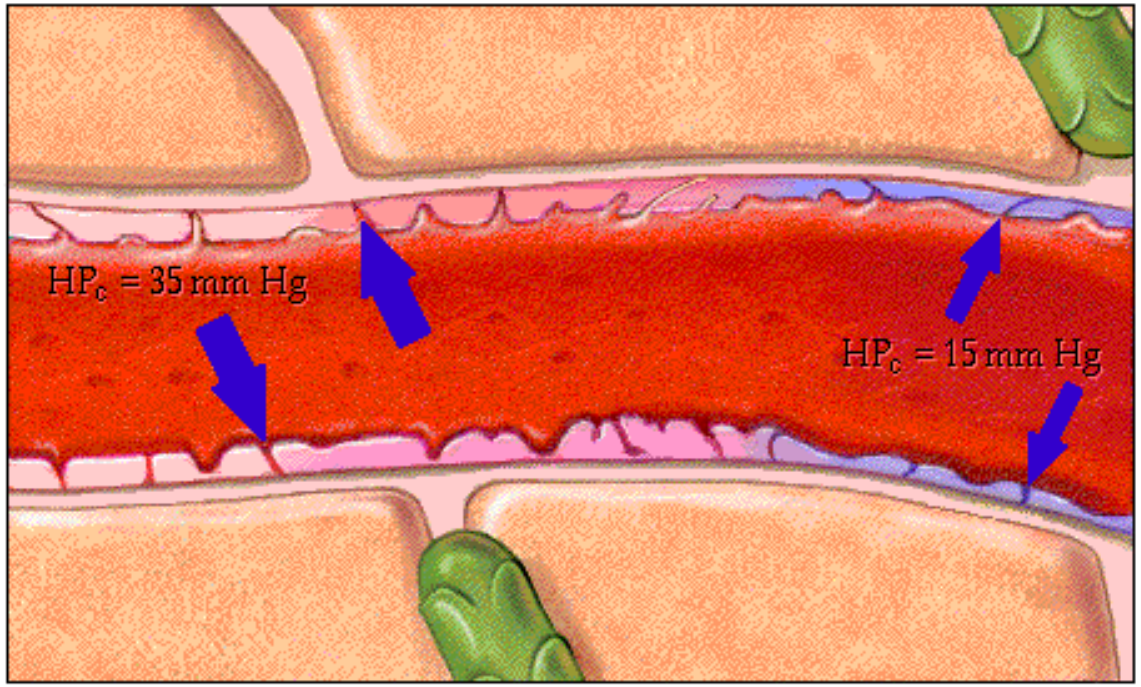
Autoregulation and capillary dynamics

- **The Starling Equation** Quantifies the Interaction of Oncotic and Hydrostatic Forces Acting on Water
- Net pressure = (Pc − Pi) − (πc − πi)
  - Pc : capillary hydrostatic pressure
  - Pi : interstitial fluid hydrostatic pressure
  - πc : capillary plasma oncotic pressure
  - πi : interstitial fluid oncotic pressure

Autoregulation and capillary dynamics

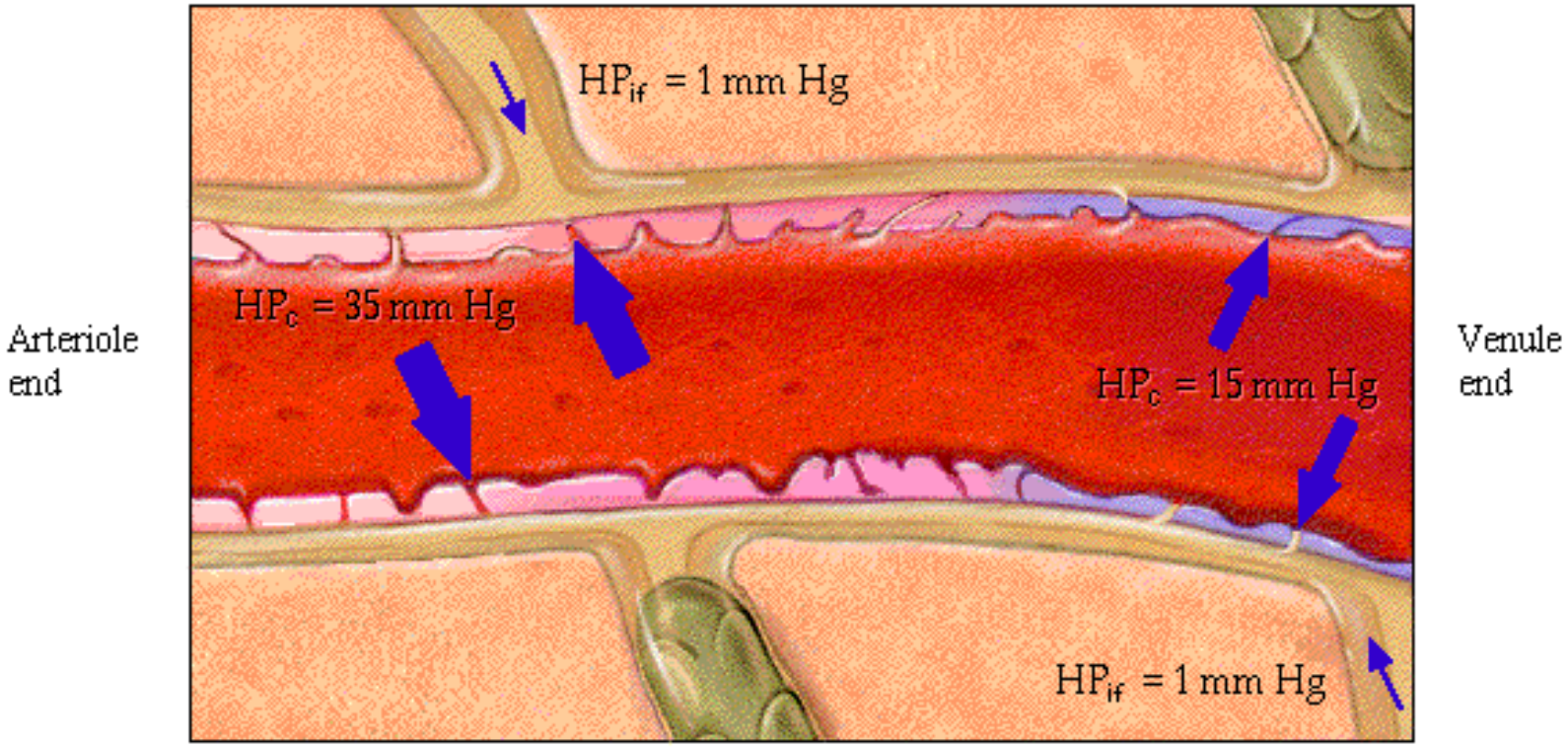
In capillaries, **hydrostatic pressure** is exerted by blood. Thus, capillary hydrostatic pressure(HP_c) is equivalent to the blood pressure in the capillaries.

Arteriole end

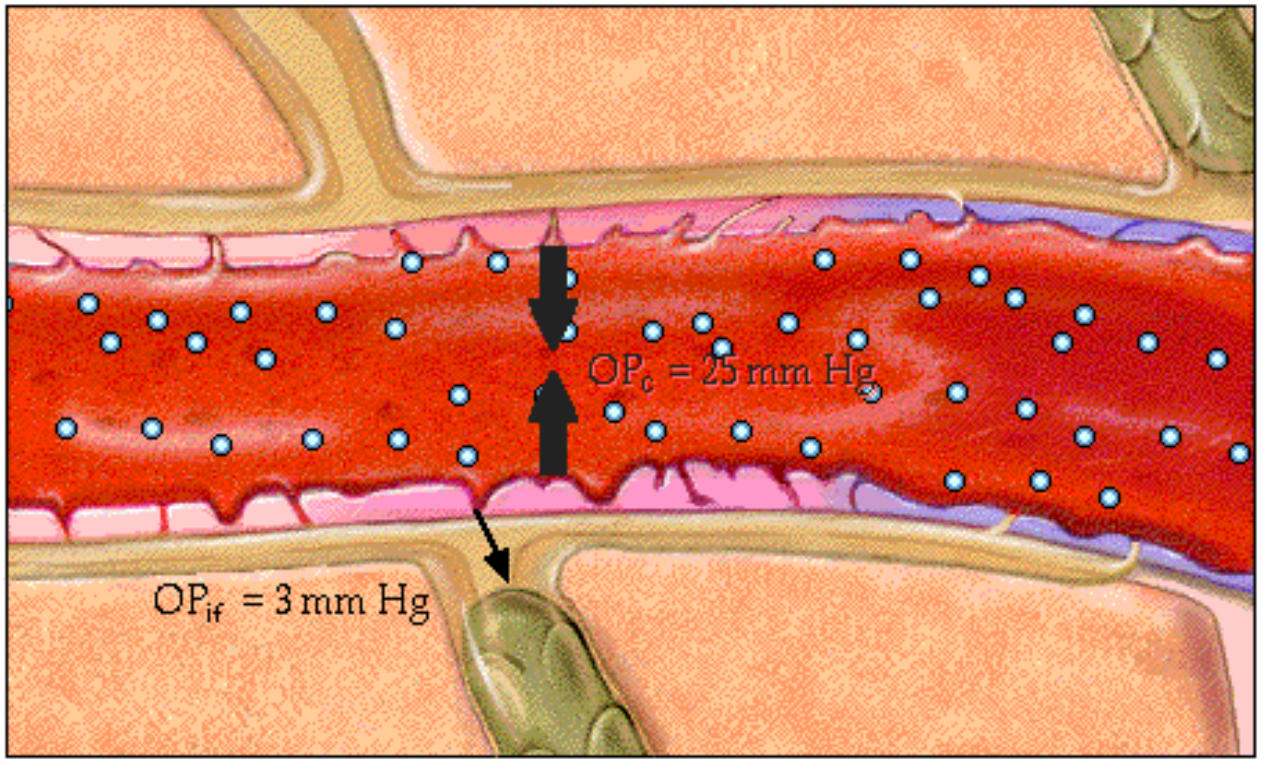


Venule end

Autoregulation and capillary dynamics

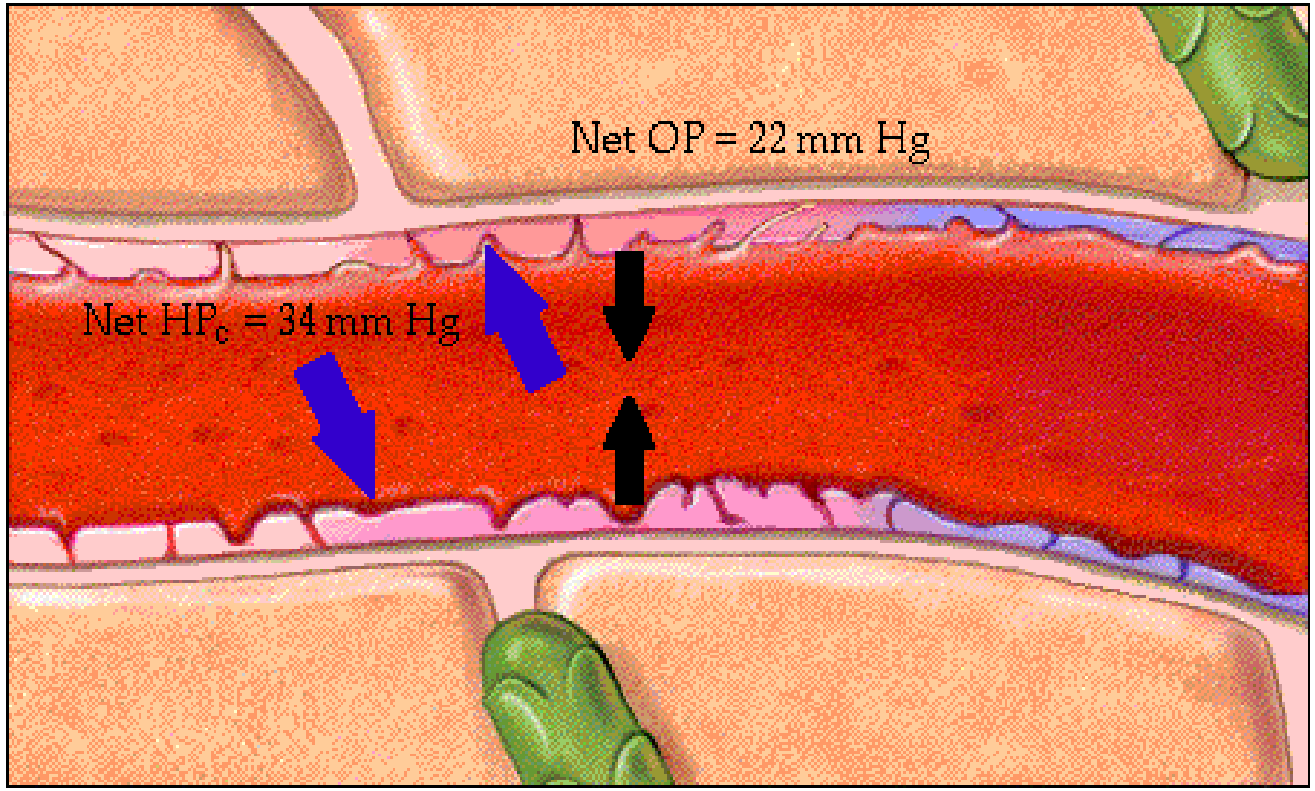


Autoregulation and capillary dynamics



Autoregulation and capillary dynamics

Arteriole end

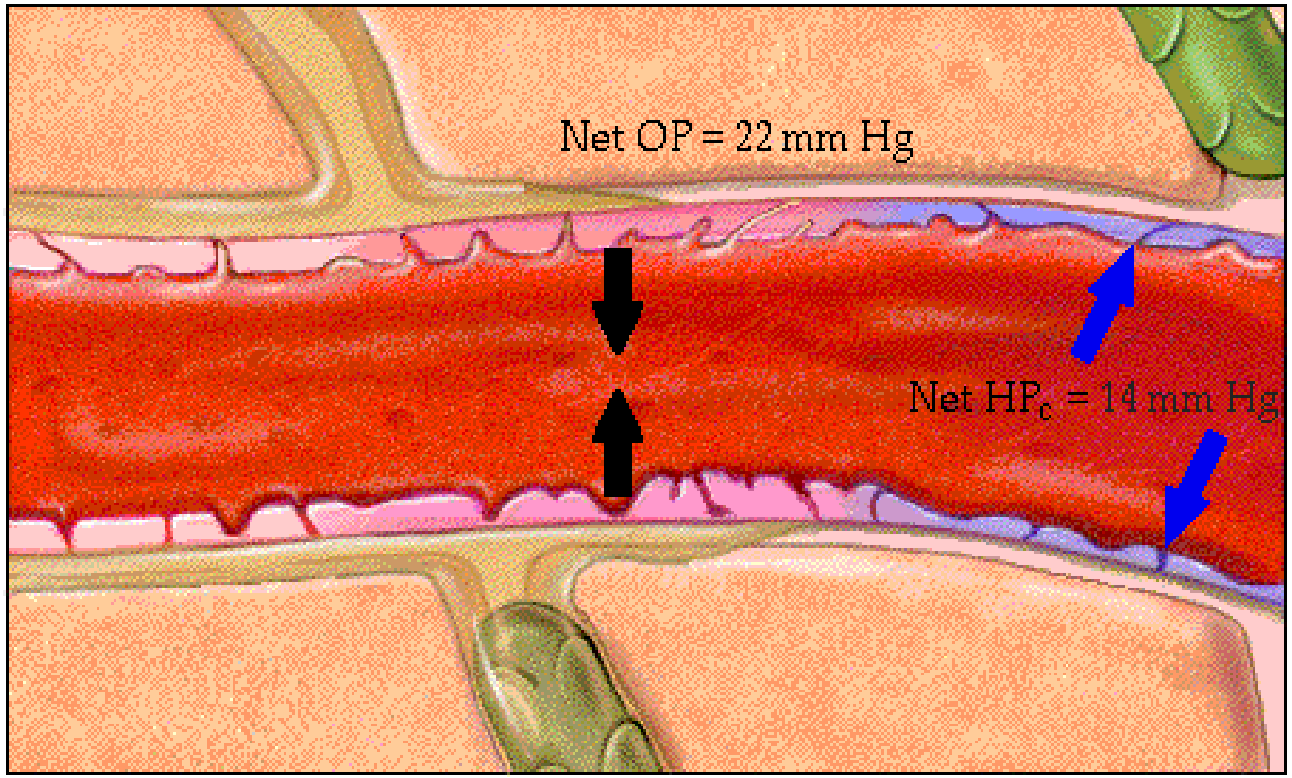


Venule end

Net force (determines direction of flow) = Net HP - Net OP

Autoregulation and capillary dynamics

Arteriole end

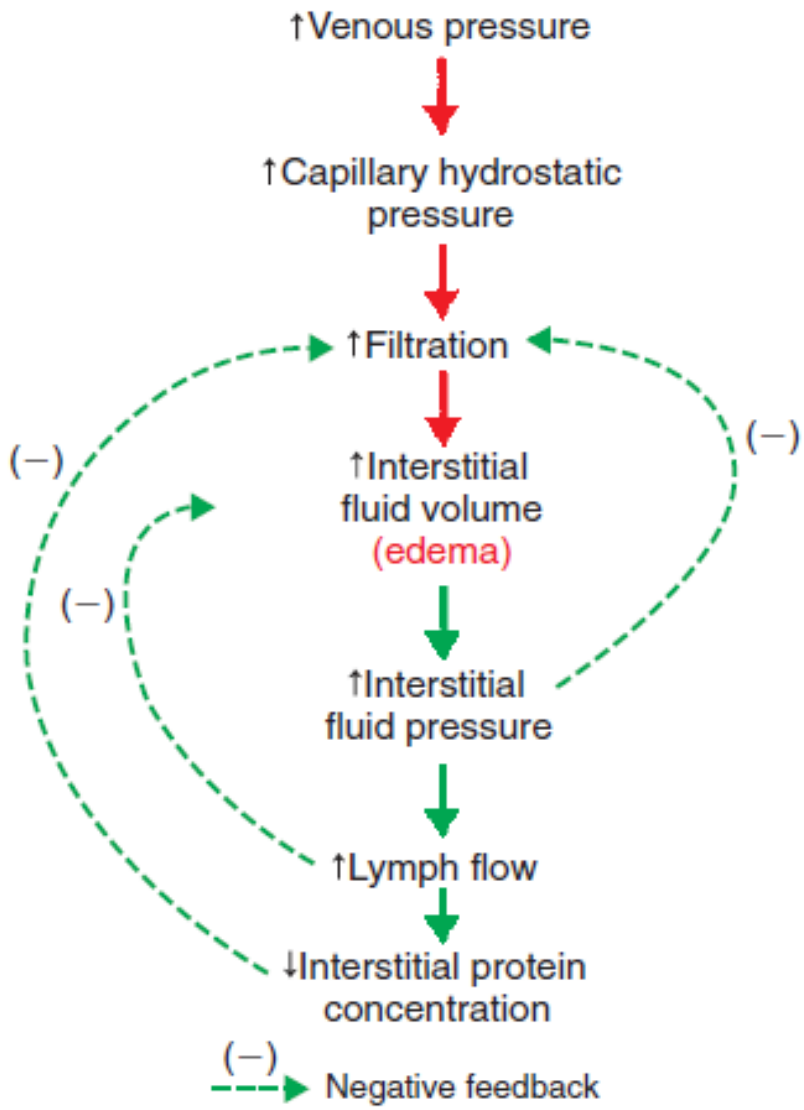


Venule end

Net force (determines direction of flow) = Net HP - Net OP

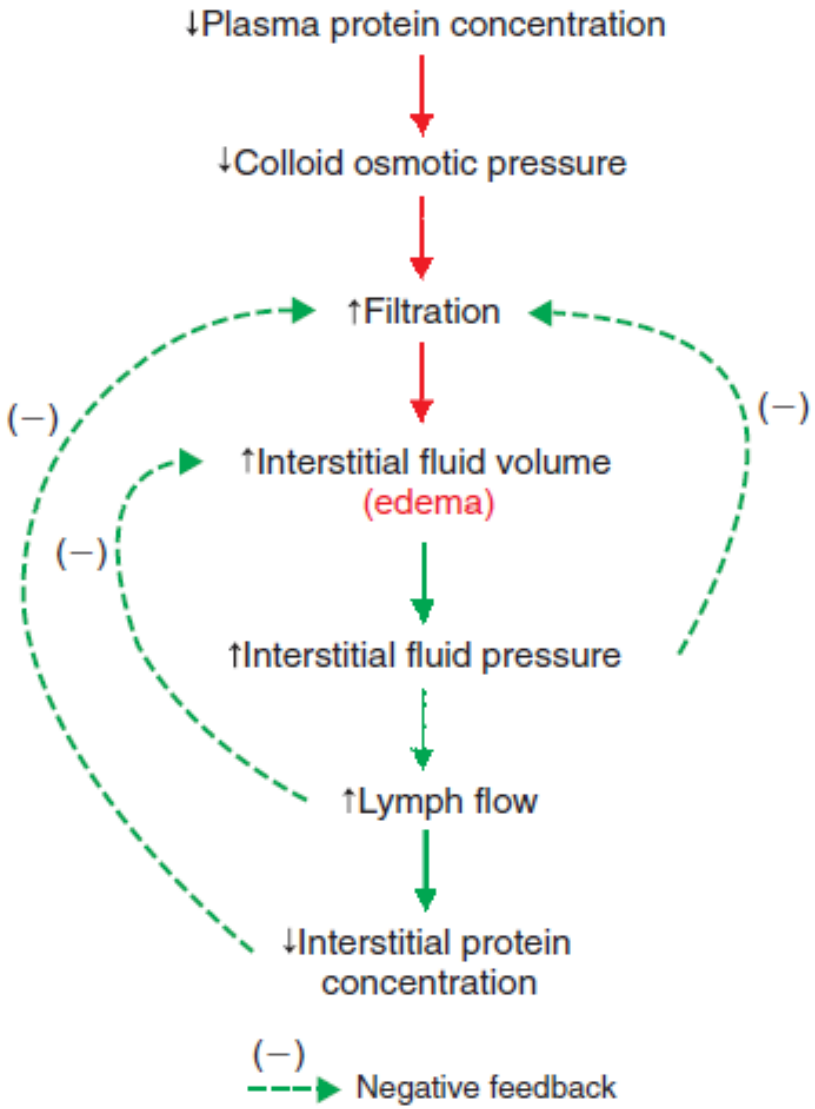
Edema

Increase in venous pressure leads to increase in interstitial fluid volume (**edema**).
The *dashed lines (negative feedback)* indicate the counteracting effects of the three safety factors against edema.
First, an increase in interstitial fluid hydrostatic pressure reduces the rate of filtration back toward normal.
Second, an increase in lymph flow reduces interstitial fluid volume back toward normal.
Third, a decrease in interstitial fluid protein concentration reduces the rate of filtration back toward normal.



Edema

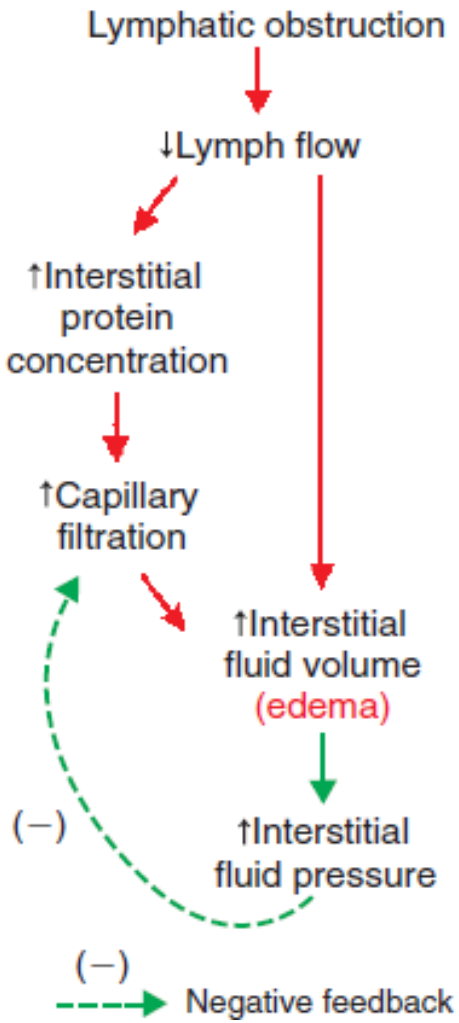
Decrease in plasma protein concentration leads to edema, but the degree of edema is limited by the same three safety factors as shown in previous diagram



Edema

Lymphatic obstruction leads to edema.

Lymphedema is clinically troublesome because only one of the normal three safety factors is operative to limit the degree of edema.

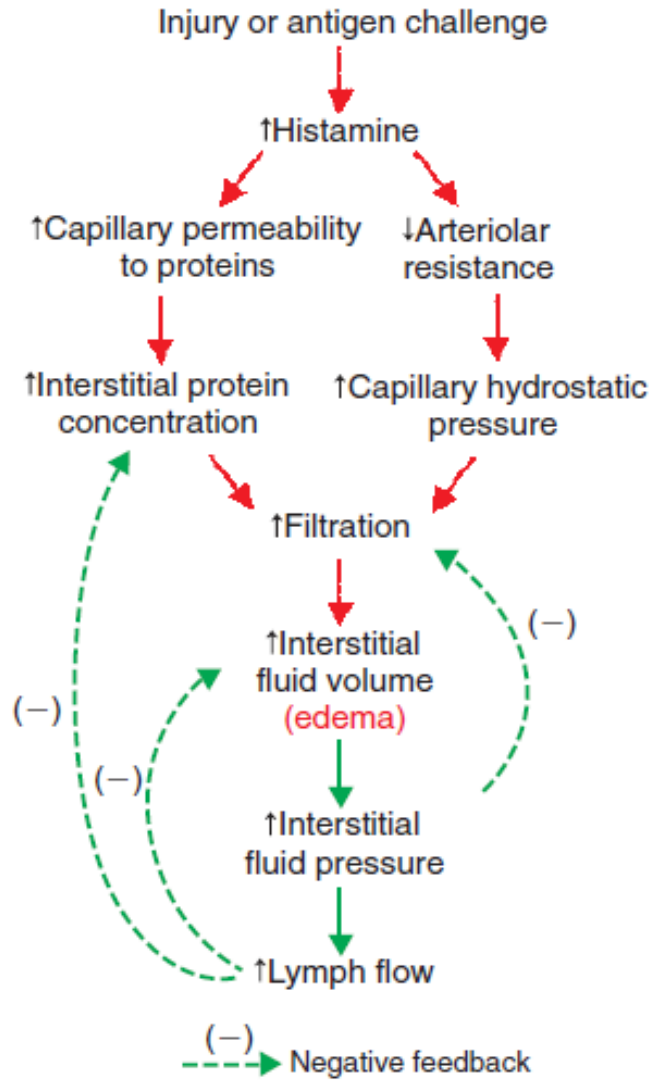


Edema

Histamine mediates the changes that lead to edema in response to a physical injury or an antigen challenge.

The normal three safety factors against edema are intact and help to limit the degree of edema.

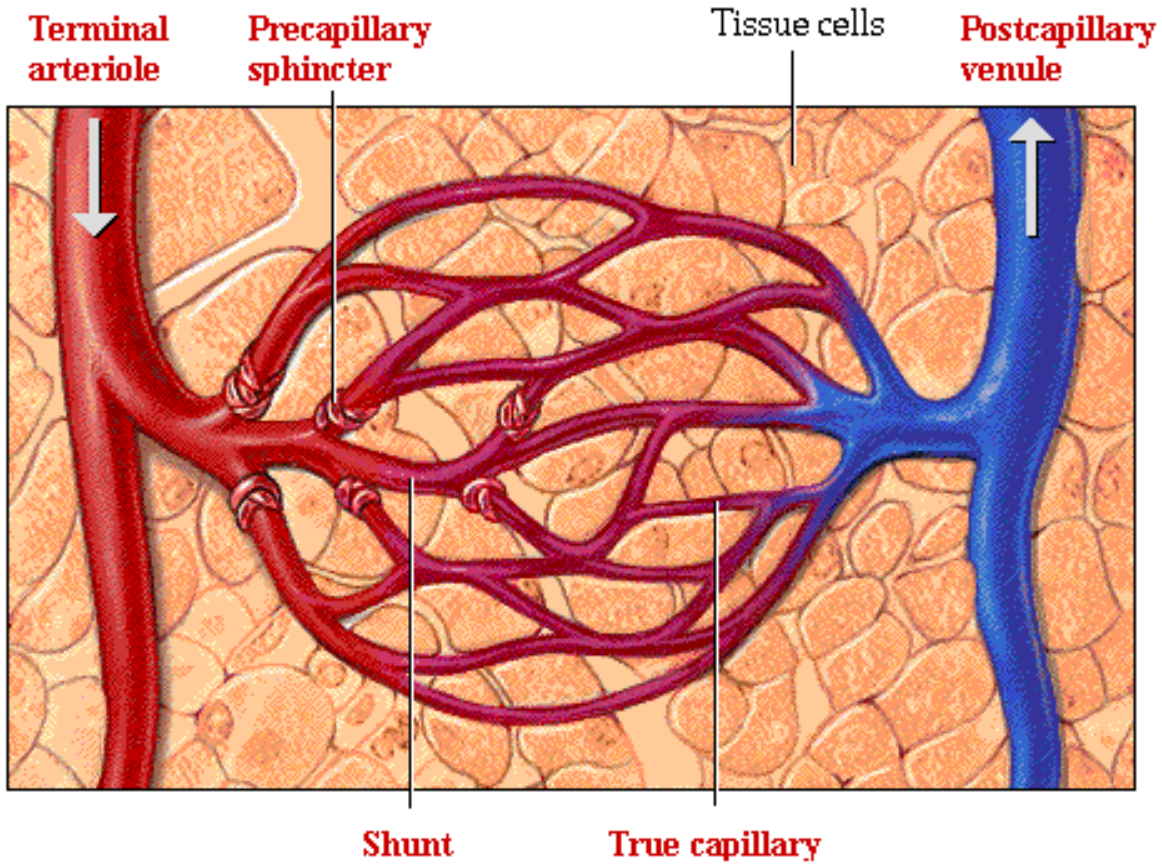
Treatment with an antihistamine (a drug that blocks histamine receptors on arterioles and capillaries) also helps to reduce edema in these cases.



Local Control of Blood Flow

Capillary bed

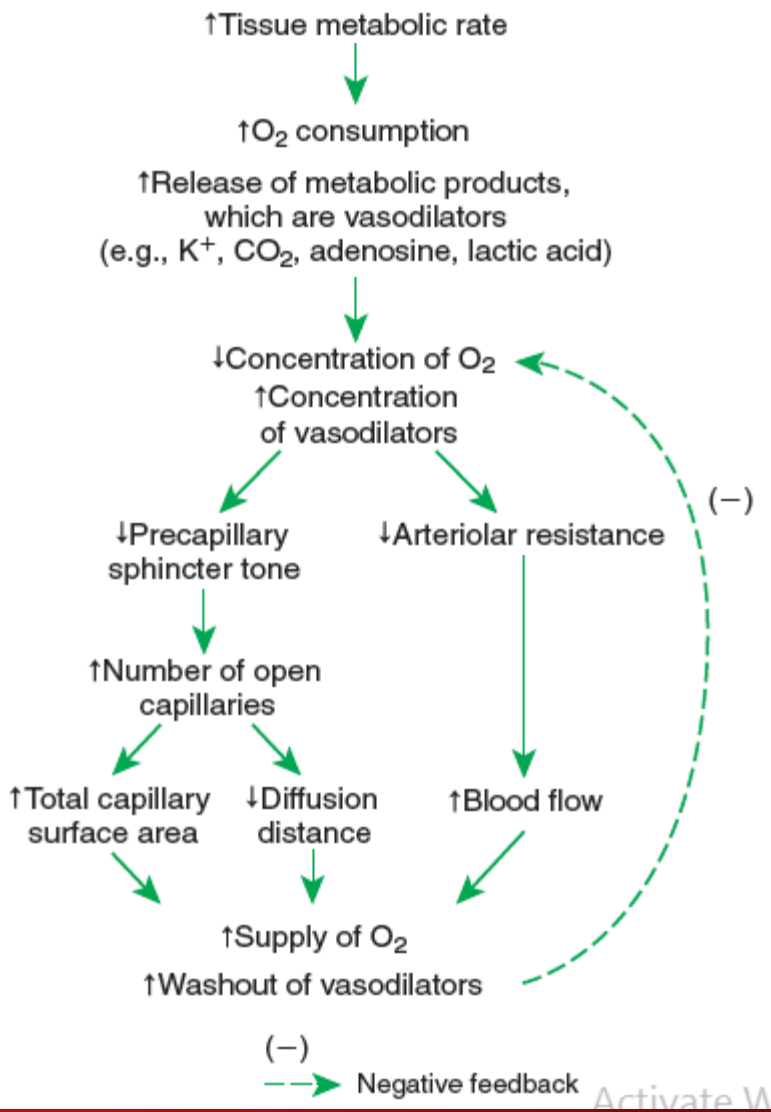
Blood flow regulation occurs at arterioles and within capillary beds.



Metabolic control of blood flow

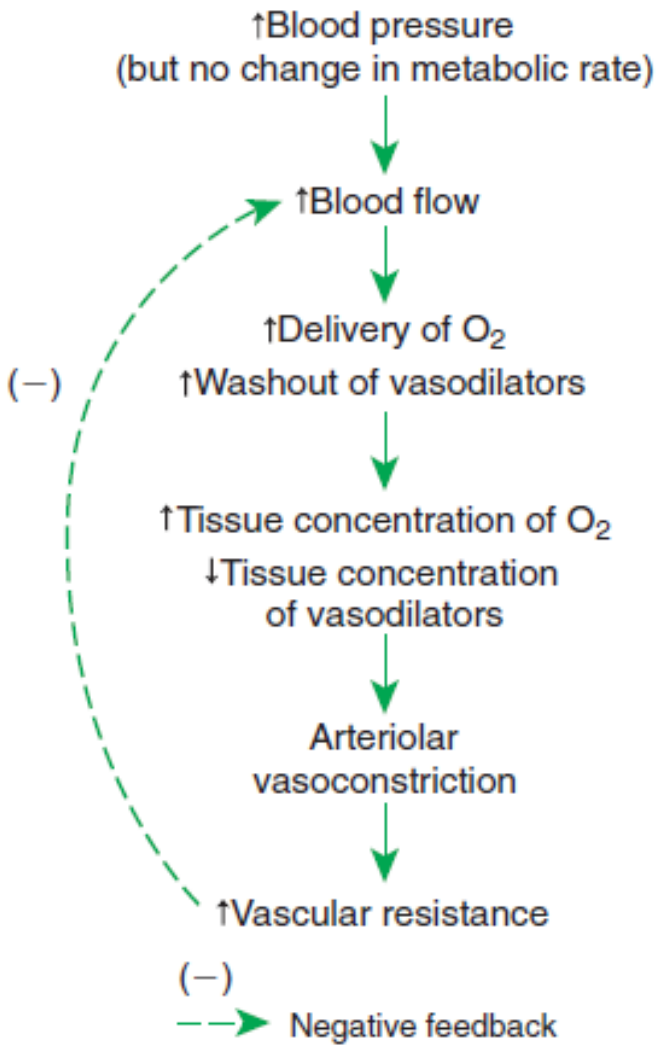
Metabolic control of blood flow is a local (intrinsic) mechanism that acts within a tissue to match the blood flow to the tissue with the metabolic activity of the tissue.

As a tissue becomes more active metabolically, the metabolic control mechanism increases blood flow and thereby regulates the concentration of oxygen and metabolic products in the tissue.



Autoregulation of blood flow

The same metabolic mechanism that is responsible for active hyperemia and reactive hyperemia can also account for autoregulation, in which blood flow to an organ stays relatively constant despite changes in perfusion pressure.



Good Luck