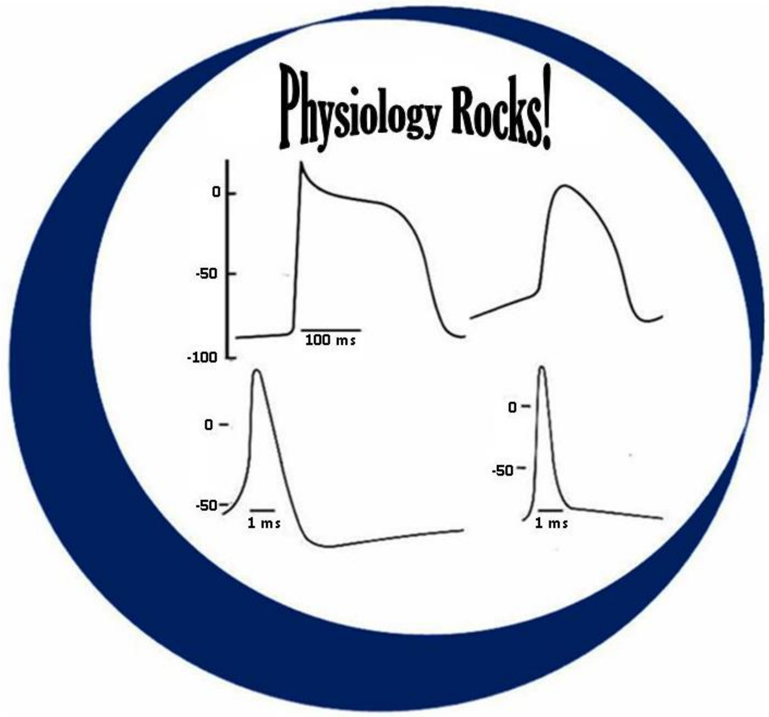
Lecture 16



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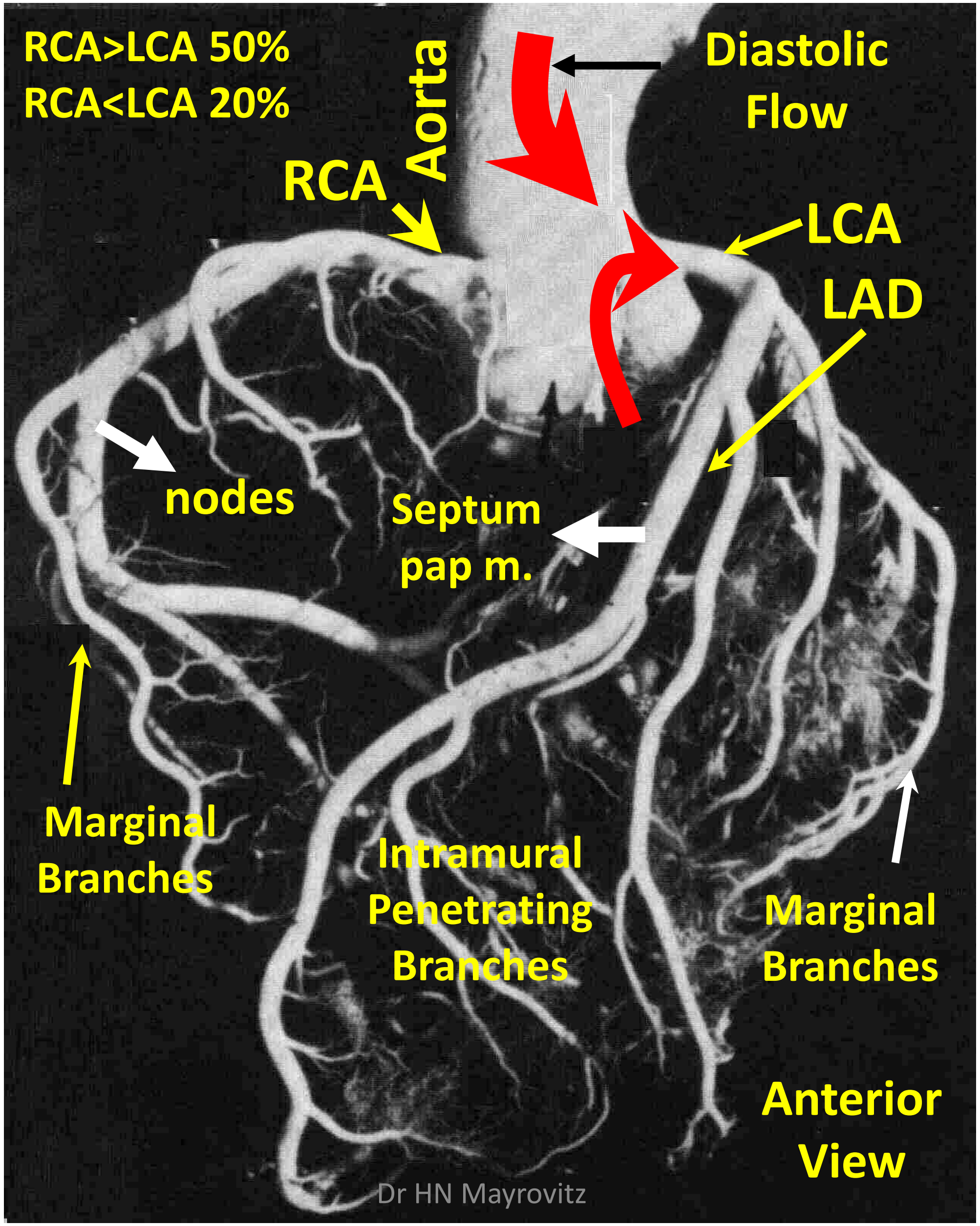
Topics

- Heart circulation features
- Microcirculation features
- Lymphatic system features
- Venous system features

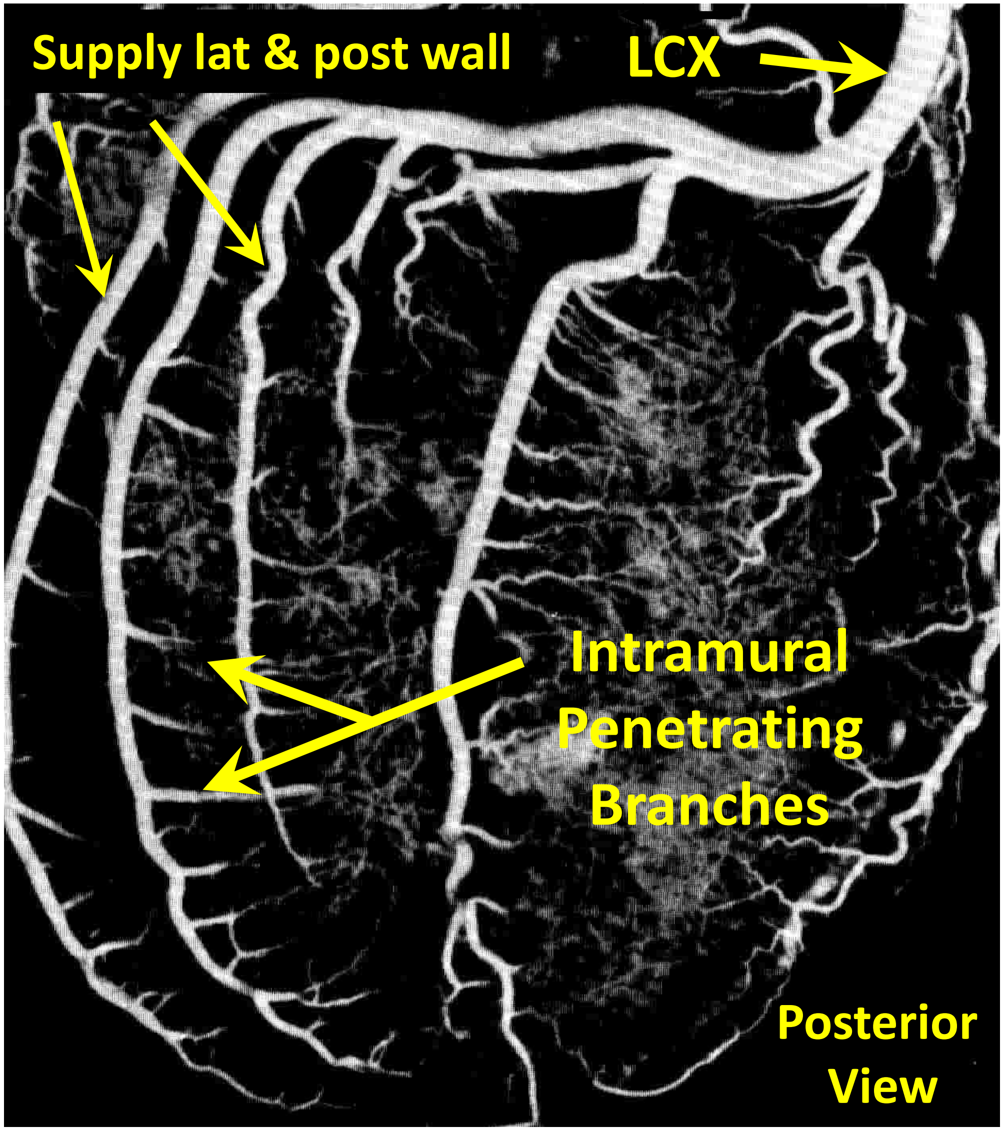
Features of Coronary Circulation

- **Vasculature**
- **Phasic Blood Flow Features**
- **Myocardial Oxygen Extraction**
- **Coronary Autoregulation**
- **Regional blood flow timing**

Coronary Circulation

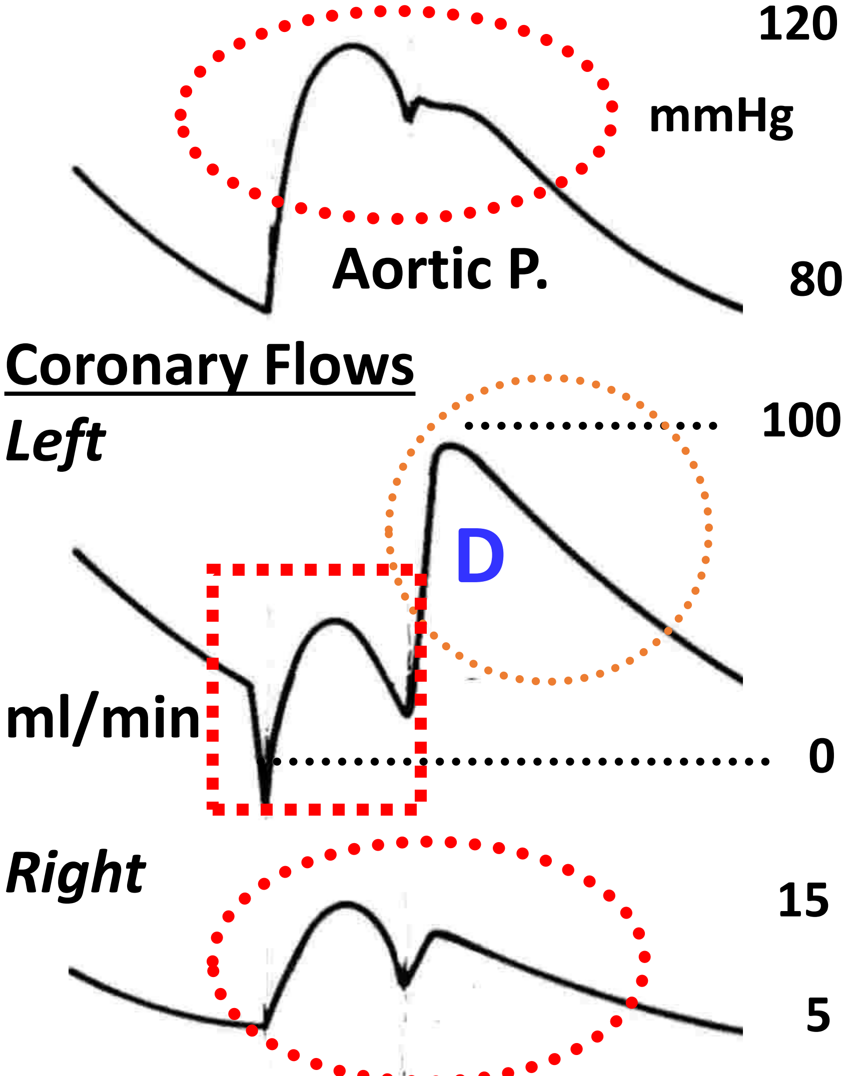


Coronary Circulation

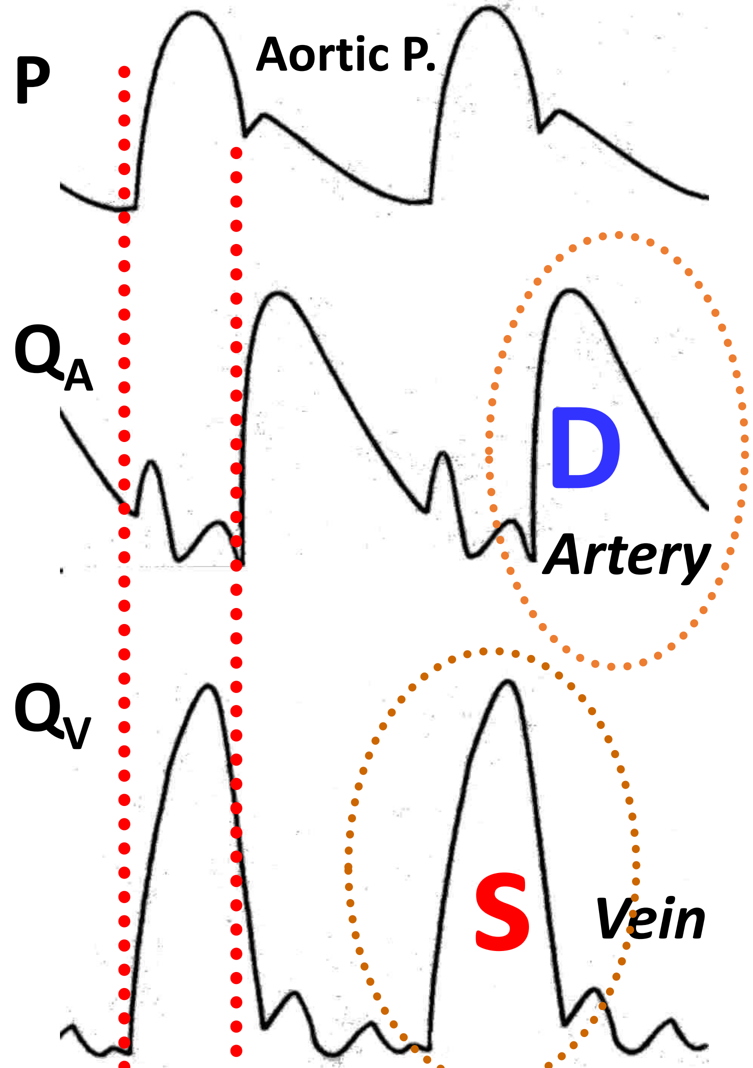


Phasic Coronary Blood Flow

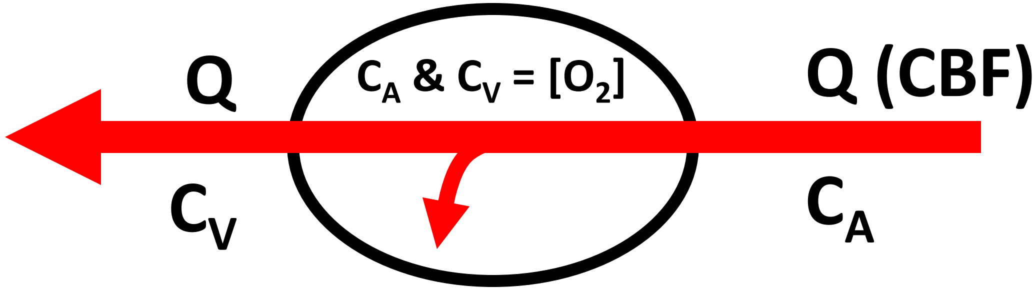
Left vs. Right Ventricle



Inflow vs. Outflow



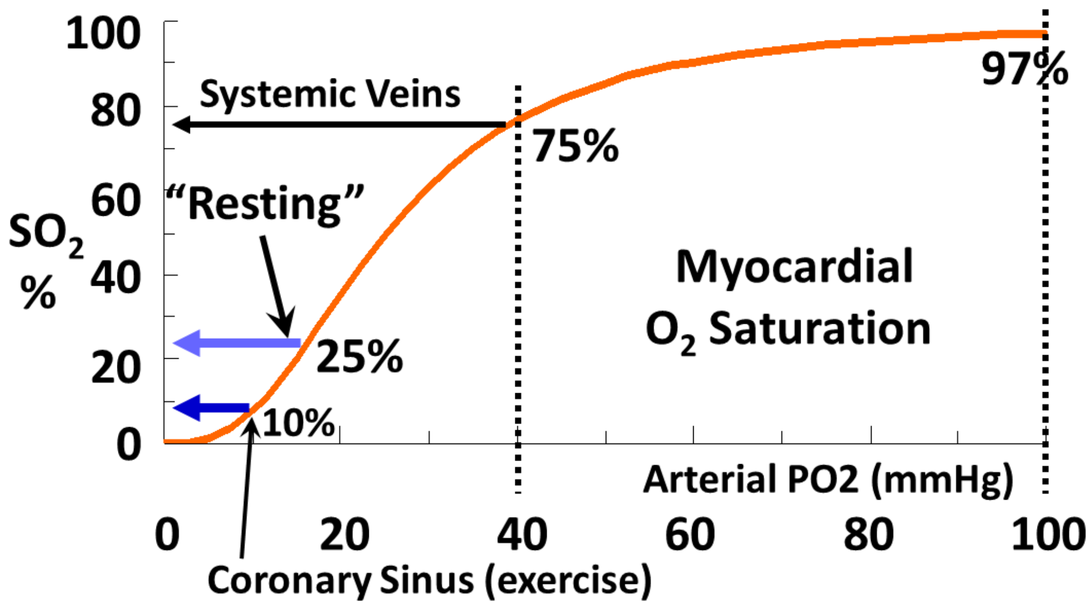
Myocardial O_2 Extraction



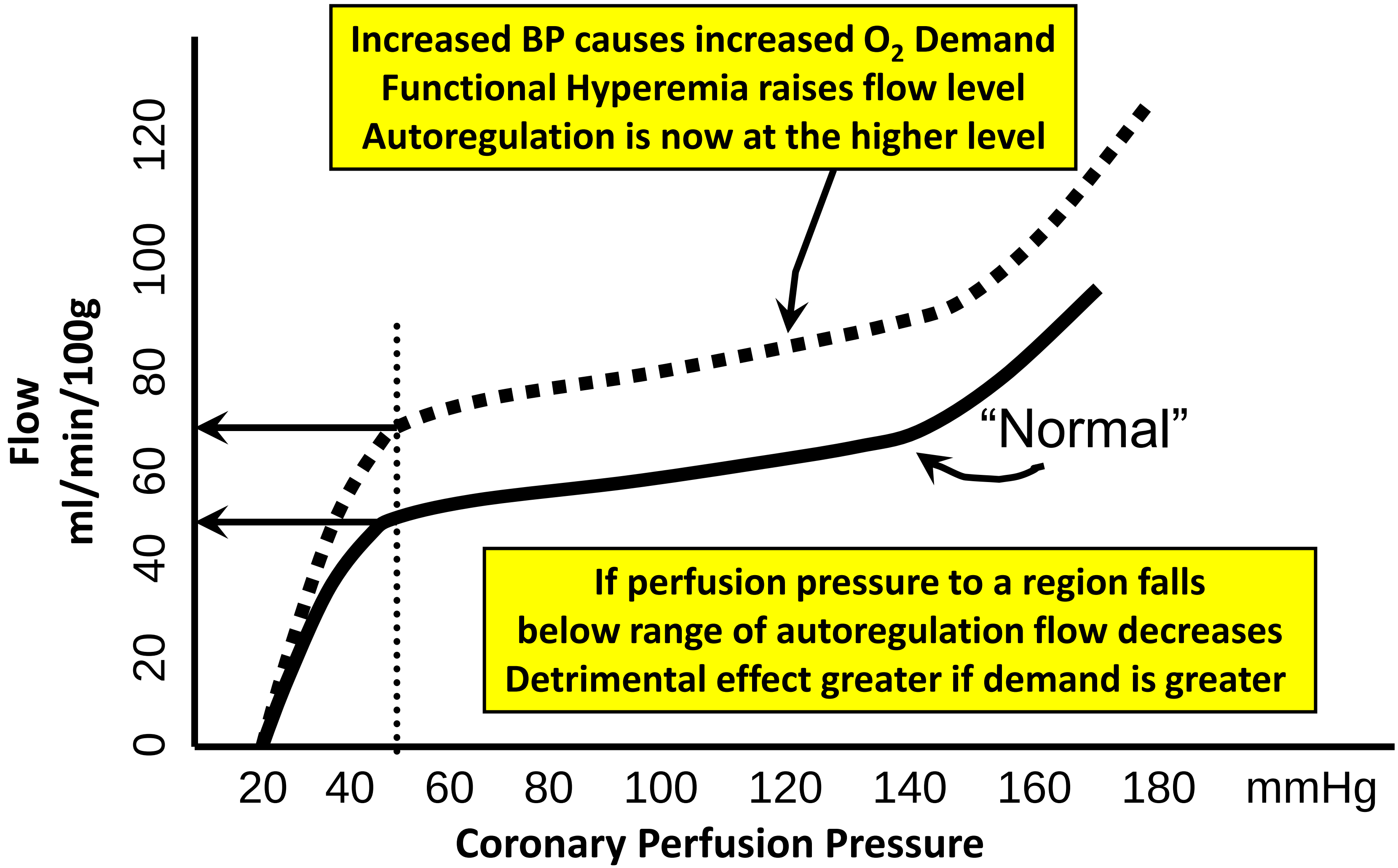
O_2 consumption=Q (C_A - C_V) [ml/O_2/min]

Extraction [mlO_2/100ml]

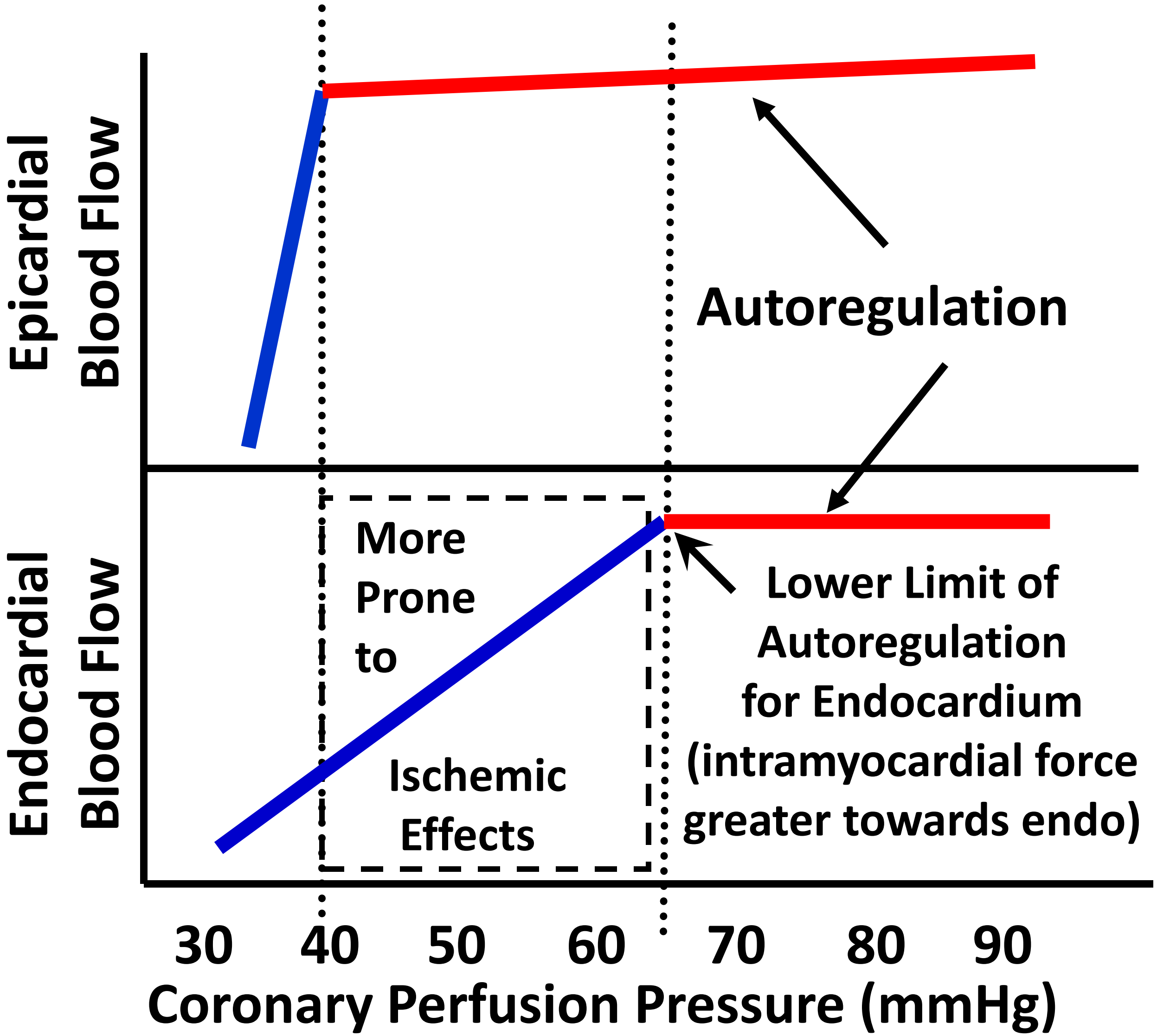
75-90% → Flow-Dependent



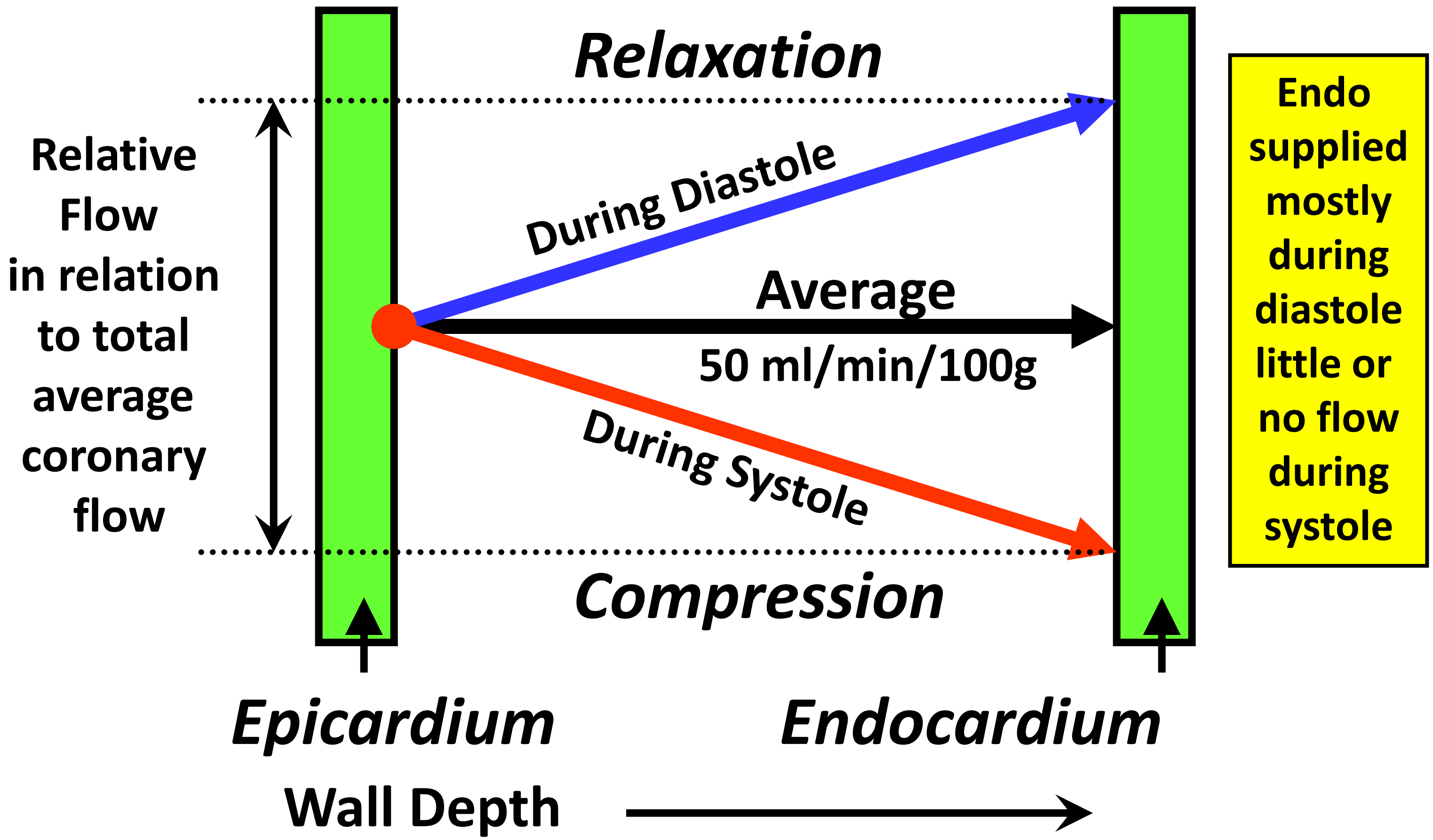
Coronary Autoregulation



Regional Autoregulatory Differences



Regional Blood Flow Distribution



Features of the Microvascular System

- **Capillary Structure –Function Variability**
- **Transcapillary Transport and Exchange**
- **Role of the Glycocalyx**

Online Videos

NormalMicrocirculation.wmv (37.7MB)
http://www.youtube.com/watch?v=gP9qFlFAyXk

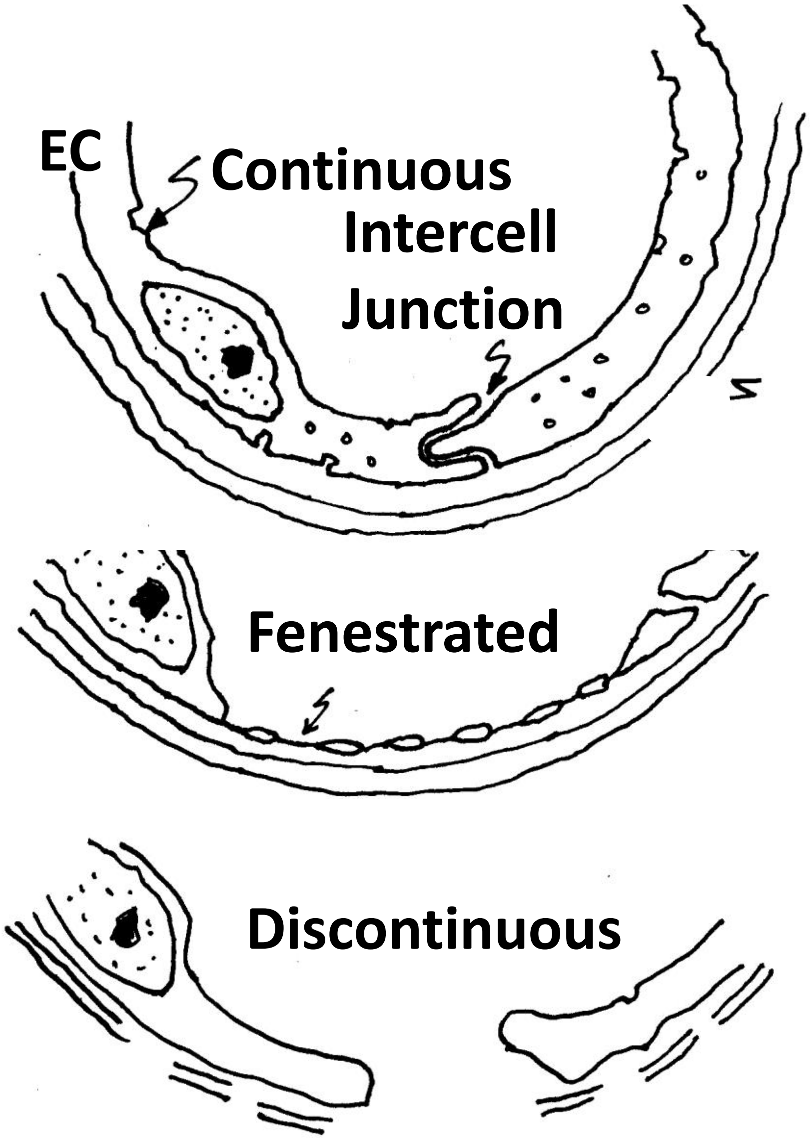
Vasoconstriction_NE.wmv (54.9MB)
http://www.youtube.com/watch?v=k8J_1uH-woE

Vasodilation_Adenosine.wmv (33.4MB)
http://www.youtube.com/watch?v=PQ-Oq6mnlTQ

Vasomotion.wmv (48.3MB)
http://www.youtube.com/watch?v=6E_OLwVsf9w

CapillaryBloodFlow.wmv (66.5MB)
http://www.youtube.com/watch?v=QuWhKN1bHLA

Capillary Variability Among Tissues



- Heart
- Skeletal M.
- Skin
- Lung

"Small pore size" r ~ 2.5 nm

- Brain-Spinal cord-Retina

Tight Junctions: r <= 0.5 nm

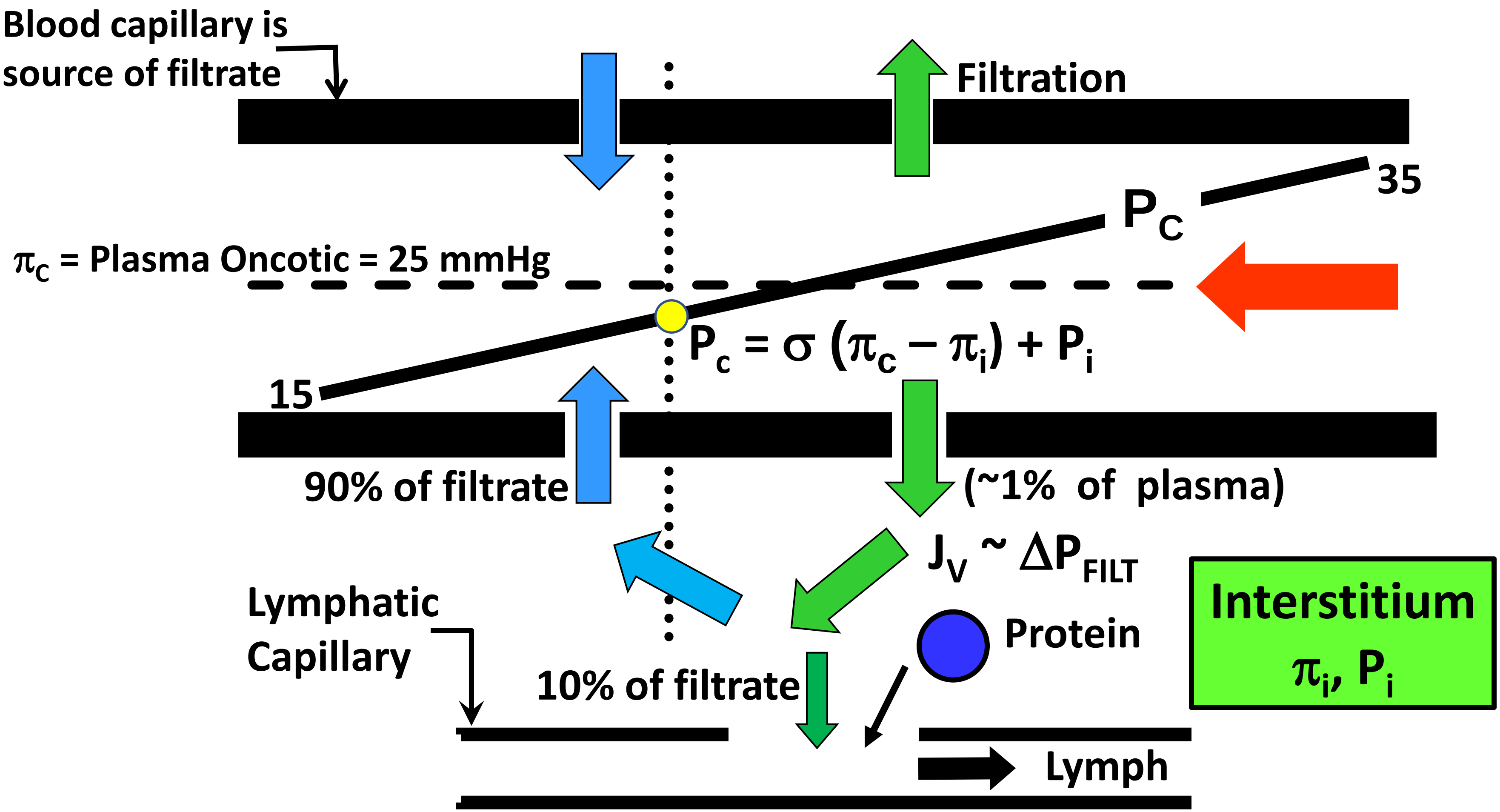
- Kidney glomeruli
- Intestinal mucosa
- Endocrine Glands

3-8 nm

- Bone Marrow
- Spleen
- Liver

	Radius (nm)
Solutes	
Nacl	0.14
Glucose	0.16
Proteins	
Albumin	3.5
Myoglobin	1.9

Classic View of Fluid Exchange

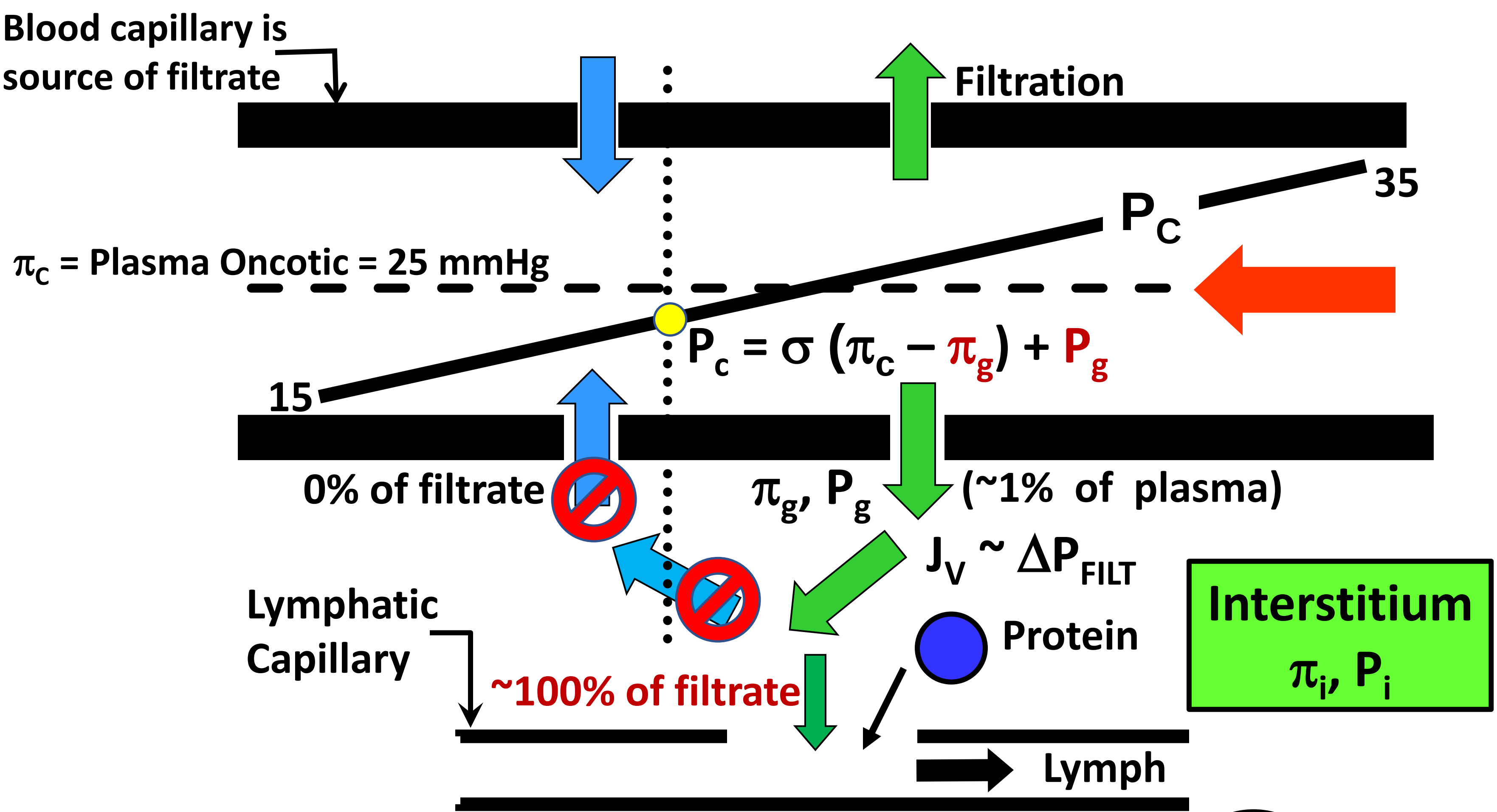


$$\Delta P_{FILT} = (P_c - P_i) - \sigma\ (\pi_c - \pi_i) = 0\ ?$$

$$P_c = \sigma\ (\pi_c - \pi_i) + P_i$$

π_i = Interstitial Oncotic pressure
P_i = Interstitial hydrostatic pressure
σ = reflection coefficient

Proposed Revision to Classic View of Fluid Exchange



$$\Delta P_{FILT} = (P_c - P_g) - \sigma\,(\pi_c - \pi_g)$$

Most but not all tissues

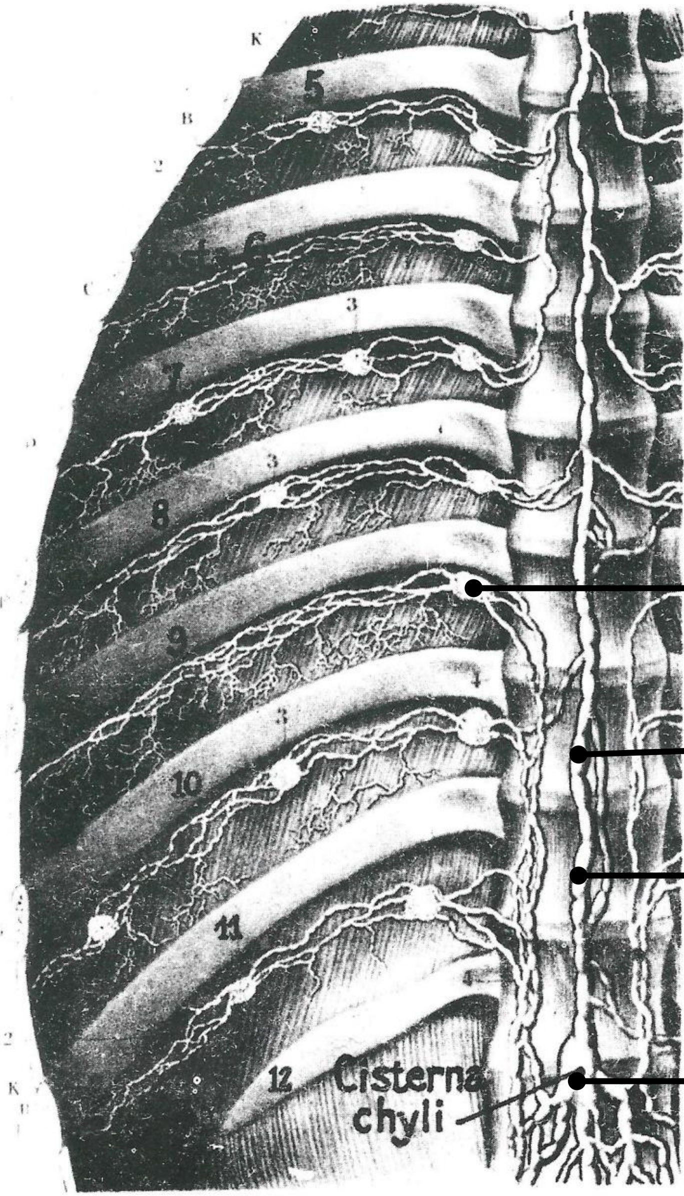
π_g = Sub-glycocalyx Oncotic pressure
P_g = Sub-glycocalyx hydrostatic pressure

Supporting Evidence: J Physiology 2004;557:704, Cardiovascular Res 2010;87:198-210, Clin Invest 2014; 124 (3):915-921

Features of the Lymphatic System

- **Anatomical Depiction**
- **Functional Arrangements**
- **Ducts and Lymph Nodes**
- **Lymphatic Capillaries and Designations**
- **Lymphangions and Transport**
- **General Arrangement**
- **Edema and Lymphedema**

Lymphatic Anatomical Depiction



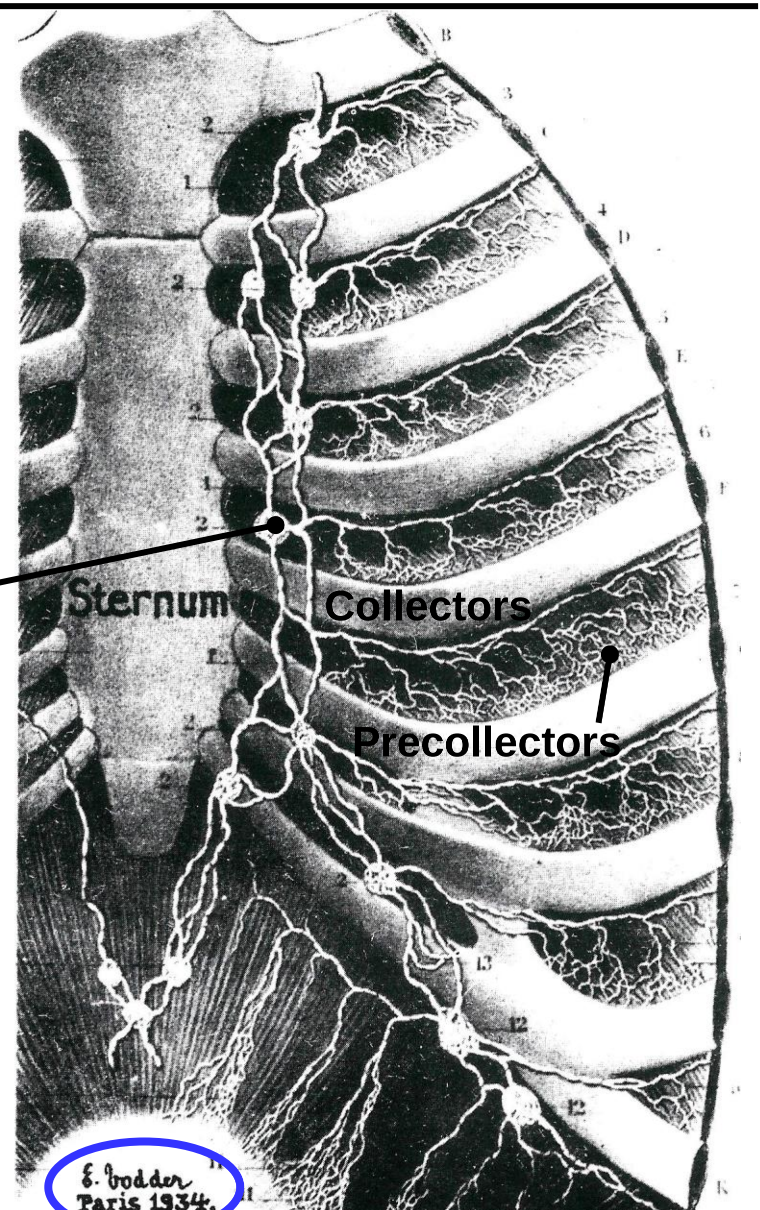
Attribution
Estrid and Emil Vodder

Lymph Nodes

Lymphangions

Thoracic Duct

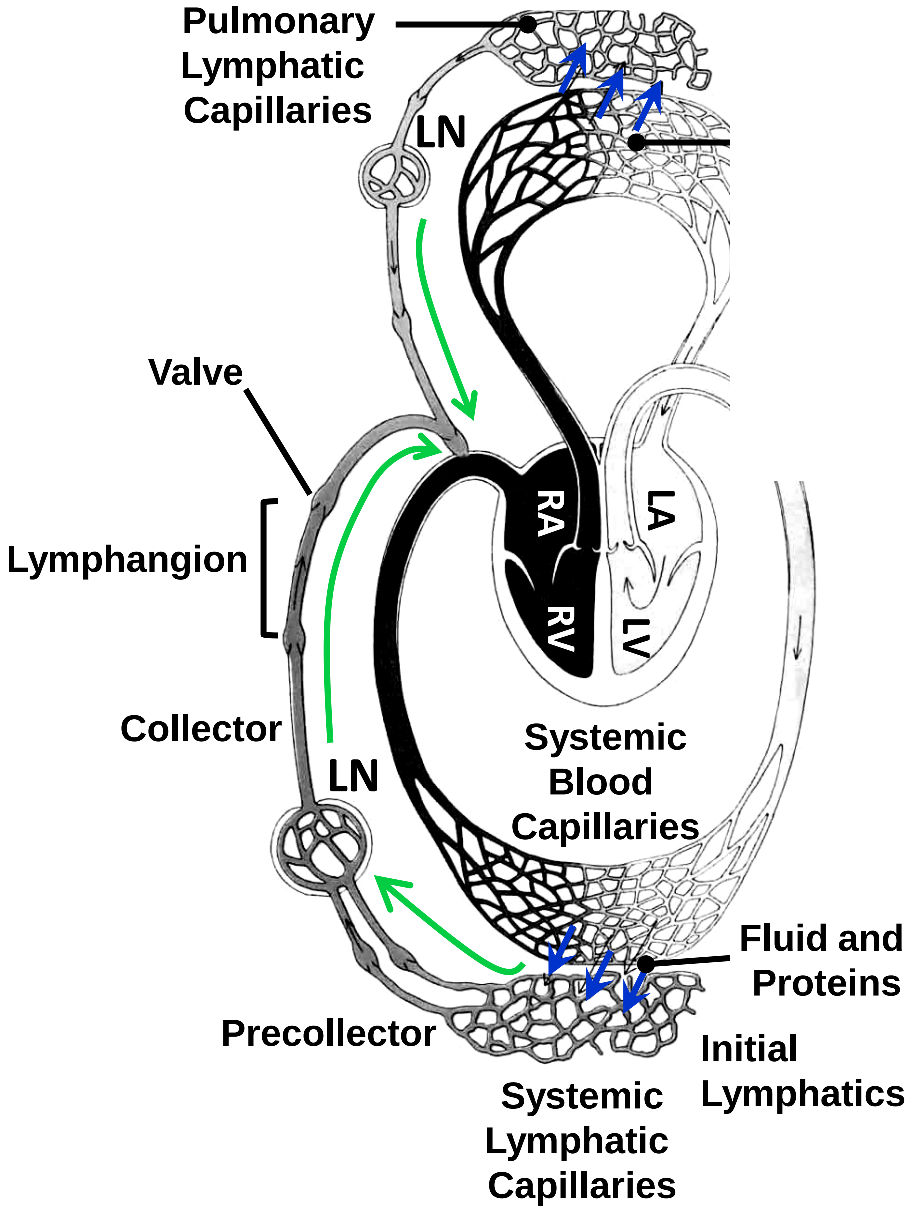
Start of Thoracic Duct



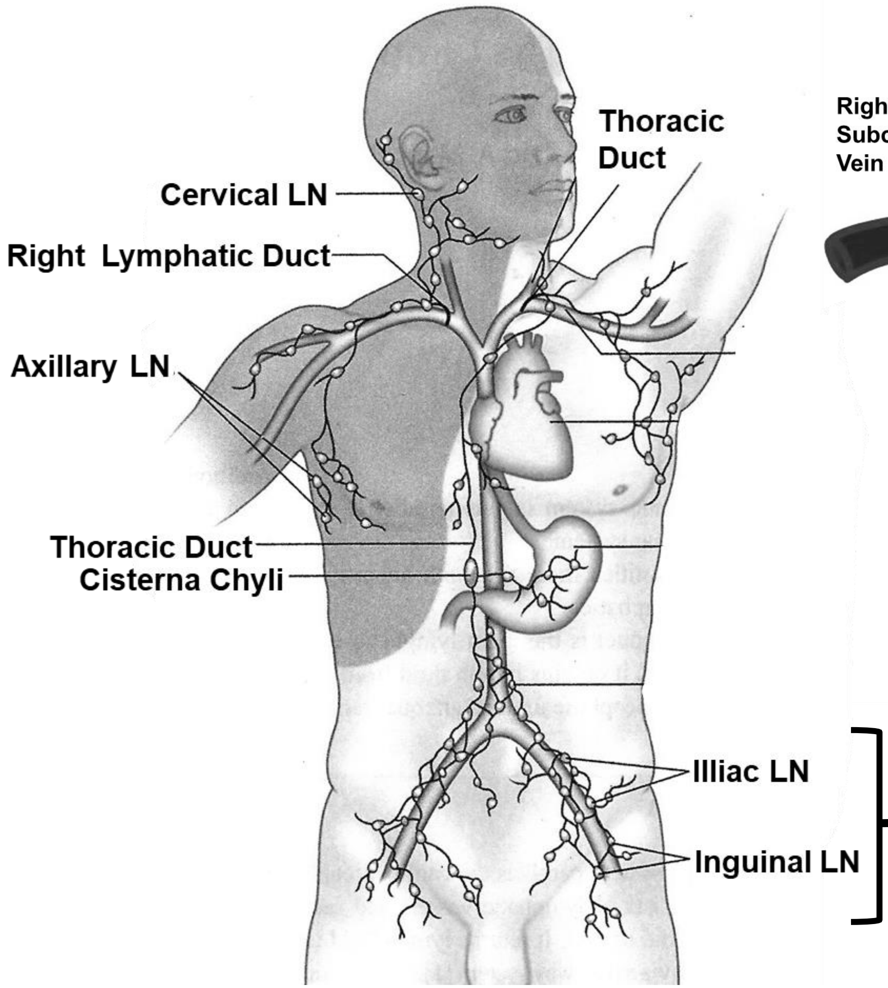
Intercostal Lymphatics and Nodes

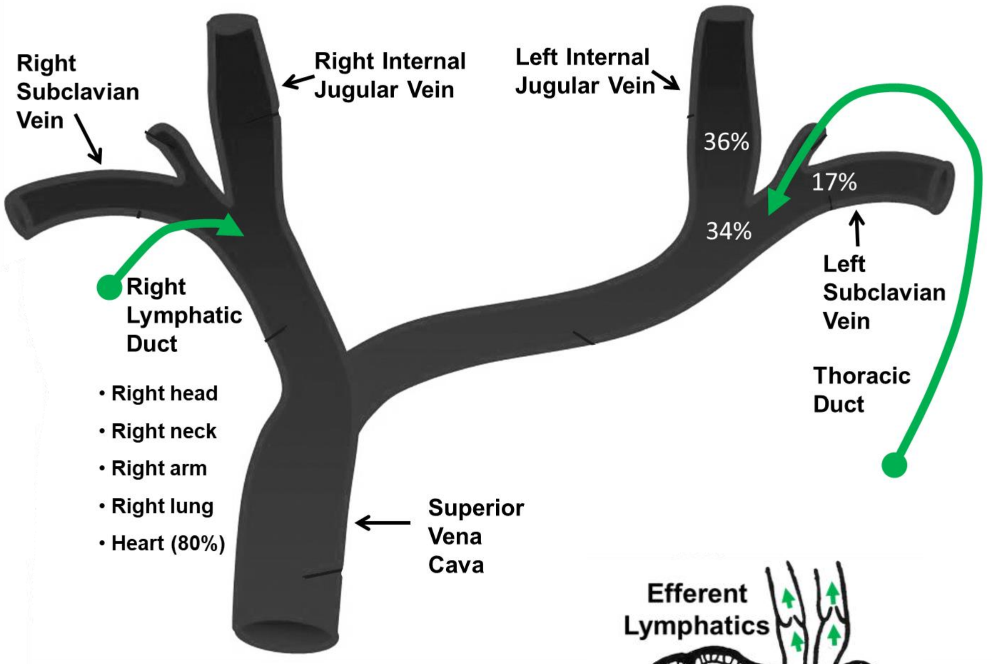
Parasternal Lymphatics

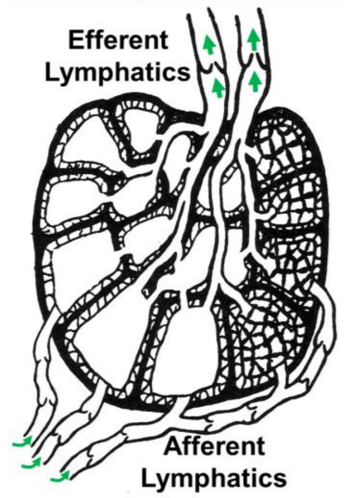
Lymphatic Functional Arrangements



Lymphatic Drainage-Ducts-Nodes

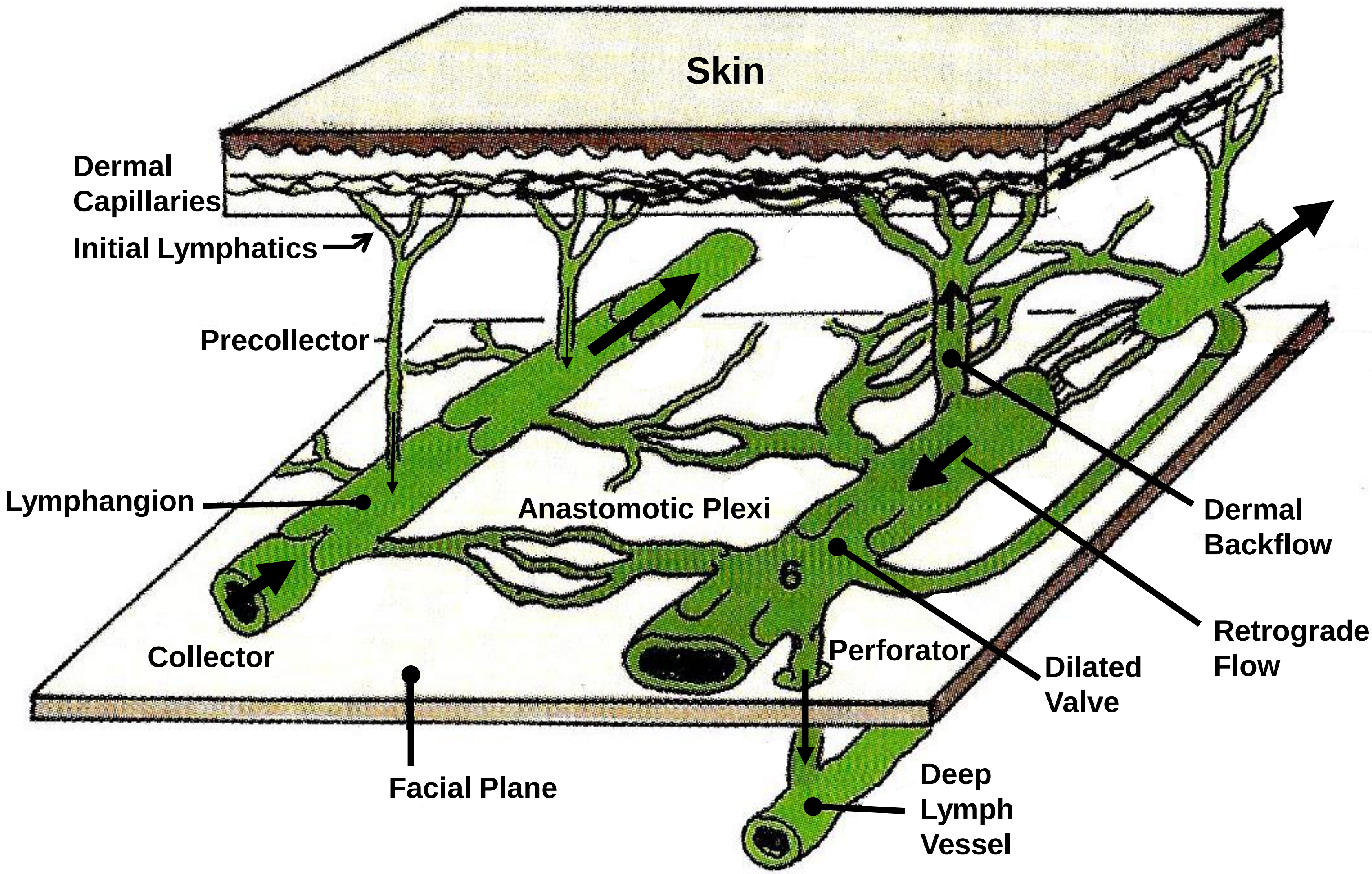




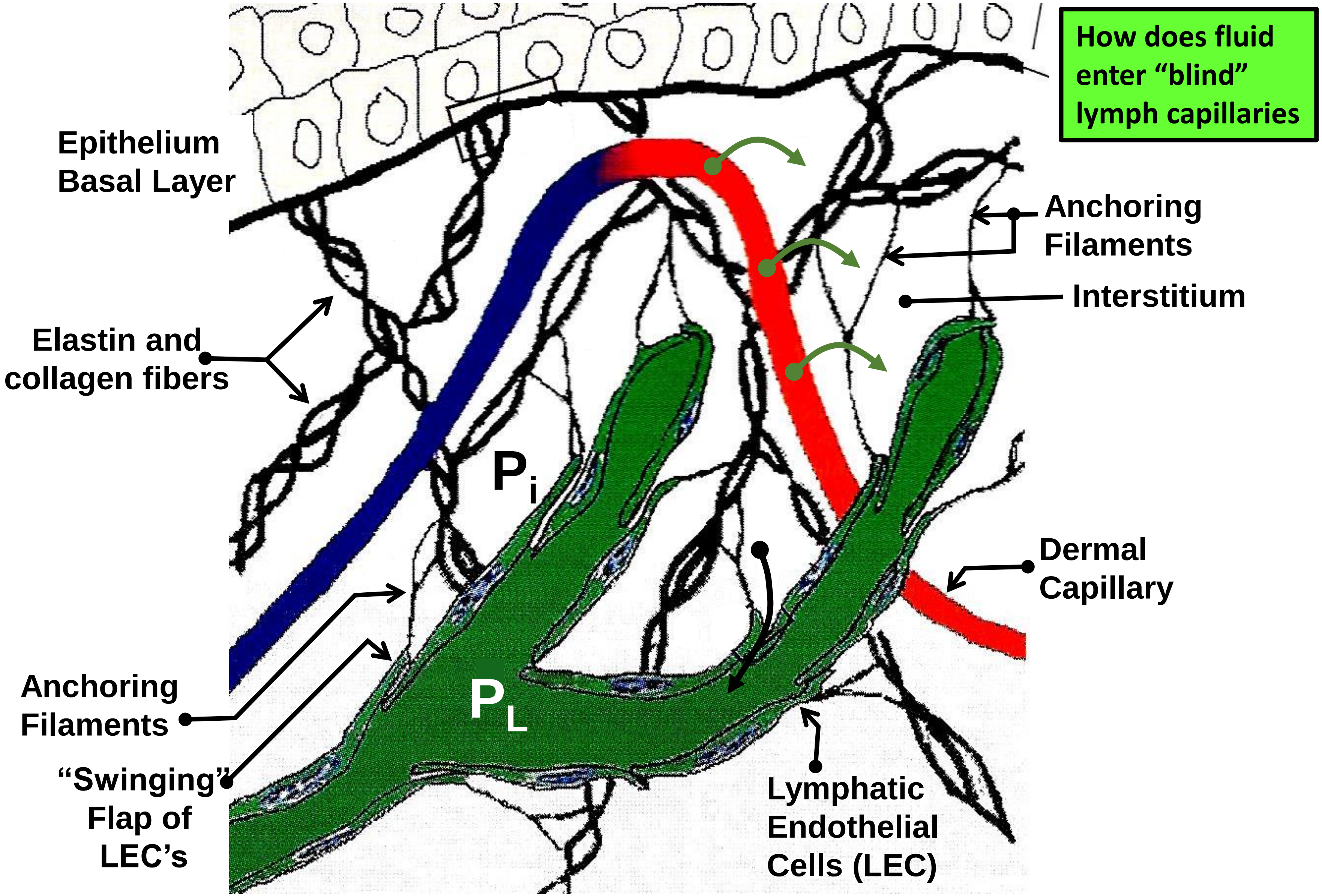


Dr HN Mayrovitz

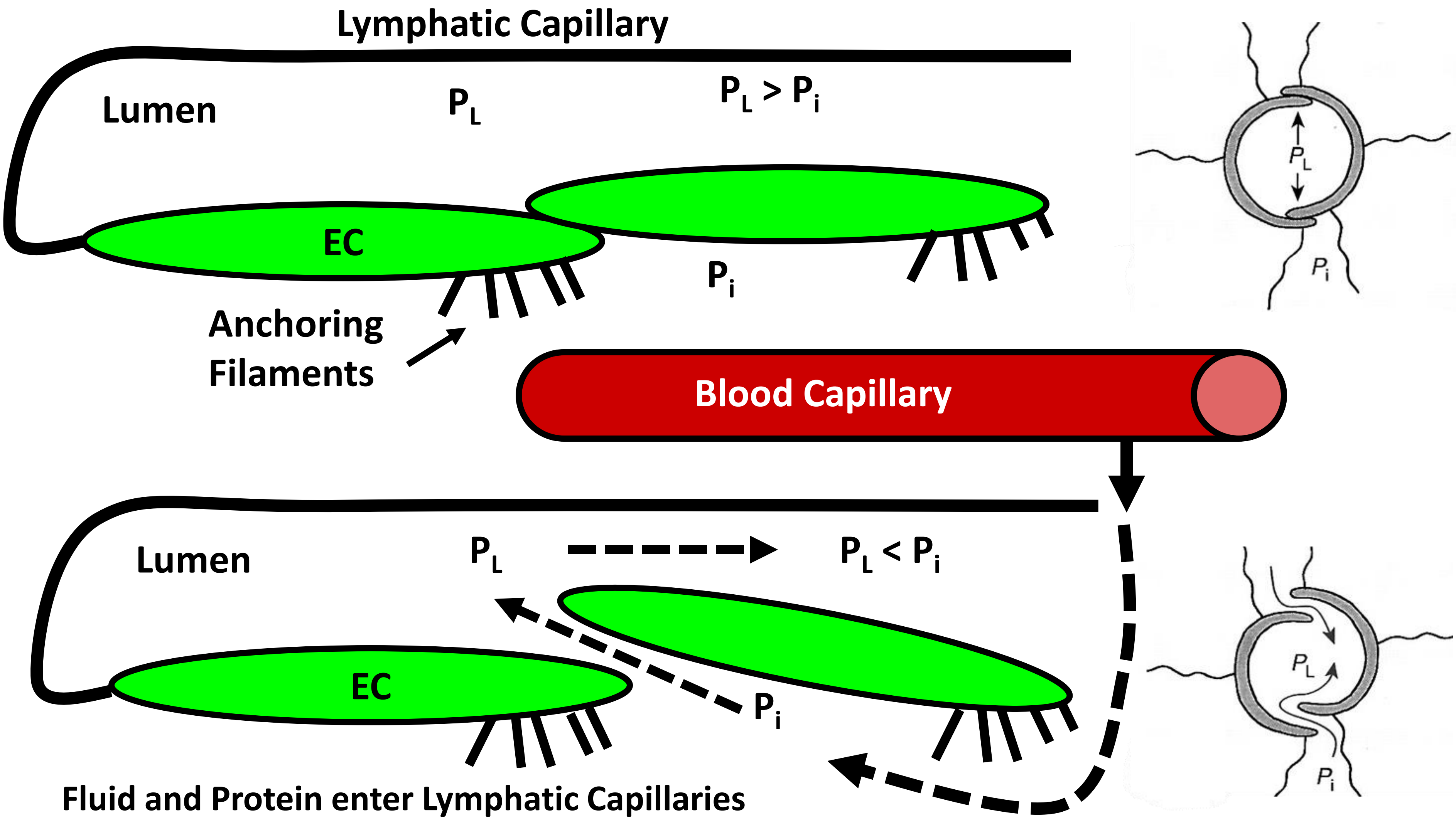
Lymphatic Vessel Designations and Features



Initial Lymphatics – Lymph Capillaries



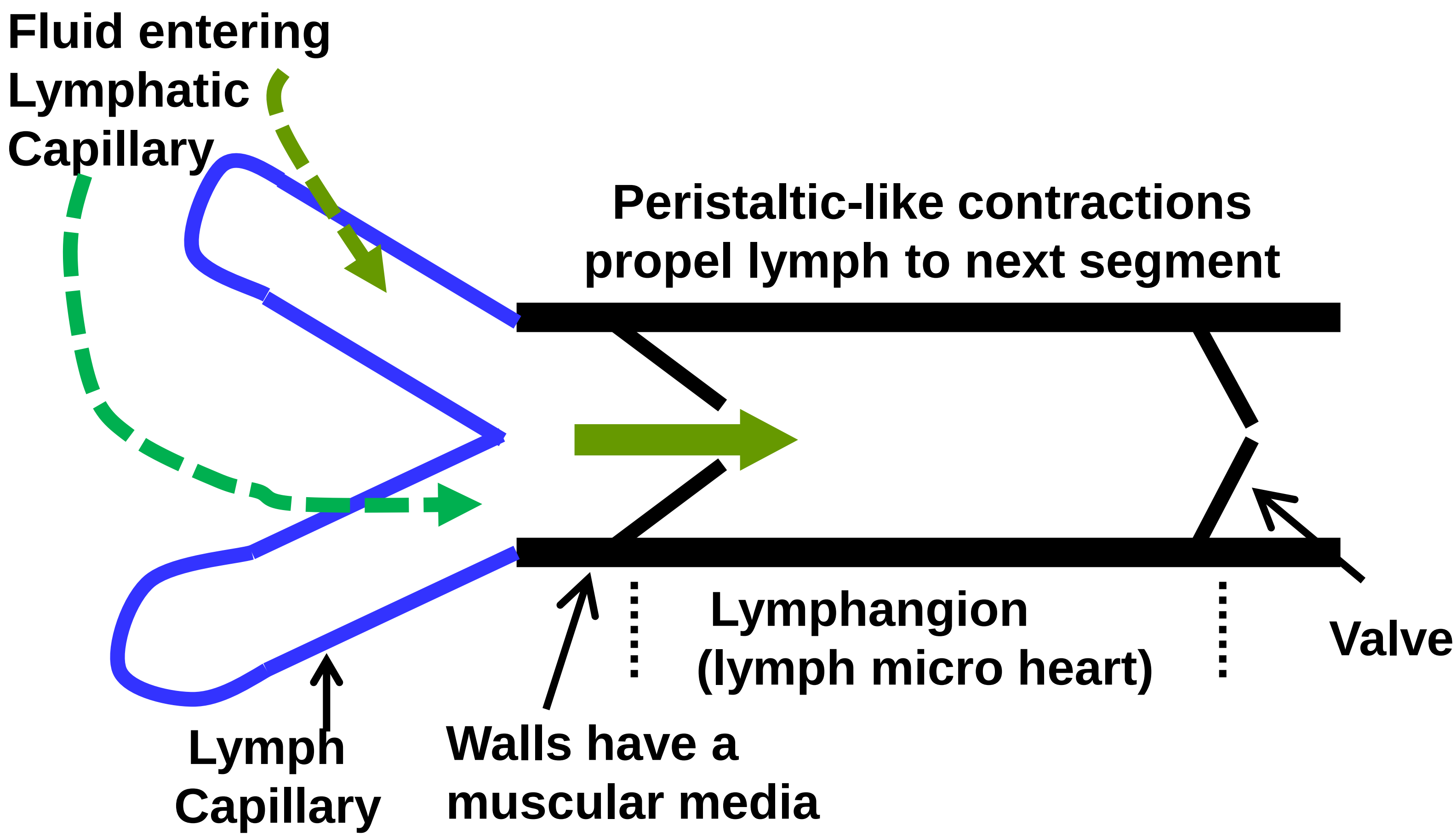
Entry into Lymphatic Capillaries



Pathway for fluid entry when $P_i > P_L$

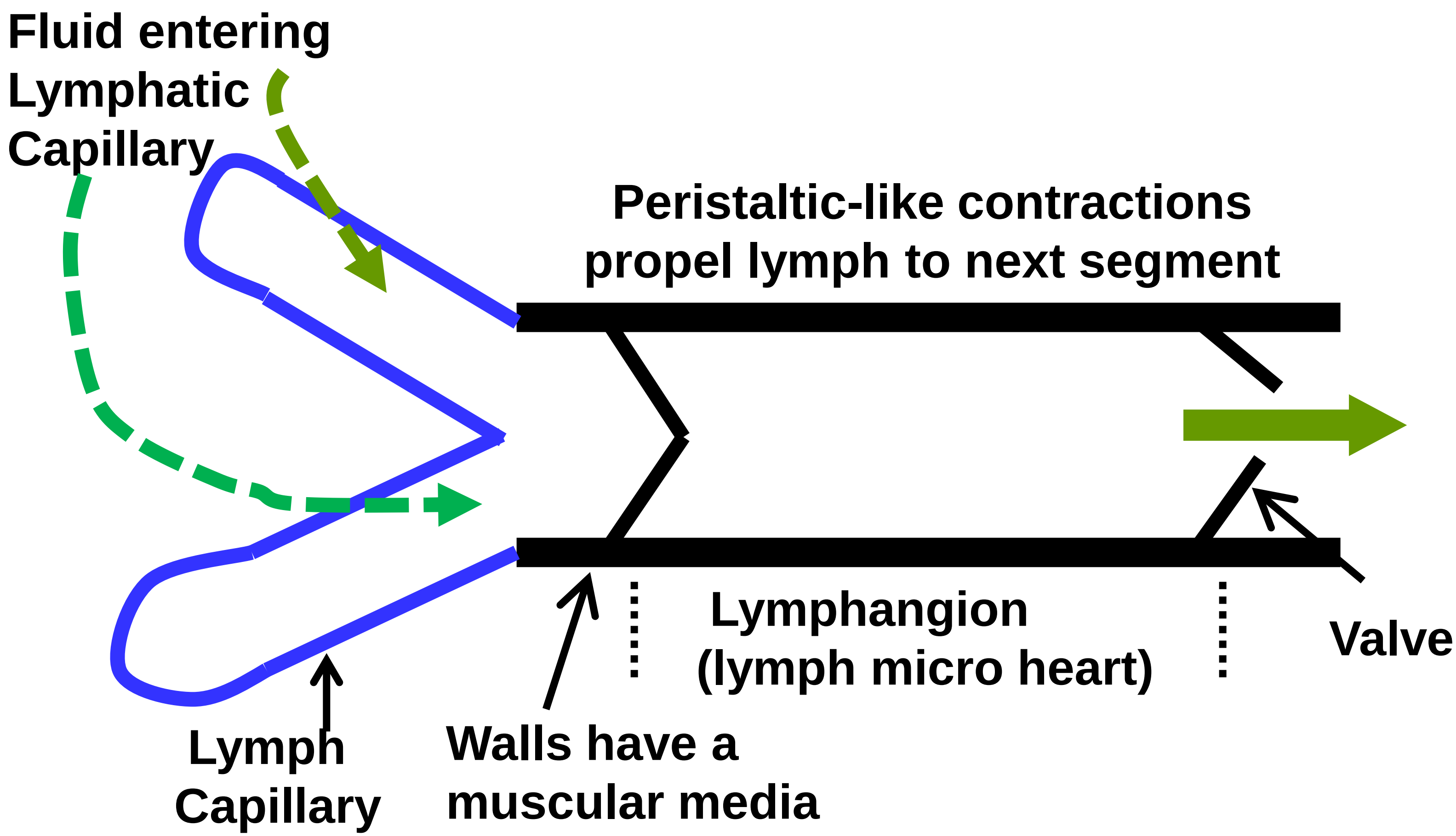
P_L = Intraluminal lymphatic pressure
P_i = Interstitial pressure
EC = Endothelial cell

Lymphangions: Lymphatic "Hearts"



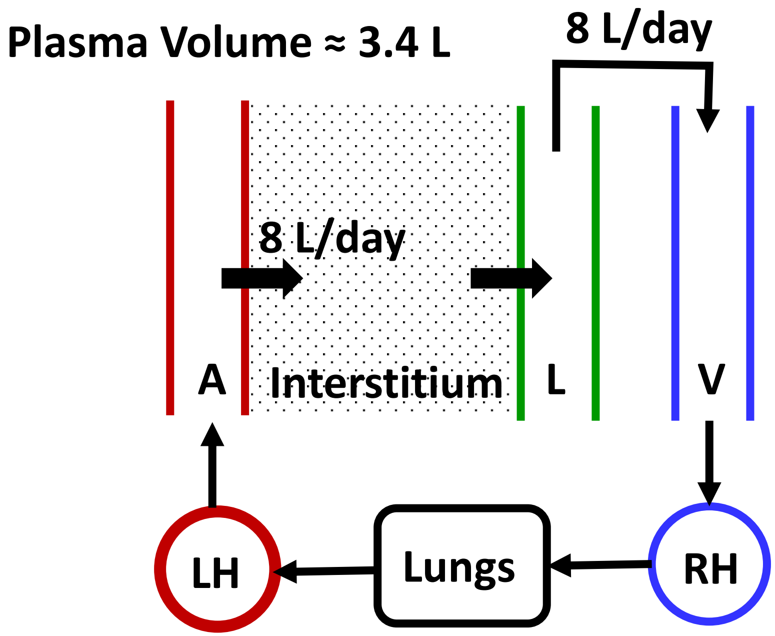
Contraction force and frequency is preload and afterload dependent - analogous to heart

Lymphangions: Lymphatic "Hearts"



Contraction force and frequency is preload and afterload dependent - analogous to heart

Blood Plasma – Lymphatic – Venous Connection



A → Arterial System
L → Lymphatic System
V → Venous System
LH → Left Heart
RH → Right Heart

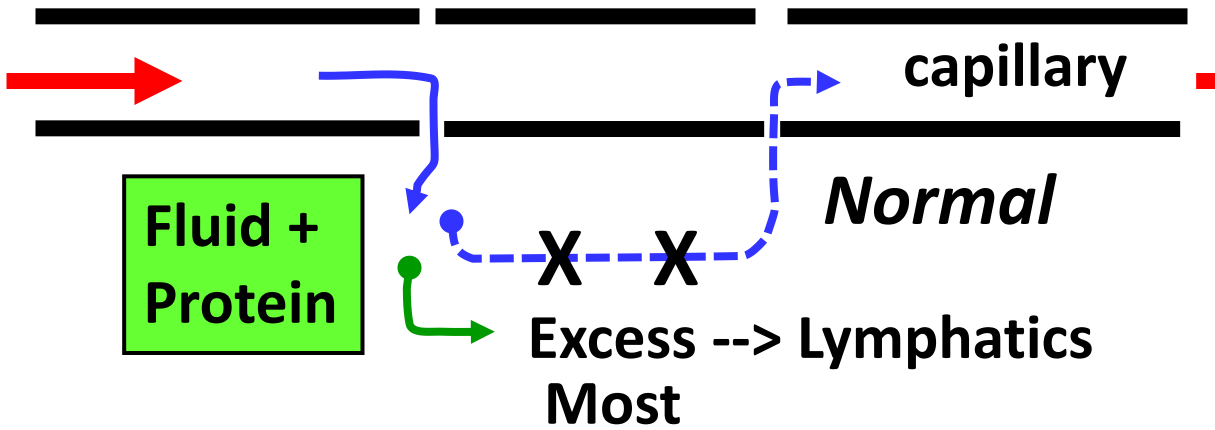
- Male Blood volume (BV) ≈ 75 ml/Kg
- For a 75 Kg man BV = 5.625 L
- If hematocrit is 40% then his plasma volume (PV) is 3.4 L
- Plasma filters from arterial capillaries into the interstitium at an average of 8 L/day
- It is collected and moved through the lymphatic system to be returned to the venous system

- For the 75 Kg man this means that in about 10 hours the entire plasma volume will be exchanged;

8L/24hr = 0.33 L/hr

3.4L/0.33L/hr = 0.425 x 24 = 10.3 hours

Edema and Lymphedema



If Net Filtration Exceeds
Lymphatic Transport Capacity

Overload = Edema

+ [Protein]

= Lymphedema

Clinical Lymphedema Images

Unilateral Breast Cancer Treatment-Related LE

Unilateral Lower Extremity Lymphedema

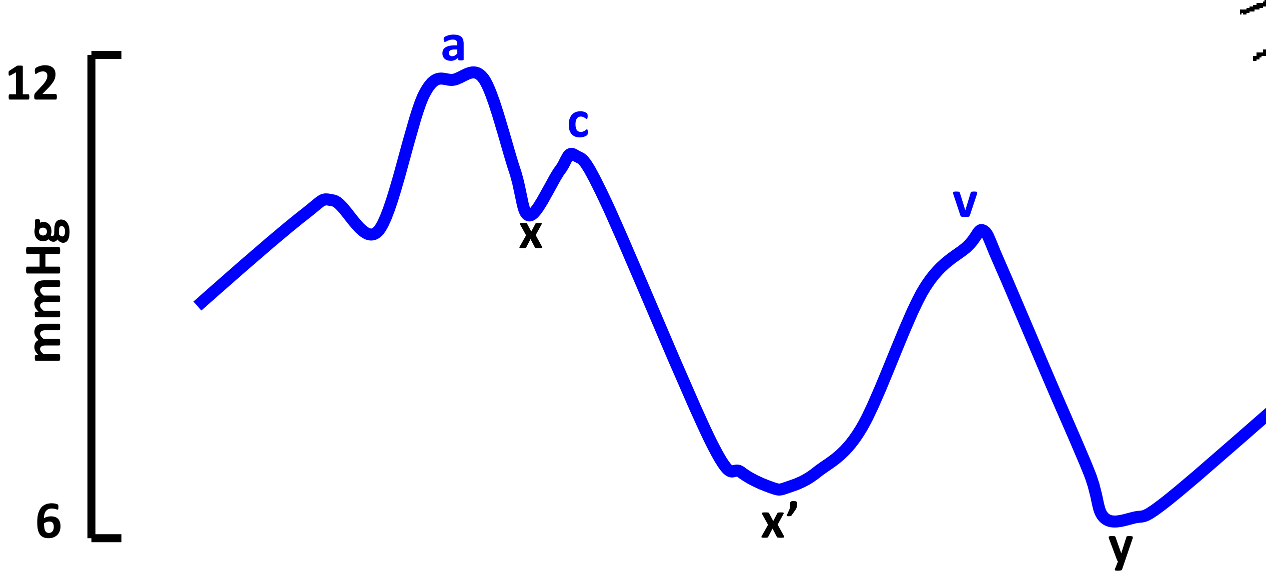
Bilateral Lower Extremity Lymphedema

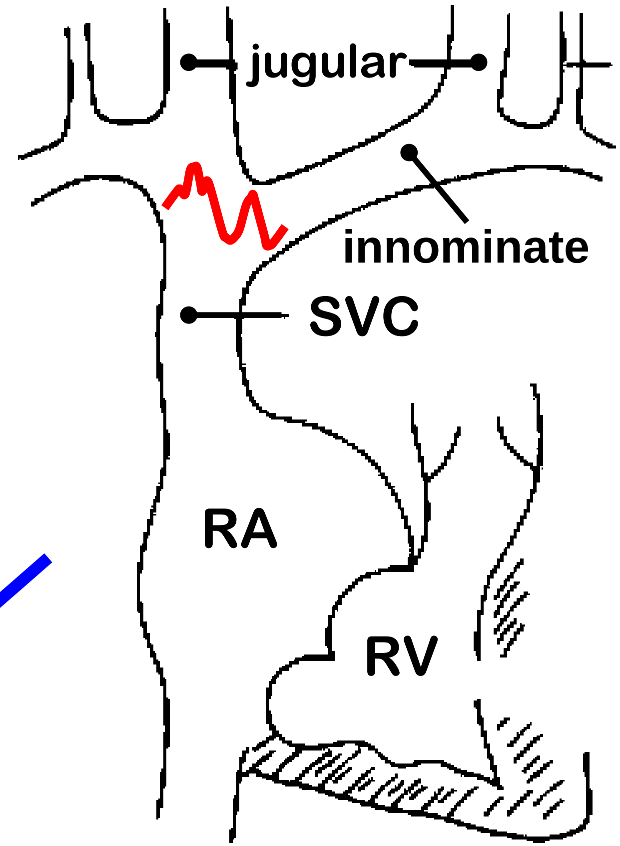
Features of the Venous System

- **Review of Central Venous Pressure Pulse**
- **Gravity Effects**
- **Venous Valves Dysfunction**
- **Respiratory Pump**
- **Reservoir Function**

Central Venous Pressure Pulse Overview
(Jugular Pressure Pulse)

3 positive going waves





a-wave → RA contraction

x-wave → RA relaxation

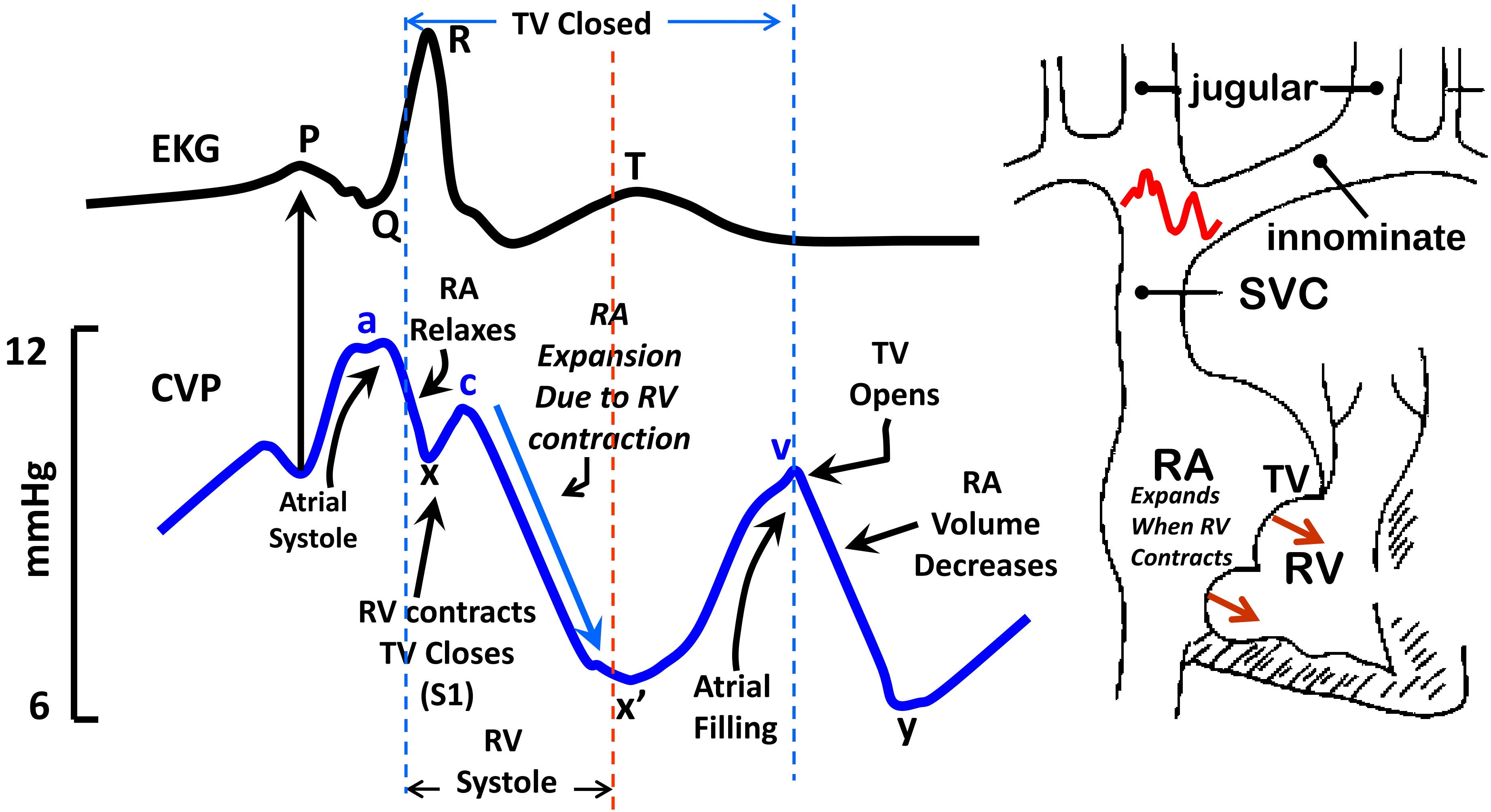
c-wave → TV closure

→ Interrupts decline

v-wave → RA filling - TV closed

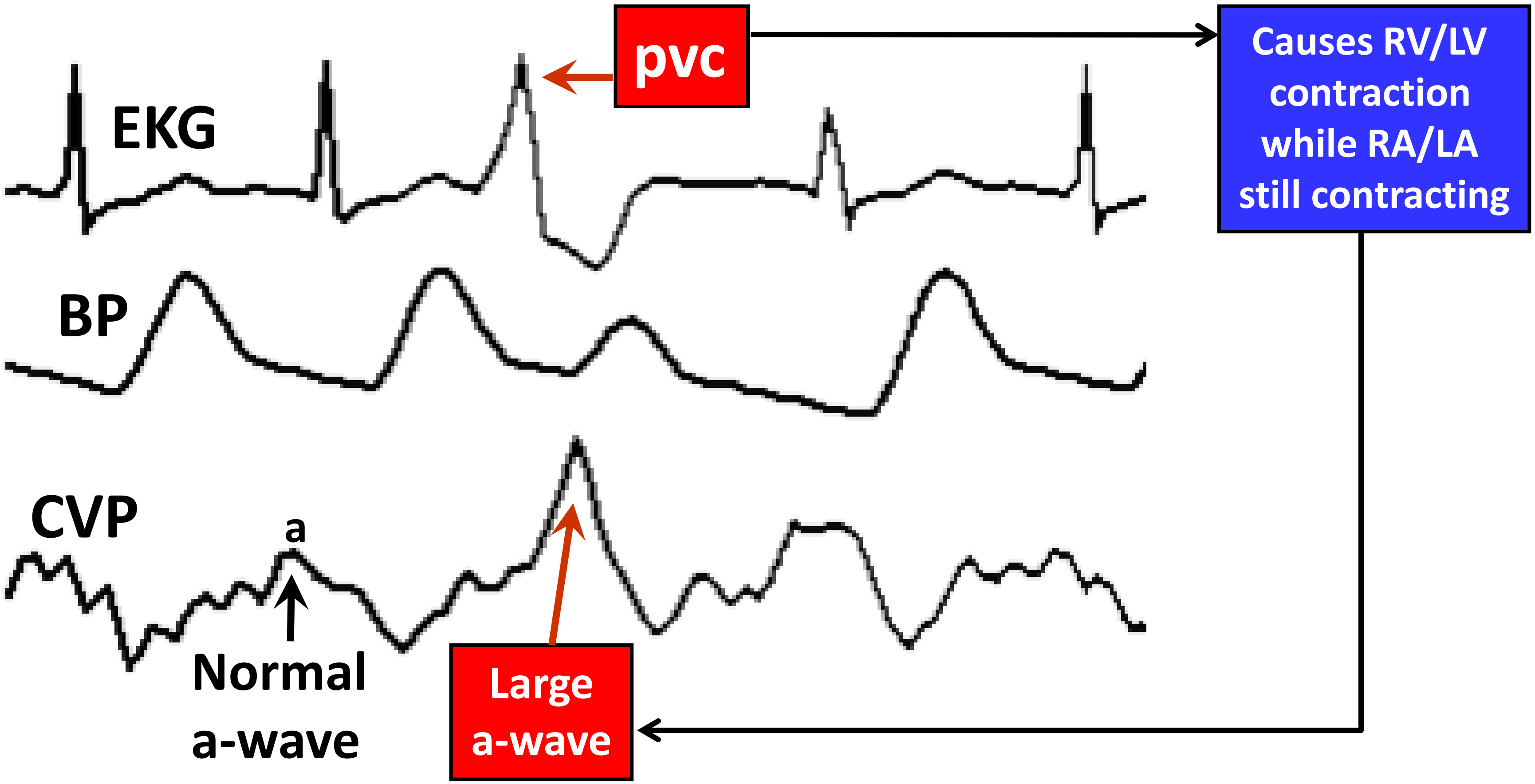
y-wave → RV filling - TV open

CVP Pulse in Relation to EKG



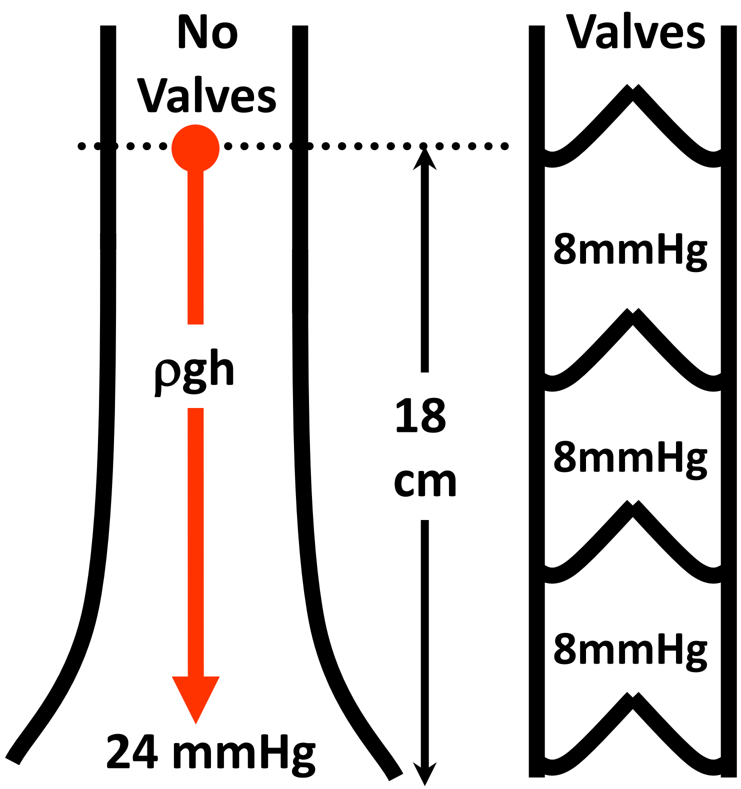
a-wave: Venous distension and backward pressure wave during right atrial (RA) systole
x-decent: RA relaxes
c-wave: RV contraction closes TV that bulges into RA (interrupts decent)→ RAP transient increase
x': continuation of x-decent (RV contraction continues "expands" atrium – RAP falls)
v-wave: Rise in RAP with atria filling (Relaxing RV → RA expansion reversed)
y-decent: Decline in RAP when tricuspid valve reopens – RV filling

Large a-wave if atrial contracts while ventricle not relaxed



- *a-waves increased if RA contracts while RV contracting*
- *a-waves increased if tricuspid valve stenosis*
- *a-waves increased if atrium contracts with TV closed*
- *a-waves disappear in atrial fibrillation*
- *a-waves increased if low RV compliance*

Valves and Calf Muscle Pump

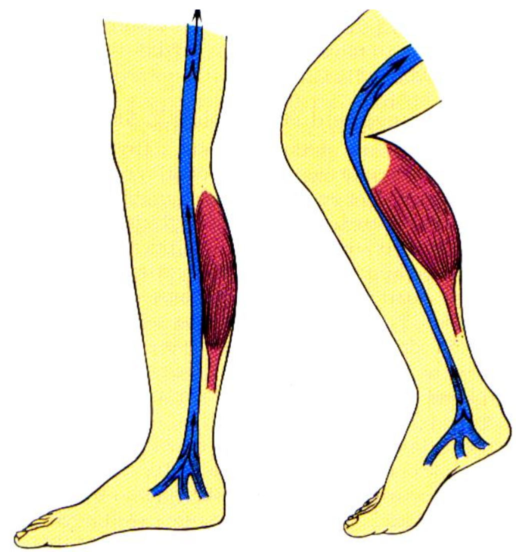


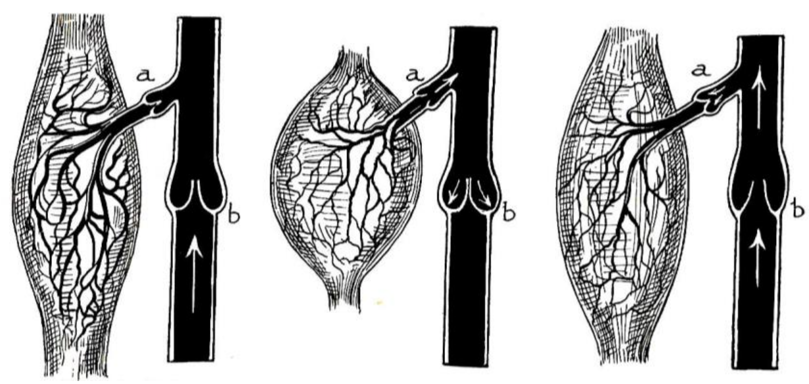
Valves segment pressure

Hydrostatic
Pressure
Column
Segmented

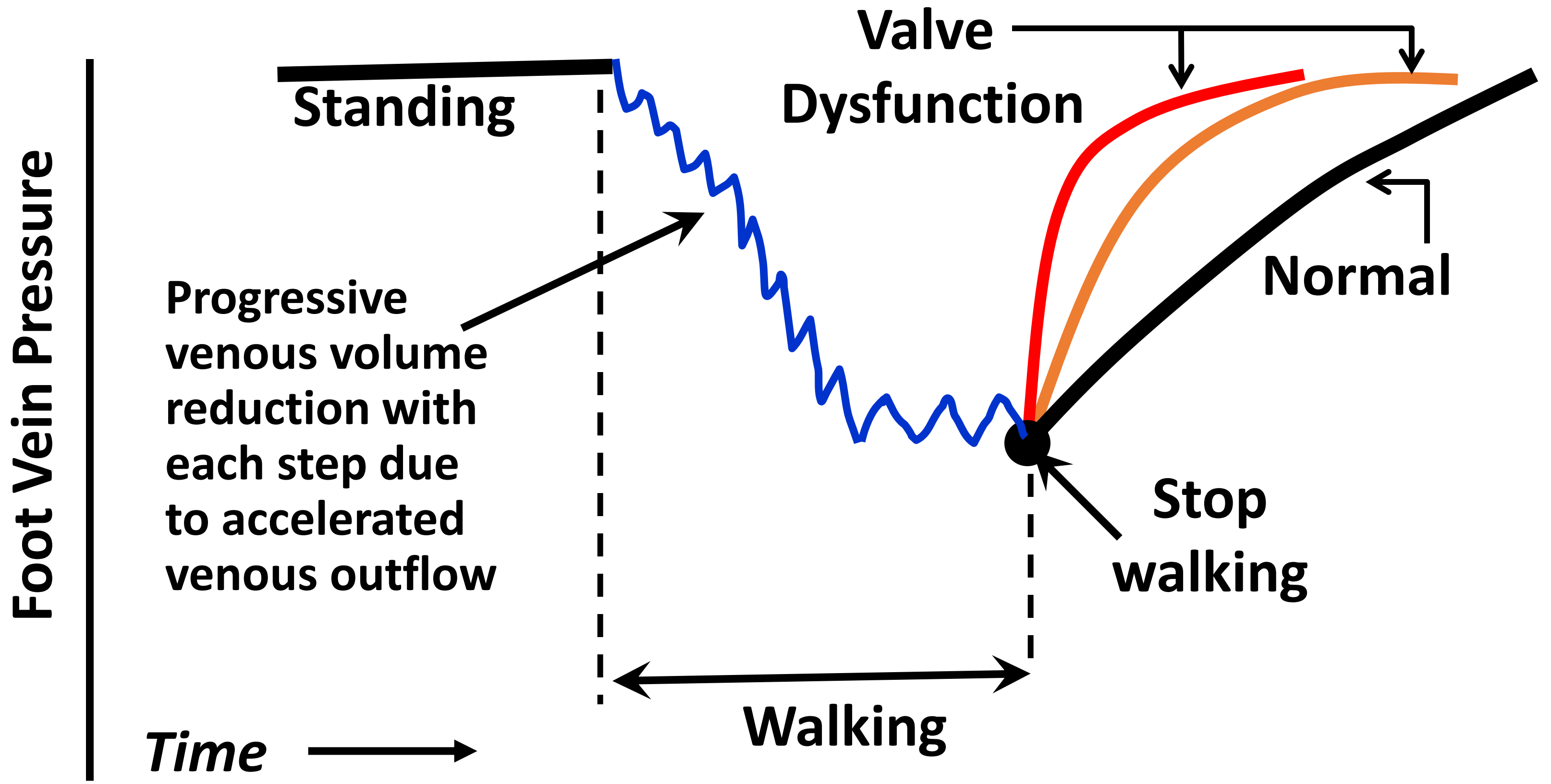
6 cm
P=8 mmHg

Calf Muscle
Pump



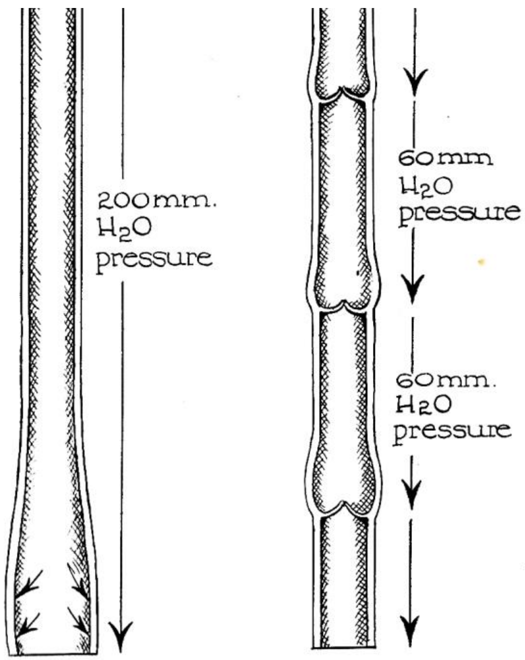


Ambulatory Venous Pressure



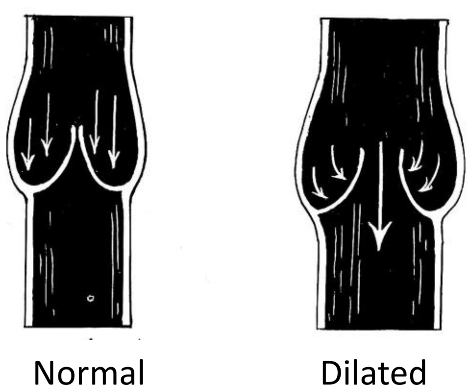
Venous Valve Segmentation and Incompetence

A

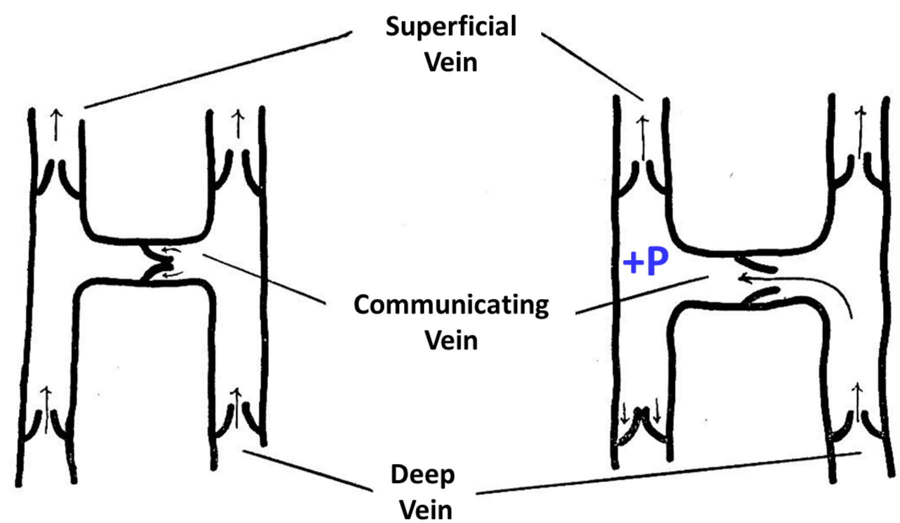


- (A) Segmentation reduces gravitational pressure component that contributes to passive dilation
- (B) Venular overdilation or valve structural change leads to venous valve incompetence
- (C) When incompetence of communication vein valves then increased pressure in superficial veins that may lead to vein wall changes and skin breakdown

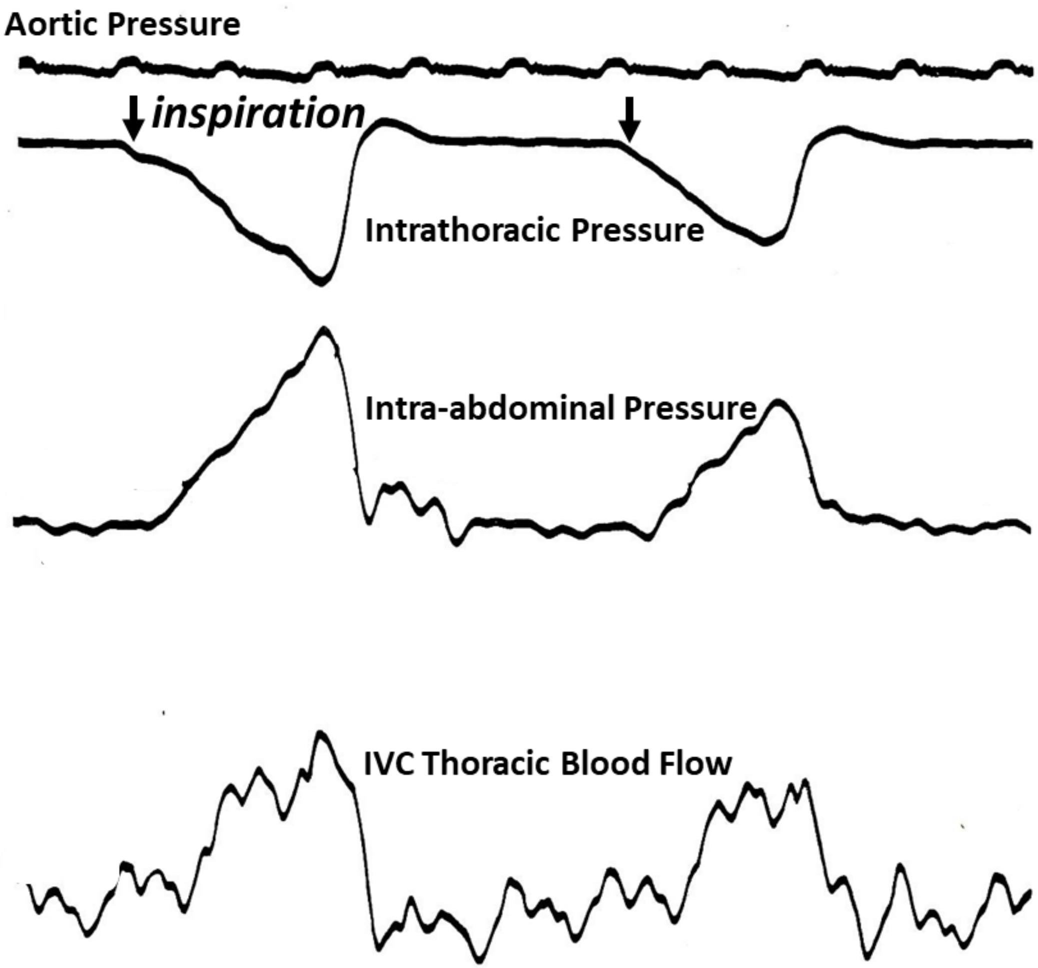
B



C



Respiratory Pump

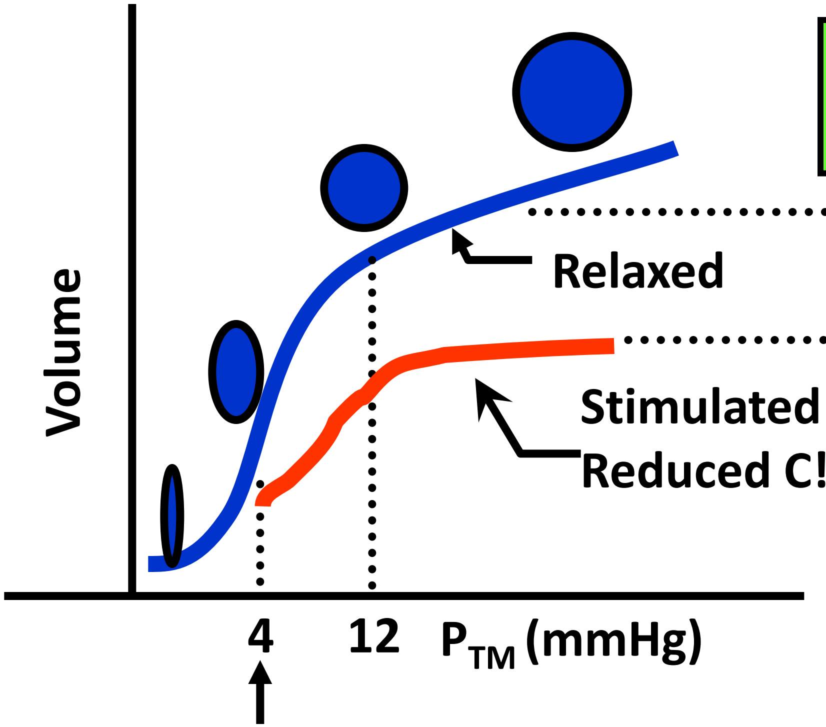


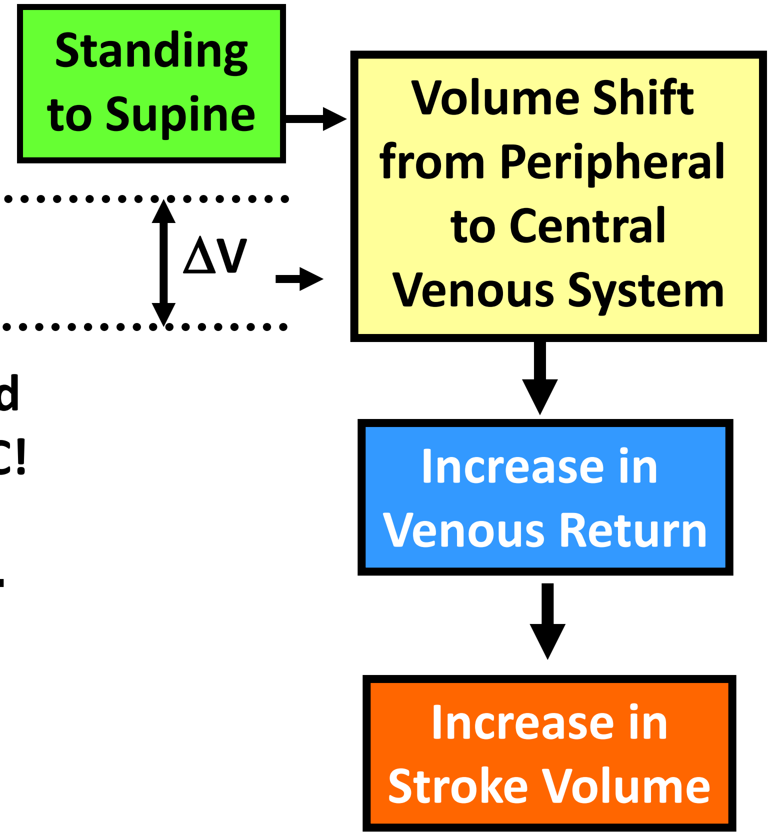
- **Inspiration causes**
  - **→ decreased thoracic pressure**
  - **→ increased abdominal pressure**

- **Reduced thoracic pressure increases transmural pressure in thoracic IVC**
- **Lowers resistance**
- **increased blood flow**

- **Thus, inspiration is normally associated with increased blood to the right heart**
- **This action is referred to as the Respiratory Pump → aids venous return**

Venous Volume Reservoir Role





Maximum Venous System Compliance is at about 4 mmHg: C = 100ml/mmHg

At high pressures - fully circular
C is ~ same as corresponding arteries

Opposite if less sympathetic drive

End of CV Physiology Lecture 16