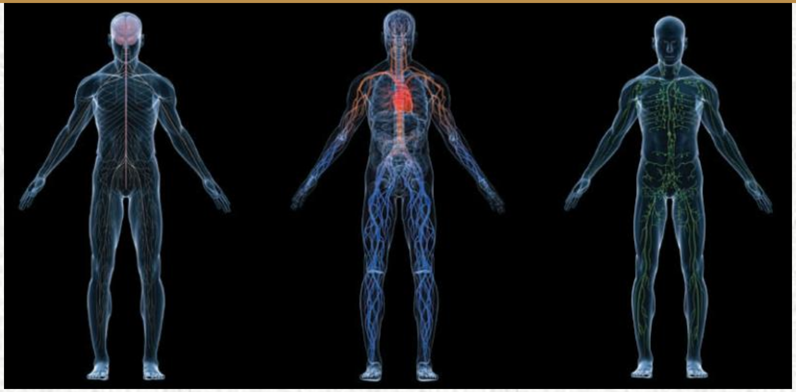
UNIT VII

GUYTON AND HALL *Textbook of*

Medical Physiology

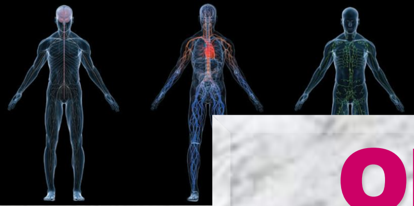
TWELFTH EDITION



Chapter 38:

Pulmonary Circulation, Pulmonary Edema, Pleural Fluid

Slides by Robert L. Hester, PhD

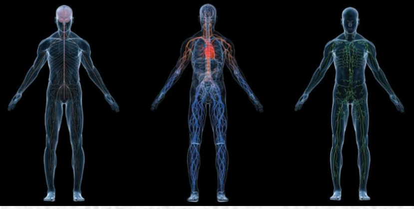


Objectives

- Describe the pulmonary circulation
- Describe the pulmonary blood pressures
- List the factors that affect diffusion
- Explain the factors that affect O_2 and CO_2 diffusion
- Composition of air in the respiratory pathway
- Describe the lung zones of perfusion
- Explain how the lungs accommodate extra flow
- Describe the Ventilation/Perfusion ratio

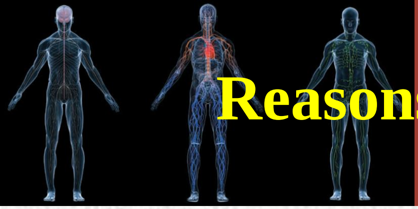
Two circulations in the respiratory system

- **Bronchial Circulation**
  - Arises from the aorta.
  - Part of systemic circulation (oxygenated).
  - Receives about 1-2% of left ventricular output.
  - Supplies the supporting tissues of the lungs, including the connective tissue, septa, and bronchi.
  - It empties into the pulmonary veins and eventually into left atrium
  - The blood flow into left side is greater by 2%...do you think left ventricular output is equal to right ventricular output?



PULMONARY BLOOD FLOW

- Pulmonary Pressures
  - Pulmonary artery pressure
    - systolic 25 mmHg
    - diastolic 8 mmHg
    - mean 15 mmHg
    - capillary 10 mmHg
- Left Atrial and Pulmonary Venous Pressures = 2 (1-5) mm Hg (estimated)
- *Pulmonary wedge pressure* = 5 mm Hg (usually its 2 to 3 mm Hg greater than the left atrial pressure)



Reasons Why Pressures Are Different in Pulmonary and Systemic Circulations

- Gravity and Distance:
  - Distance above or below the heart adds to, or subtracts from, **both** arterial and venous pressure
  - Distance between Apex and Base affected by gravity

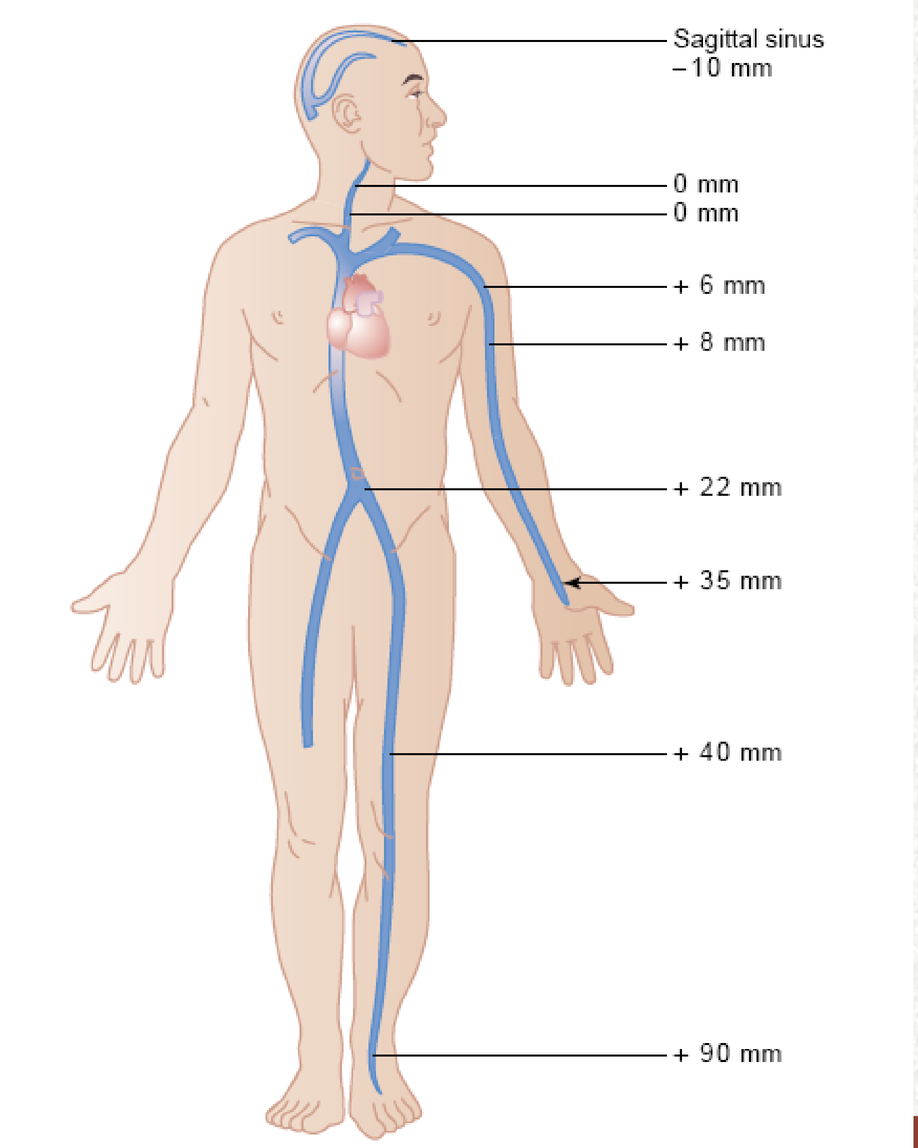
Systemic

Aorta	100 mmHg
Head	50 mmHg
Feet	180 mmHg

Pulmonary

Mean PA	**15 mmHg**
Apex	**2 mmHg**
Base	**25 mmHg**

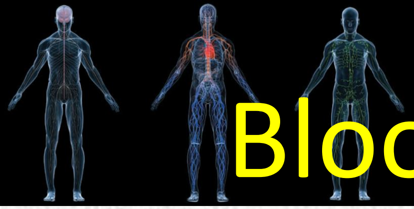
Effect of hydrostatic pressure on venous pressure in the standing position



Difference between pulmonary capillary & that of systemic

:
*

	Pulmonary capillary	Systemic capillary
Pc	10 mm Hg	17 mm Hg
Πc	28 mmHg	28 mmHg
Pi	- 5 mmHg	Zero
Πi	14 mmHg*	7 mmHg



Blood Flow to Different Organs

Tissue	Blood flow (ml/g/min)	A-V O_2] difference (Vol %)	Flow ml/min	O_2 consumption ml/min
Heart	0.8	11	250	27
Brain	0.5	6.2 (25-30% Extraction)	750-900	
Skeletal Muscle	0.03	6	1200	70
Liver	0.6	3.4 Reconditioner organ		
SKIN	0.1			
Kidney	4.2	1.4 Reconditioner organ	1250	18
Carotid bodies	20	0.5 Reconditioner organ	0.6	

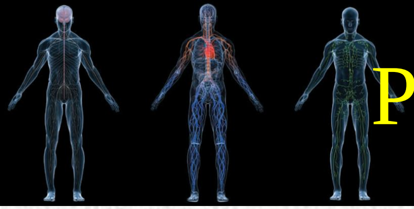
The composition of alveolar air reflects the harmony by which respiratory & cardiovascular systems are working: Ventilation: Perfusion Ratio (V/Q).

Pressure in the different areas of the lungs

- At the top, 15 mm Hg less than the pulmonary arterial pressure at the level of the heart
- At the bottom, 8 mm Hg greater than the pulmonary arterial pressure at the level of the heart.
- 23 mm Hg pressure difference between the top and the bottom of the lung
- These differences have effects on blood flow through the different areas of the lungs.

PULMONARY RESISTANCE TO FLOW

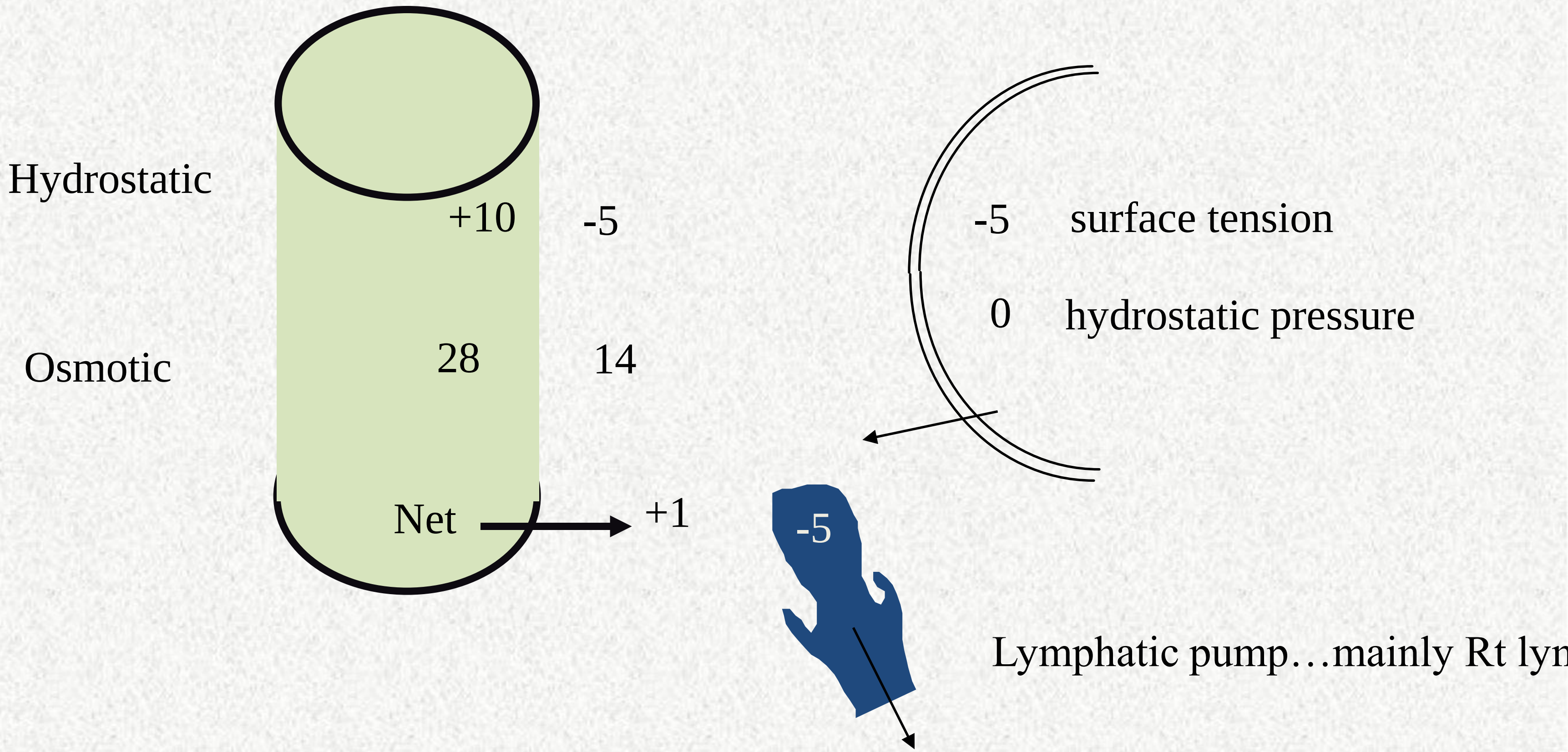
- Pressure drop of 12 mmHg $(P_m - P_{RA})$
- Flow of 5 l/min
- Resistance 1/7 systemic circulation



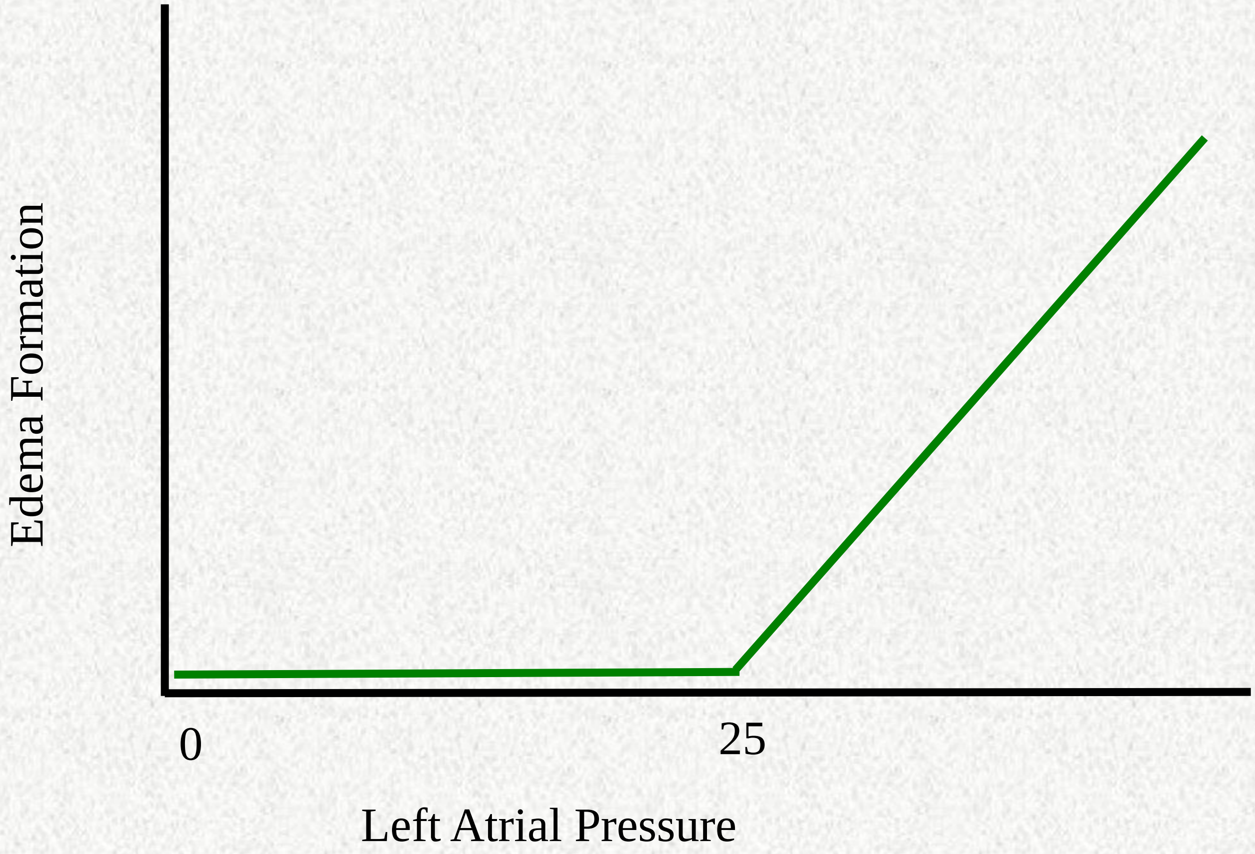
Pulmonary Capillary Dynamics

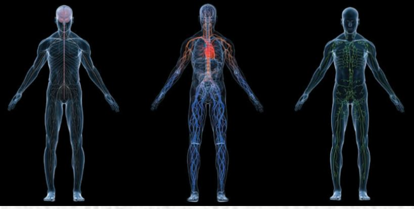
- **Outward Forces**
  - Pulmonary capillary pressure 10 mmHg
  - Interstitial colloid osmotic pressure 14 mmHg
  - Negative interstitial pressure 5 mmHg
  - **Total 29 mmHg**
- **Inward Forces**
  - Plasma osmotic pressure 28 mmHg
- **Net filtration pressure 1 mmHg**
- **Lymphatic vessels take care of this extra filtrate**
- There is plenty lymphatics which empty in the right lymphatic duct to prevent the occurrence of pulmonary edema. The left apex empties in the thoracic duct.

Pulmonary Capillary Dynamics

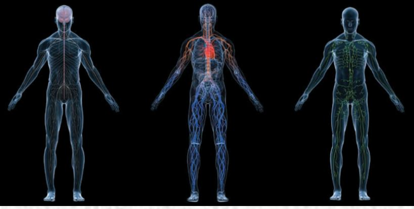


Heart Failure and Pulmonary Edema





The filtrate will be pumped by the highly effective lymphatic drainage. Actually, if, duo to Left heart failure the pulmonary **capillary P reaches 28 mmHg (equals blood colloid osmotic** pressure P) :(21 mm Hg above normal) pulmonary edema would not develop. (21 mm Hg is a safety factor). That is true in case of acute state, however, in chronic conditions (> 2 WKS) the lung become even more resistant to pulmonary edema and a capillary P **of 40-45 develop without significant pulmonary edema.**



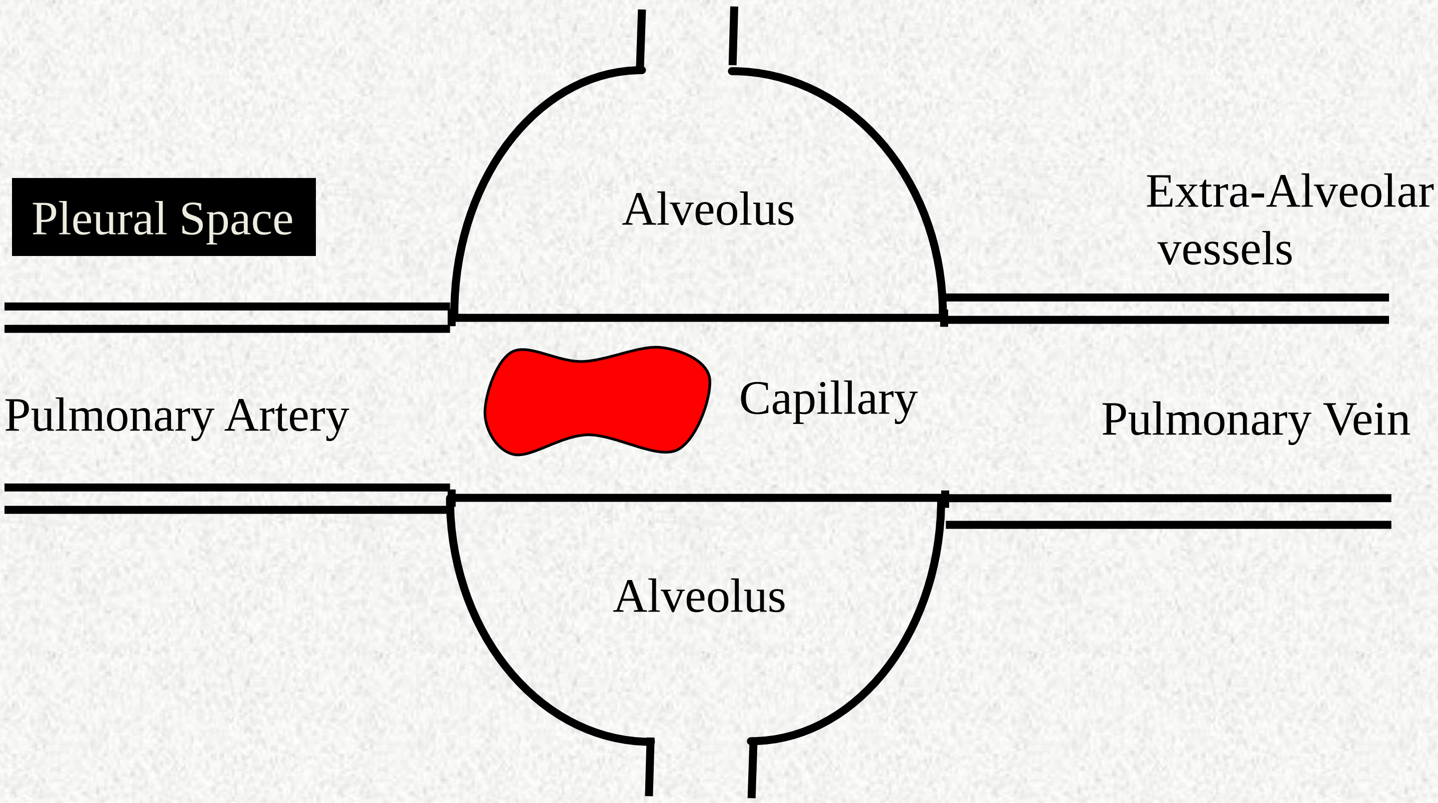
Pulmonary Edema

- Causes of pulmonary edema
  - left heart failure
  - damage to pulmonary membrane: infection or noxious gas such as , chlorine, sulfur dioxide
- Safety factor
  - negative interstitial pressure
  - lymphatic pumping

Three Zones of Pulmonary Blood Flow

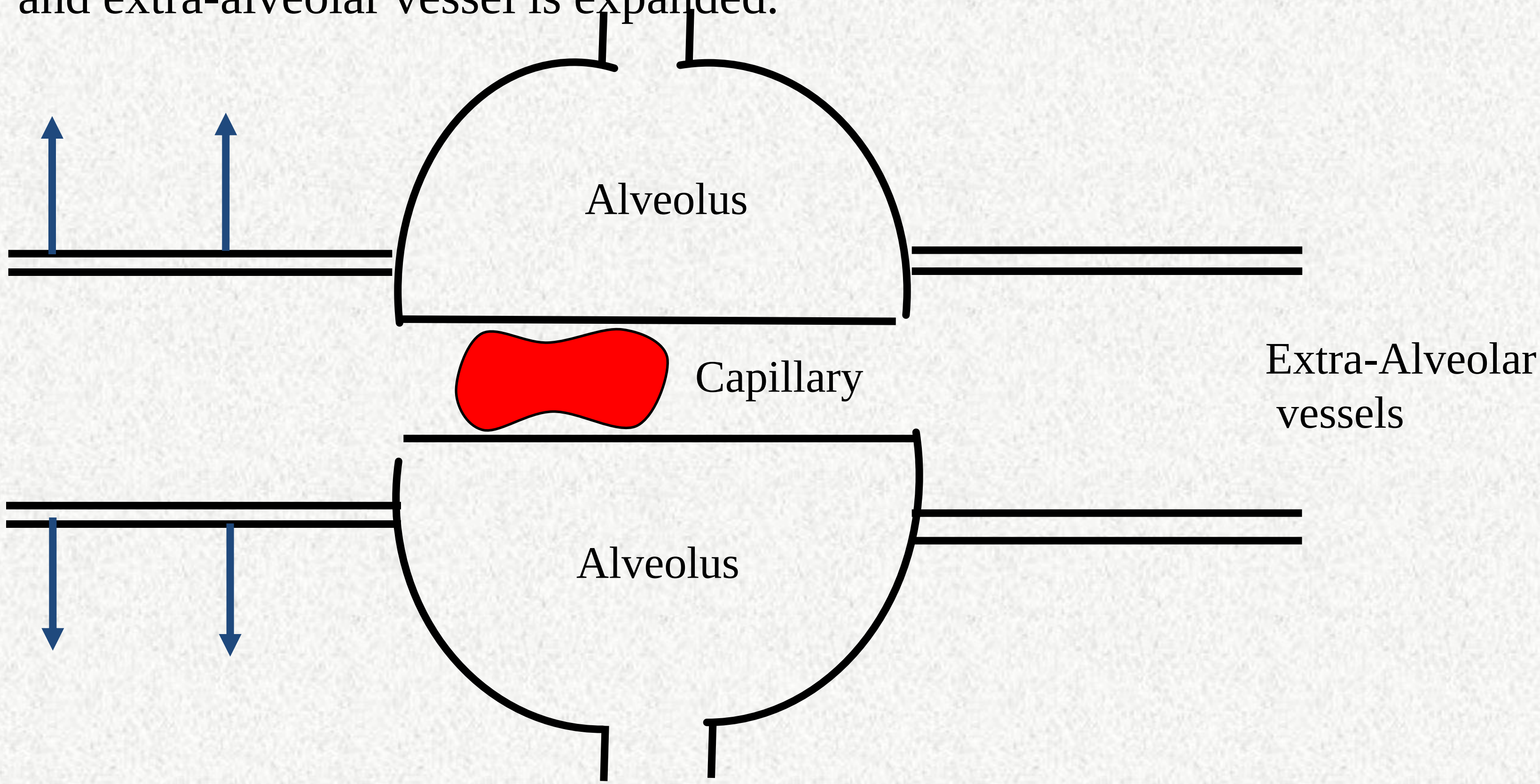
- The alveolar capillaries are distended by the blood pressure inside them and compressed by the alveolar air pressure on their outsides.
- If the alveolar air pressure (Palv) becomes greater than the pulmonary capillary blood pressure (Ppc), the capillaries will close and there is no blood flow.
- There are three possible *patterns* of blood flow (zones of pulmonary blood flow) under different normal and pathological lung conditions.

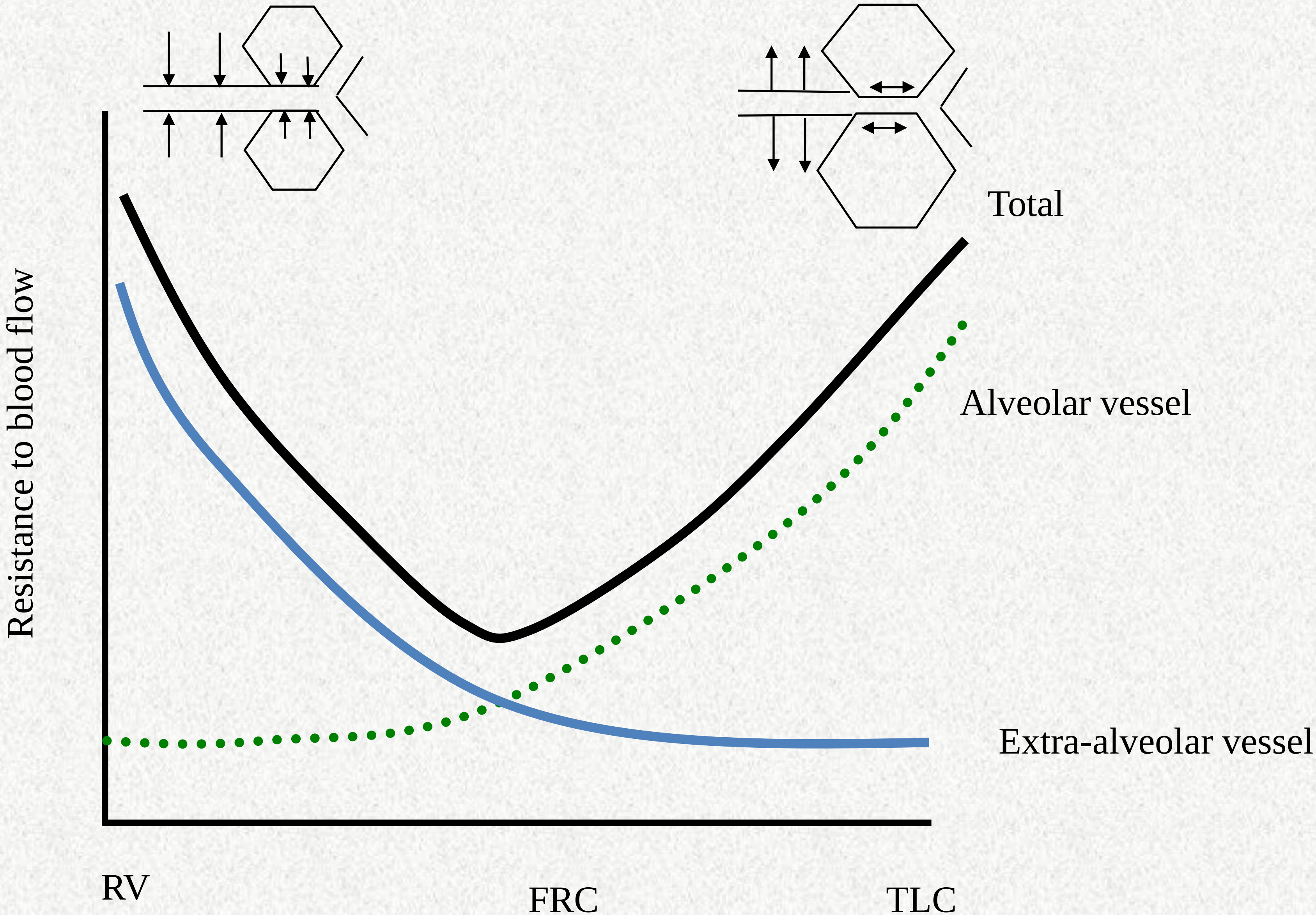
ALVEOLAR and "EXTRA-ALVEOLAR" VESSELS



ALVEOLAR and "EXTRA-ALVEOLAR" VESSELS

Pleural Pressure (-)….during inflation…alveolar capillary is compressed and extra-alveolar vessel is expanded.




Total
Alveolar vessel
Extra-alveolar vessel
Resistance to blood flow
RV
FRC
TLC

In Emphysema…FRC is more → which increase alveolar R and thus Total R
In pulmonary fibrosis where FRC is less →↑ extra-alveolar R and thus Total R

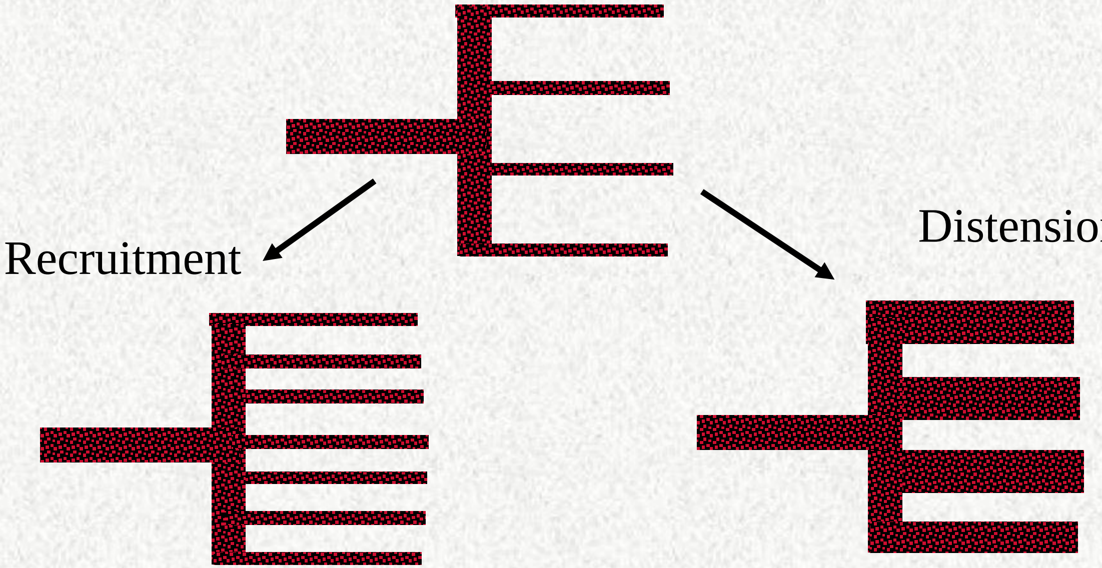
Recruitment and Distension increases Pulmonary blood flow

Pulmonary blood vessels are much more compliant than systemic blood vessels. Also the system has a remarkable ability to promote a decrease in resistance as the blood pressure rises.

***This achieved by two mechanisms*:**

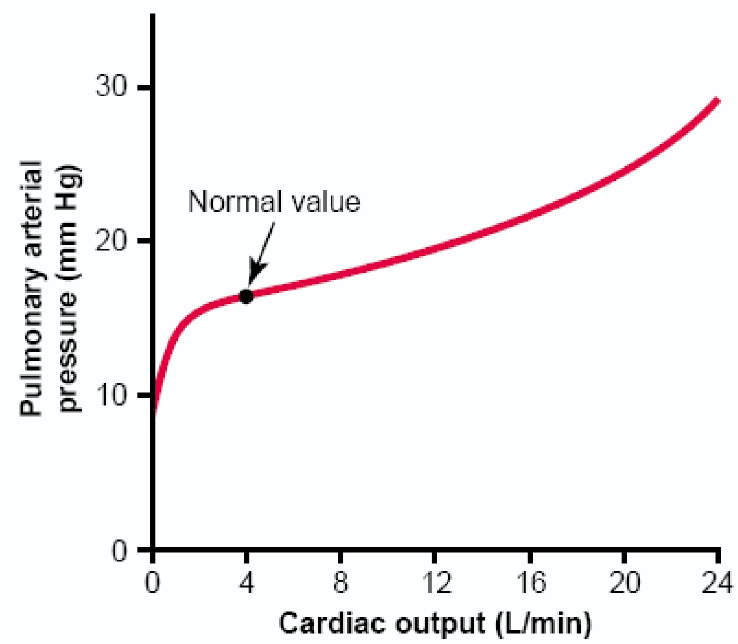
Recruitment: by increasing the number of open capillaries

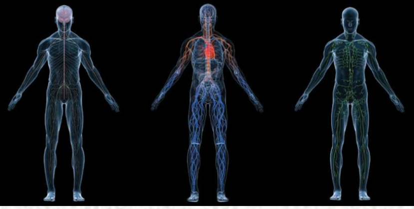
Distension: by distending all the capillaries and increasing the rate of flow



Effect of Increased Cardiac Output on Pulmonary Blood Flow and Pulmonary Arterial Pressure During Heavy Exercise

Recruitment and Distension decrease pulmonary vascular resistance, so that the pulmonary arterial pressure rises very little even during maximum exercise. During Exercise, Q might increase 5 times but still Pm increase slightly because of the decrease in pulmonary vascular resistance.





PULMONARY BLOOD FLOW

- Blood Volume…the numbers were given to you in the first lecture Wednesday…do you remember?
  - Approximately 450 ml
  - 190 ml in the arterial part
  - 190 ml in the venous part
  - 70 ml inside the capillaries
  - Some of this blood Can shift to systemic circulation

MEASUREMENT OF PULMONARY BLOOD FLOW

Fick Principle for cardiac output estimation…this slide and the next slide was discussed in the cardiovascular system module…”**cardiac output estimation**”… we don’t need to discuss this slide and the next one in the respiratory module

$$V_{O_2} = Q(Ca_{O_2} - Cv_{O_2})$$

V_{O_2} = Oxygen Consumption

Ca_{O_2} = Arterial Content

Q = Blood flow

Cv_{O_2} = Venous Content

MEASUREMENT OF PULMONARY BLOOD FLOW

$V_{O_2} = Q(Ca_{O_2} - Cv_{O_2})$

Ca_{O_2} = 20 ml O_2/100 ml blood

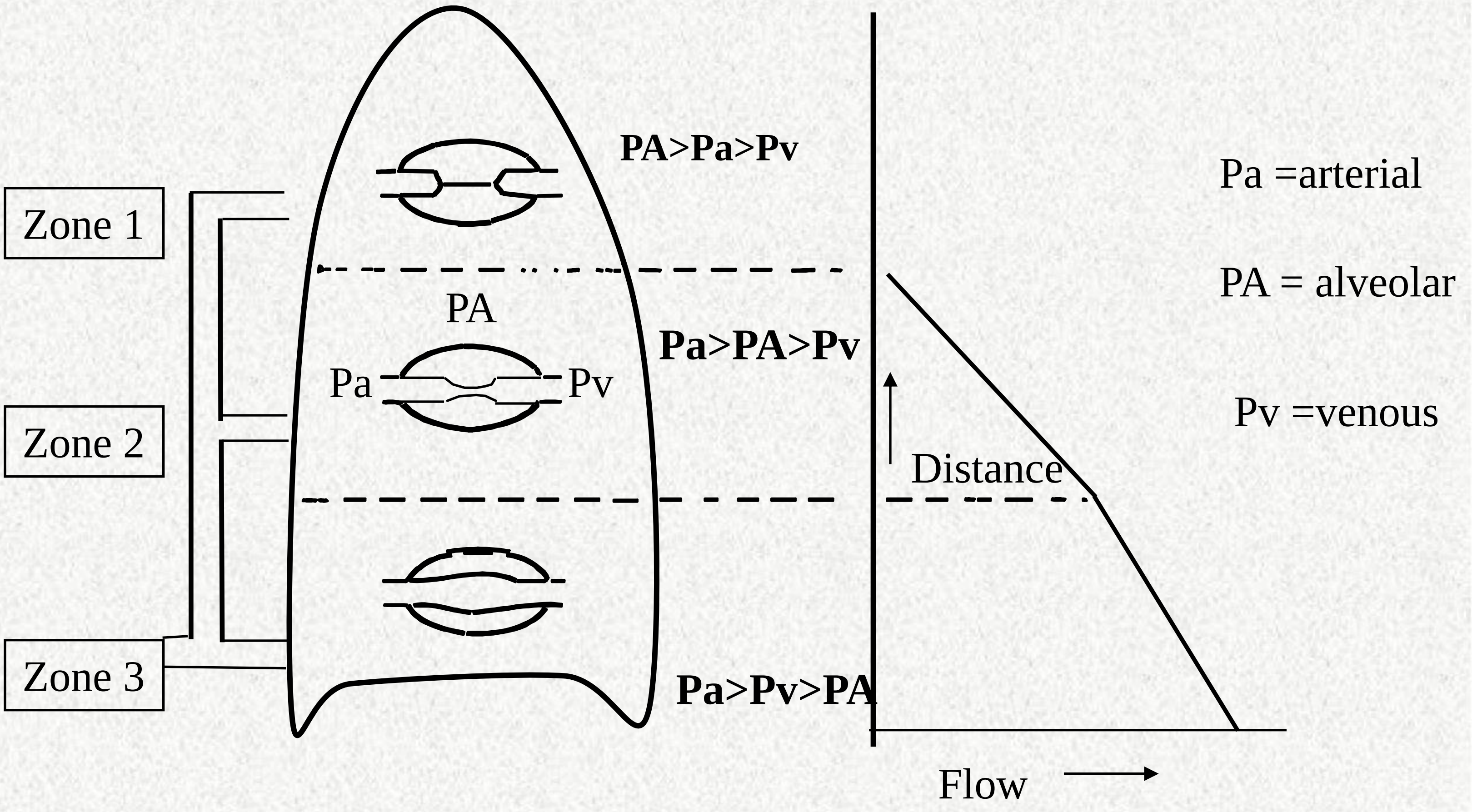
V_{O_2} = 250 ml/min

Cv_{O_2} = 15 ml O_2/100 ml blood

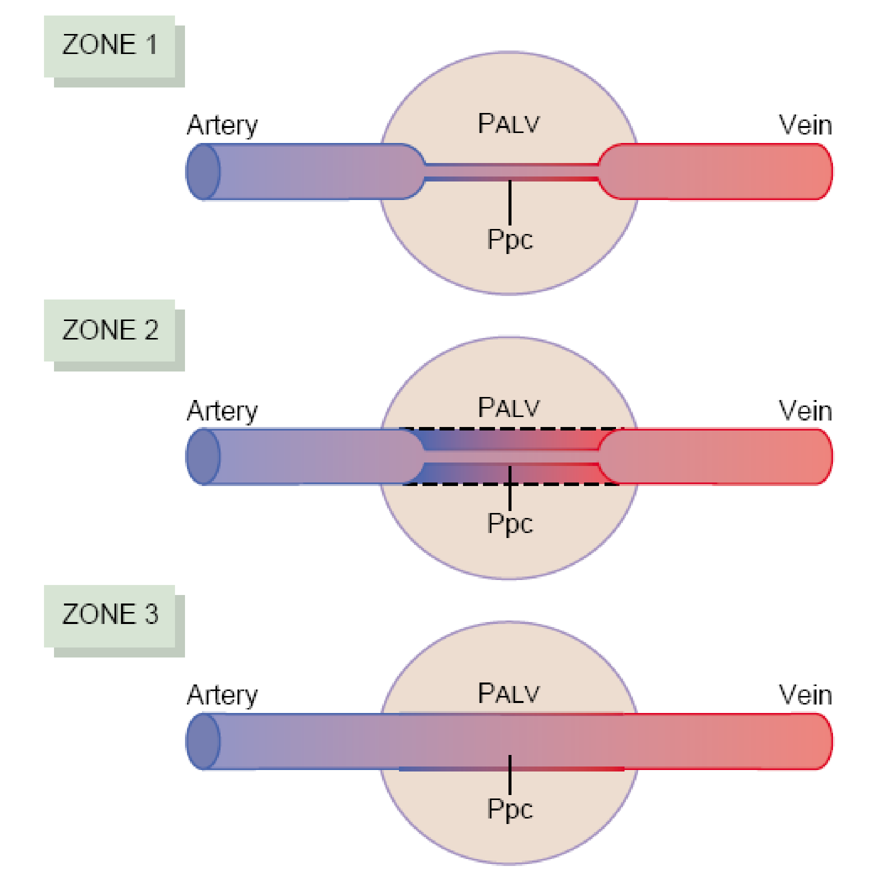
$$Q = \frac{250 \text{ ml } O_2/\text{min}}{(20-15) \text{ ml } O_2/100 \text{ ml blood}} = \frac{250 \text{ ml } O_2}{\text{min}} * \frac{100 \text{ ml blood}}{5 \text{ ml } O_2}$$

Q = 5000 ml blood /min

Hydrostatic Effects on Blood Flow



Zones of Pulmonary Blood Flow



- *Zone 1:*
- ✓ ***no flow***
- ✓ alveolar air pressure (Palv) is higher than pulmonary arterial pressure (Ppc) during any part of cardiac cycle…This zone does not exist in human lung.
- *Zone 2:*
- ✓ ***intermittent flow***
- ✓ systolic arterial pressure higher than alveolar air pressure, but diastolic arterial pressure below alveolar air pressure.
- *Zone 3:*
- ✓ ***continuous flow***
- ✓ pulmonary arterial pressure (Ppc) remain higher than alveolar air pressure at all times.

Lung diseases can be classified physiologically as **<u>shunt-producing</u>** (V/Q less than 0.8) or **<u>dead-space- producing</u>** (V/Q greater than 0.8) diseases.

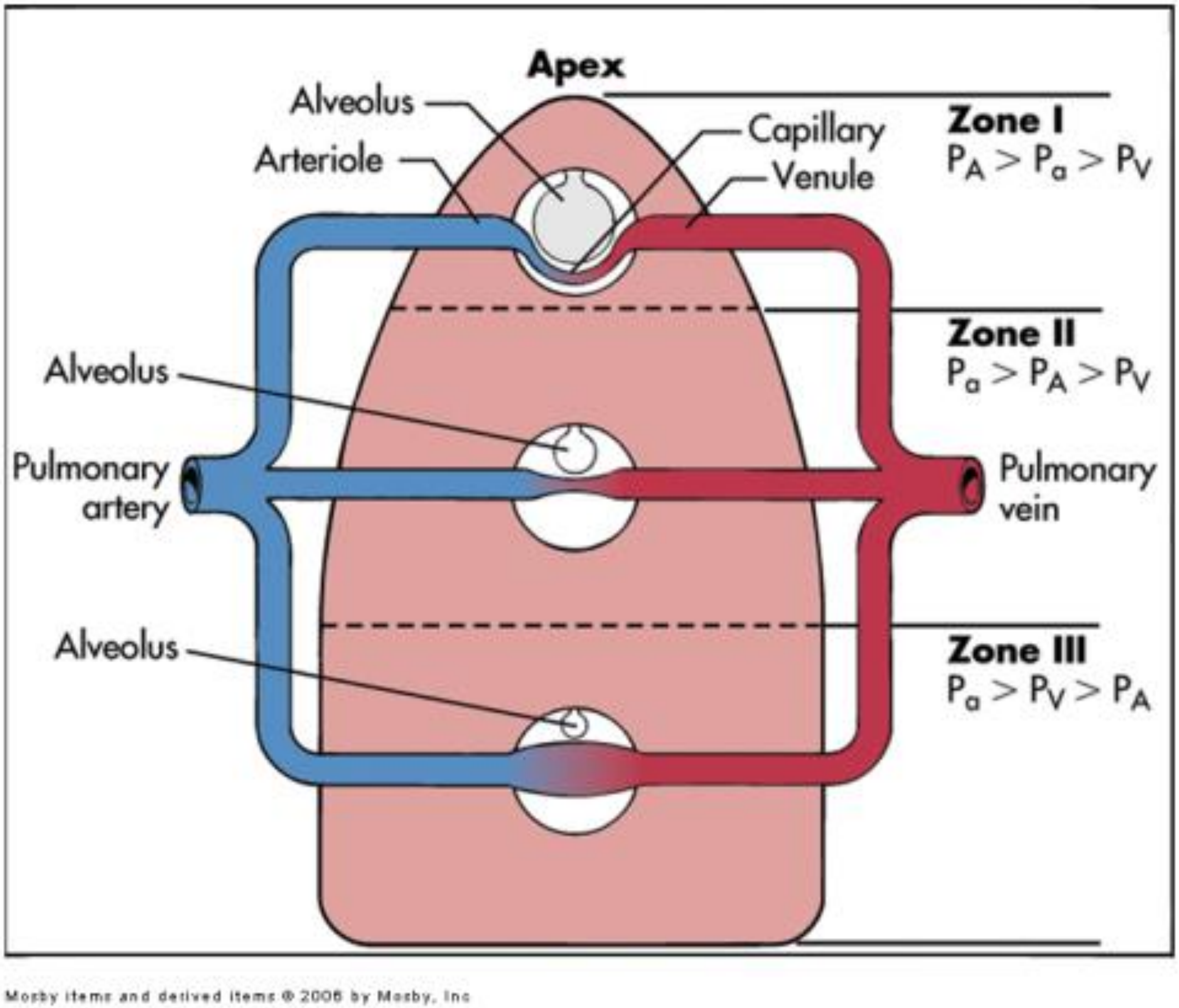
<u>Fortunately,the</u> apical regions are not as quantitatively important as other regions in the lung because their small size and their immobility.

Zone 1: No blood flow during systole and during diastole. The pressure in the artery is somehow less than enough to push any blood to the capillaries. Thus the capillary pressure remains negative or less than the zero alveolar pressure. This zone does not exist in human lung. In bleeding we may have this zone. A second case is when breathing against positive intra-alveolar pressure ”PEEP” we may obstruct blood flow to certain areas of the lung.

Zone 2: Intermittent blood flow. There is blood flow during systole only. This zone exists in human lung at the apex in the upright position. When a person lies down all lung become zone 3.

Zone 3: Continuous blood flow. There is blood flow during systole and during diastole. During exercise all lung become zone 3 even the apex.

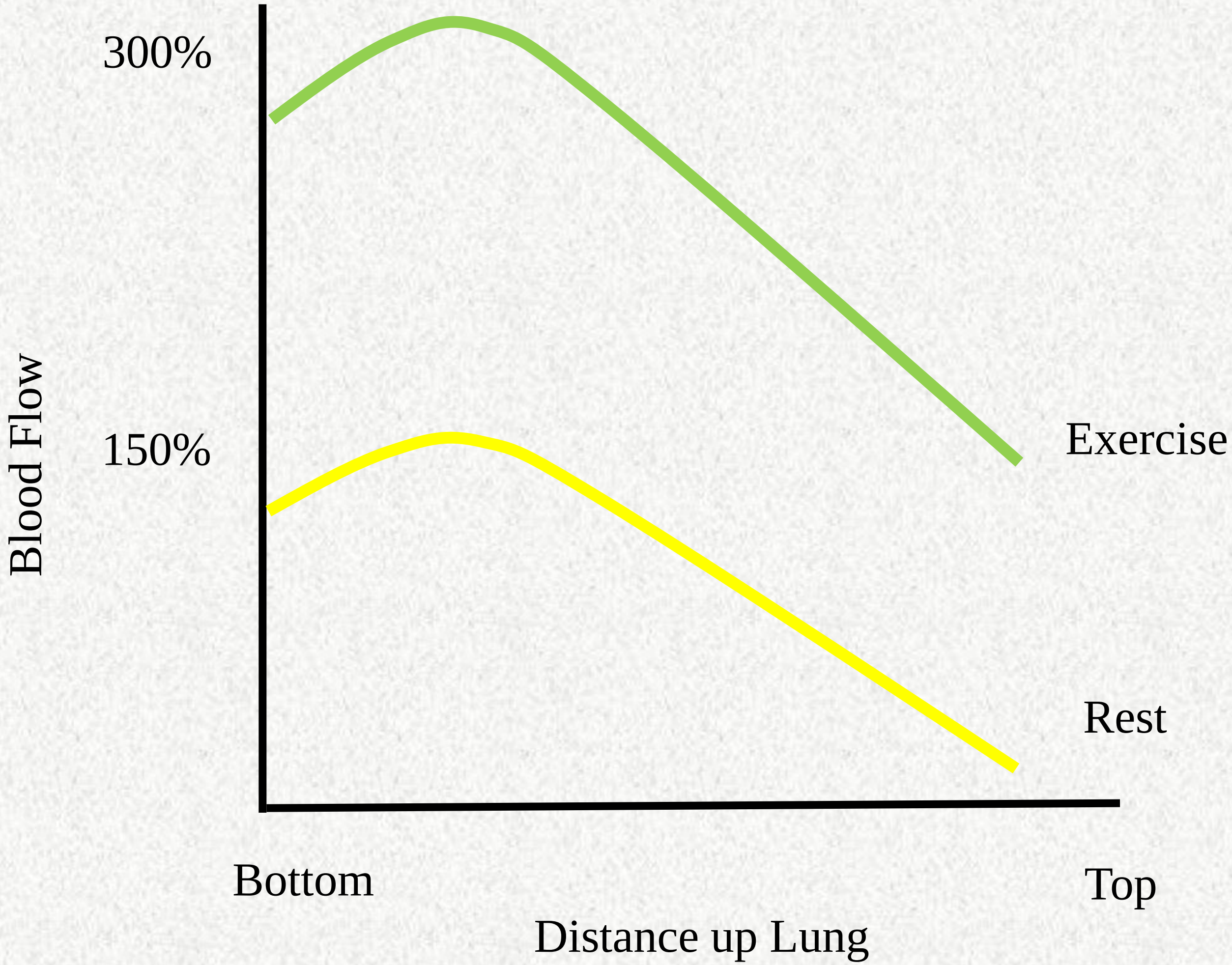
Zones of Pulmonary Blood Flow

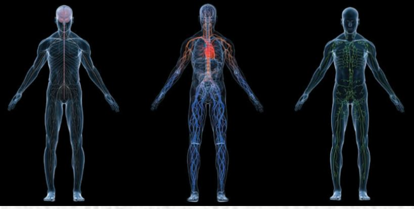


Zones of a normal lung

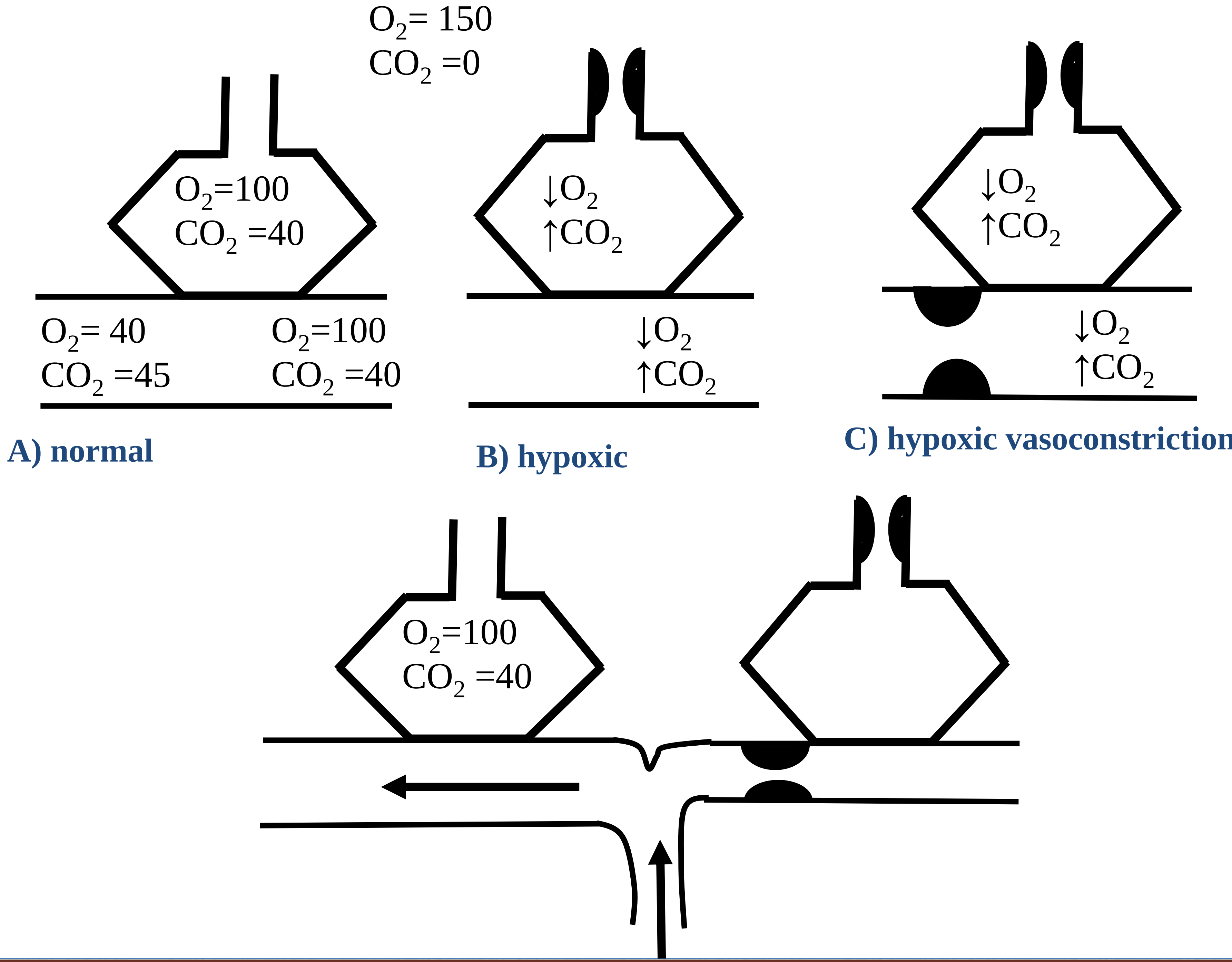
- Normally, the lungs have 2 zones for blood flow
  - zone 2 (intermittent flow) at the apices.
  - zone 3 (continuous flow) in all the lower areas.
- In normal lungs, Zone 2 begins 10 cm above the mid-level of the heart to the top of the lungs.

DISTRIBUTION OF BLOOD FLOW





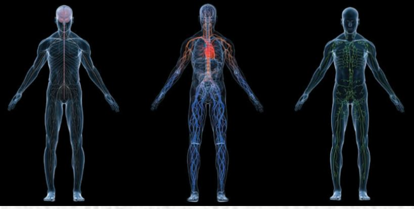
The blood flow in the apex increases 700-800% while in the base only 200-300%.



O_2= 150
CO_2 =0
O_2=100
CO_2 =40
O_2= 40
CO_2 =45
O_2=100
CO_2 =40
A) normal
↓O_2
↑CO_2
↓O_2
↑CO_2
B) hypoxic
↓O_2
↑CO_2
↓O_2
↑CO_2
C) hypoxic vasoconstriction
O_2=100
CO_2 =40

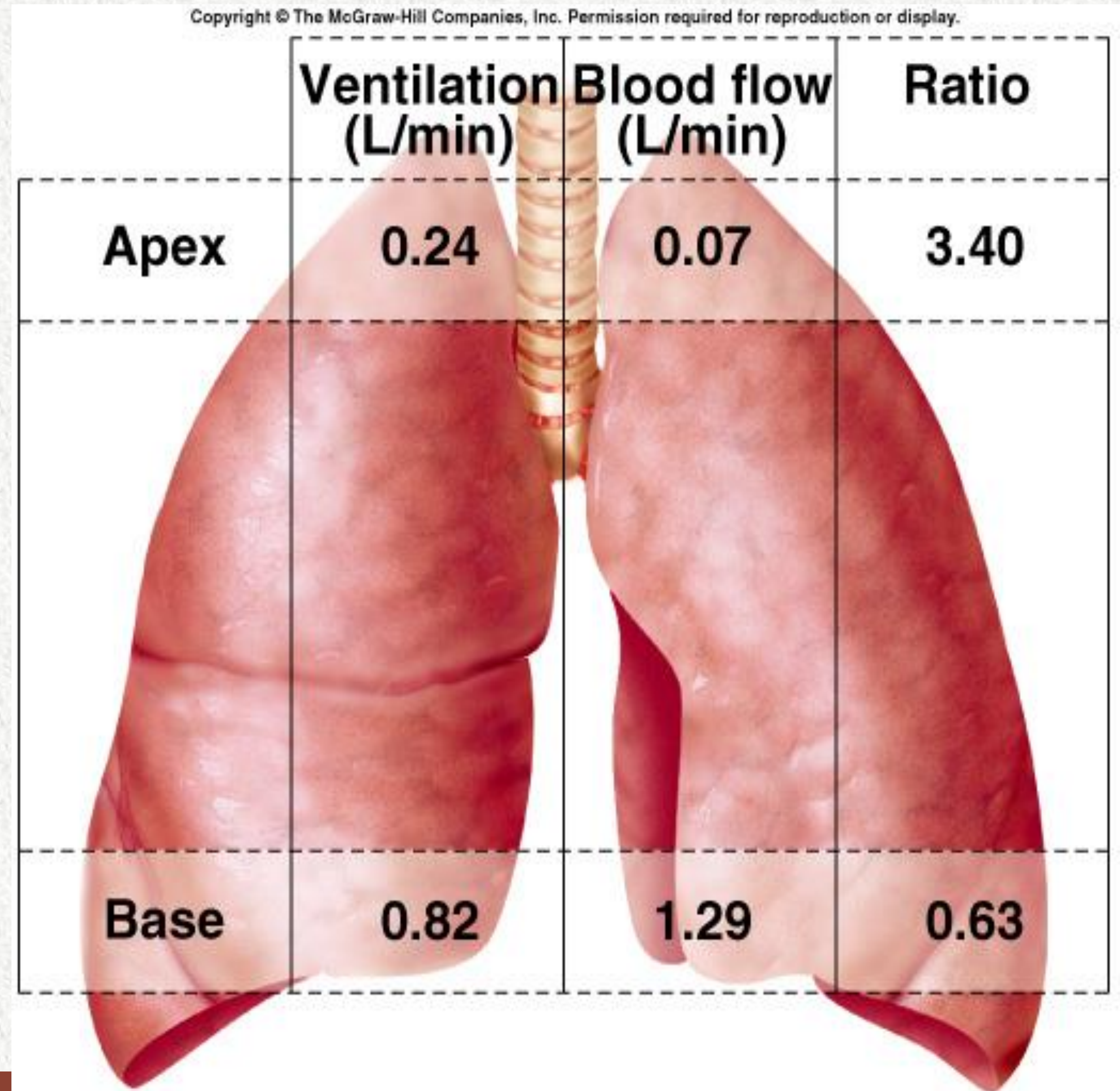
Pulmonary Circulation

- Rate of blood flow through the pulmonary circulation is = rate of flow through the systemic circulation.
  - Driving pressure in pulmonary circulation is only 10 mm Hg.
- Pulmonary vascular resistance is low.
  - Low pressure pathway produces less net filtration than produced in the systemic capillaries.
    - Avoids pulmonary edema.
- Autoregulation:
  - Pulmonary arterioles constrict when alveolar PO_2 decreases.
  - Matches ventilation/perfusion ratio.

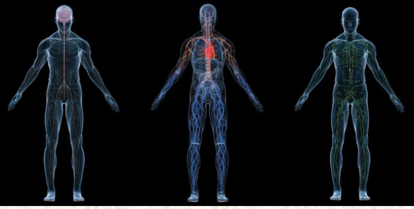


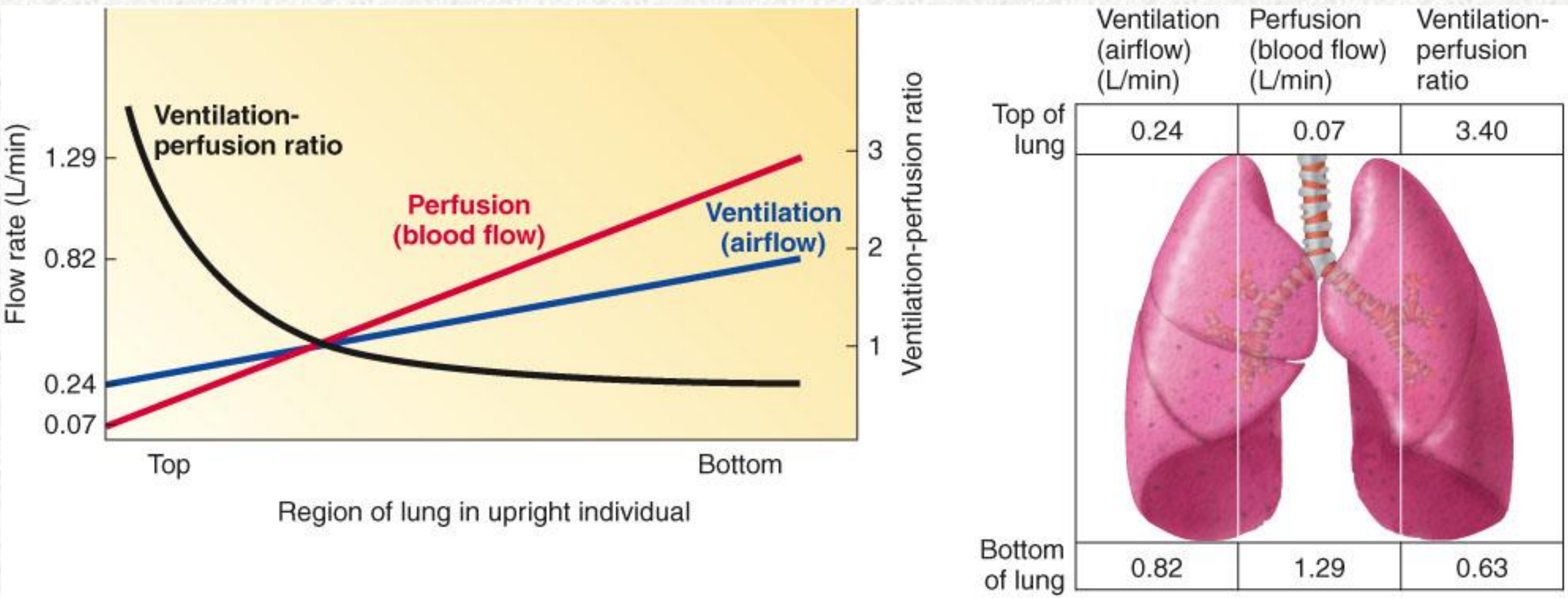
Lung Ventilation/Perfusion Ratios

- Functionally:
  - Alveoli at apex are underperfused (overventilated).
  - Alveoli at the base are underventilated (overperfused).



	Ventilation (L/min)	Blood flow (L/min)	Ratio
Apex	0.24	0.07	3.40
Base	0.82	1.29	0.63





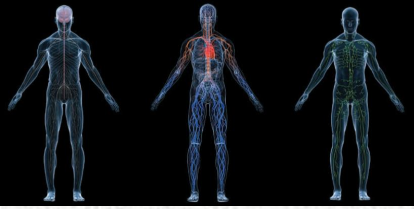
(a) Regional ventilation and perfusion rates and ventilation-perfusion ratios in the lungs

(b) Ventilation and perfusion rates and ventilation-perfusion ratios at top and bottom of lungs

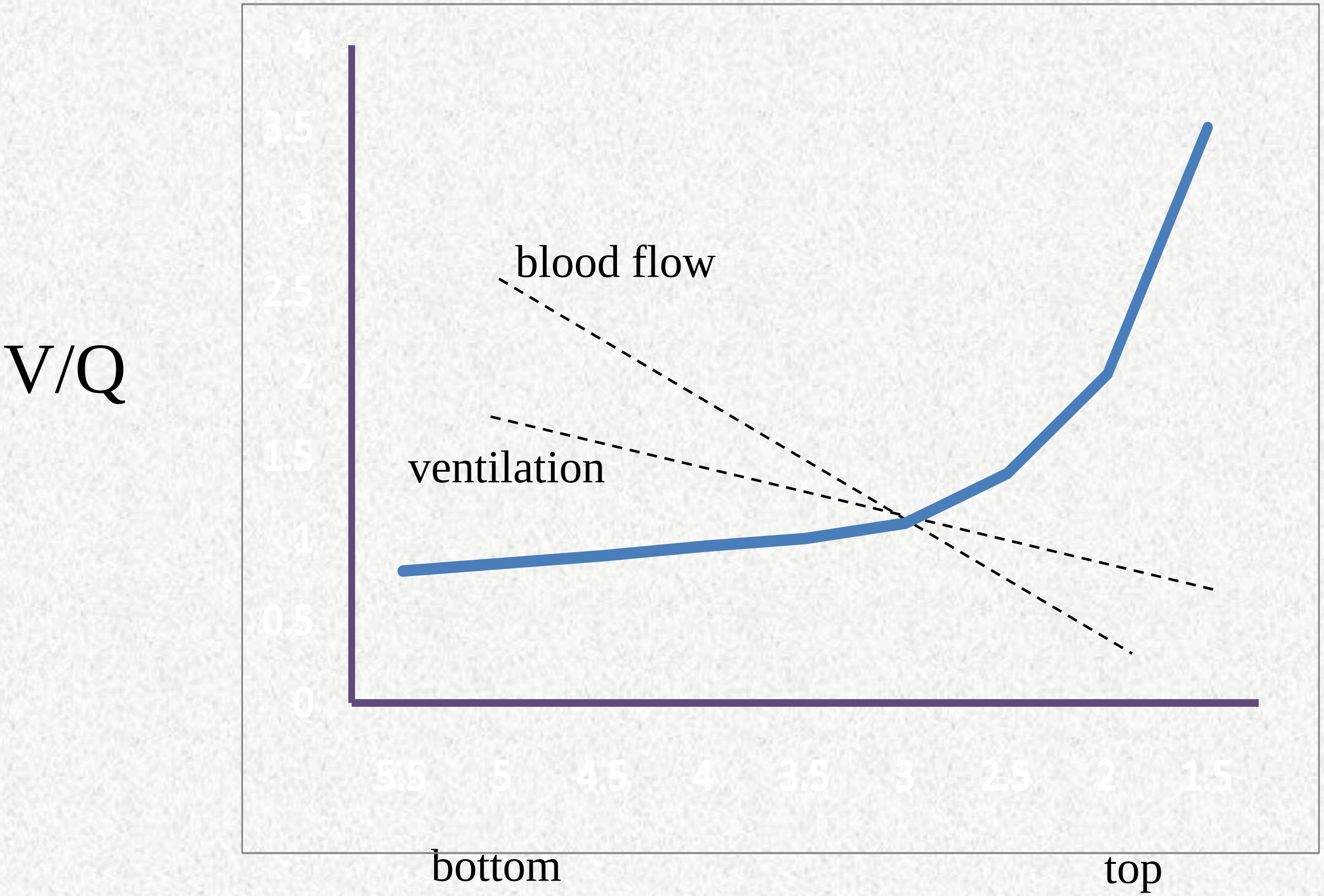
Fig. 13-24, p. 485

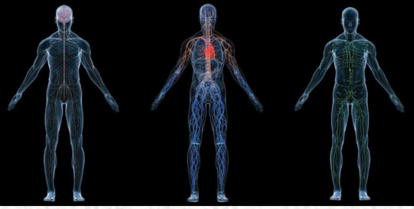
Figure 13.24: Differences in ventilation, perfusion, and ventilation-perfusion ratios at the top and bottom of the lungs as a result of gravitational effects.

Note that the top of the lungs receives less air and blood than the bottom of the lungs, but the top of the lungs receives relatively more air than blood and the bottom of the lungs receives relatively less air than blood.



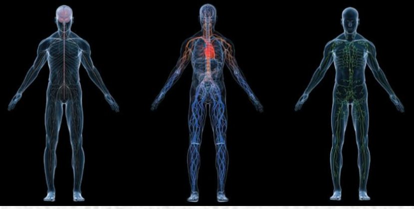
Regional V/Q Ratio





V/Q Ratio

- V/Q is ↑ in:
- 1. pulmonary embolism.
- 2. emphysema.
- 3. cigarette smokers.
- 4. pulmonary hyperventilation
- Whenever V/Q ↑
- 1. alveolar dead space ↑.
- 2. mixed expired P_ECO_2 ↓.
- 3. mixed expired P_EO_2 ↑.



Question

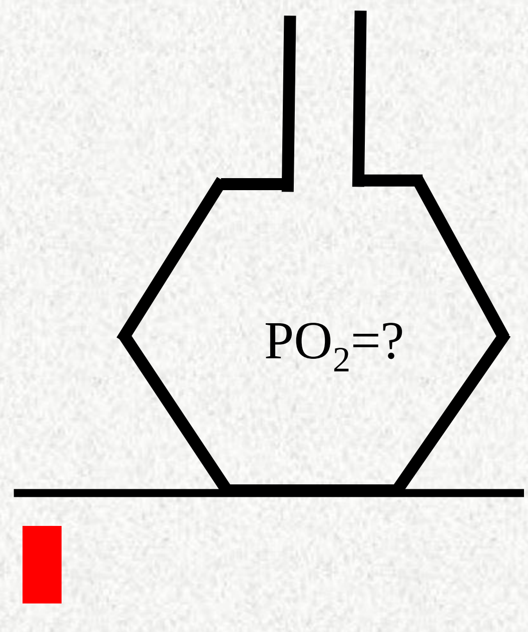
An alveoli that has normal ventilation and no blood flow (V/Q=0) has an alveolar PO_2 of

A. 40 mmHg

B. 100 mmHg

C. 149 mmHg

D. 159 mmHg



Ventilation/perfusion

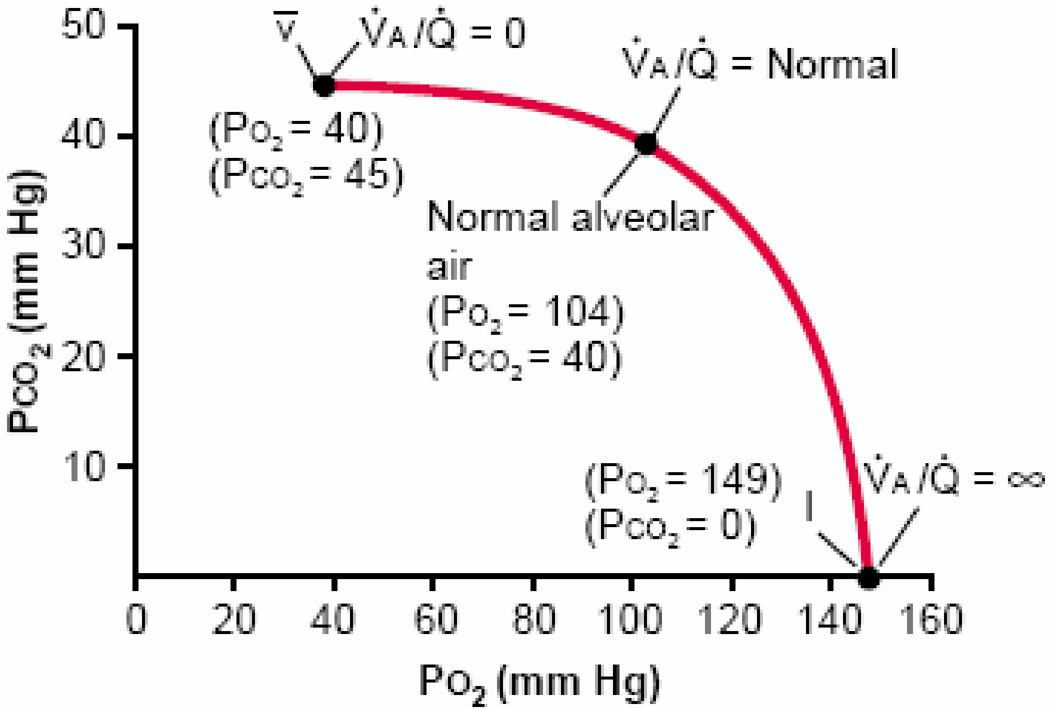
- Relationship between adequate flow and adequate ventilation is the V/Q ratio
- V/Q = (4.2 l/min)/ (5 l/min) = 0.84
- If there is no diffusion impairment then the PO_2 and PCO_2 between an alveolus and end capillary blood are usually the same. $P_AO_2-P_aO_2 \approx$ zero

Ventilation/Perfusion Ratios

- The ratio of alveolar ventilation to pulmonary blood flow = **0.84** (4.2 L/min ÷ 5 L/min).

- When the ventilation (V) is zero, but there is adequate perfusion (Q) of the alveolus, the V/Q is **zero.**
- when there is adequate ventilation, but zero perfusion, the ratio V/Q is **infinity.**
- At a ratio of either zero or infinity, there is no exchange of gases through the respiratory membrane of the affected alveoli

V/Q ratio

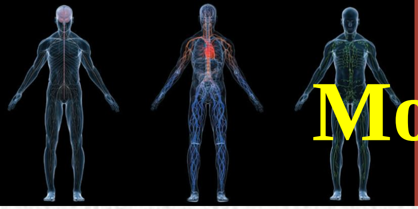


physiologic shunt:

The total amount of shunted blood per minute.

physiologic dead space:

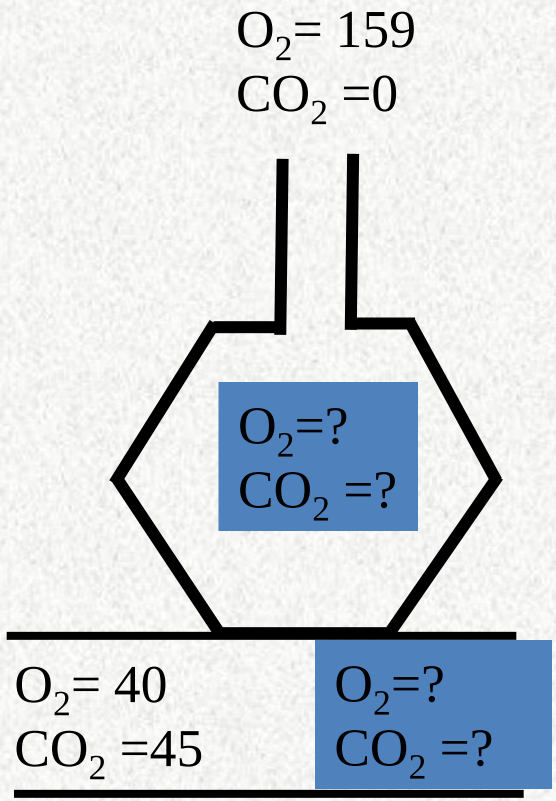
Alveolar + anatomical dead spaces



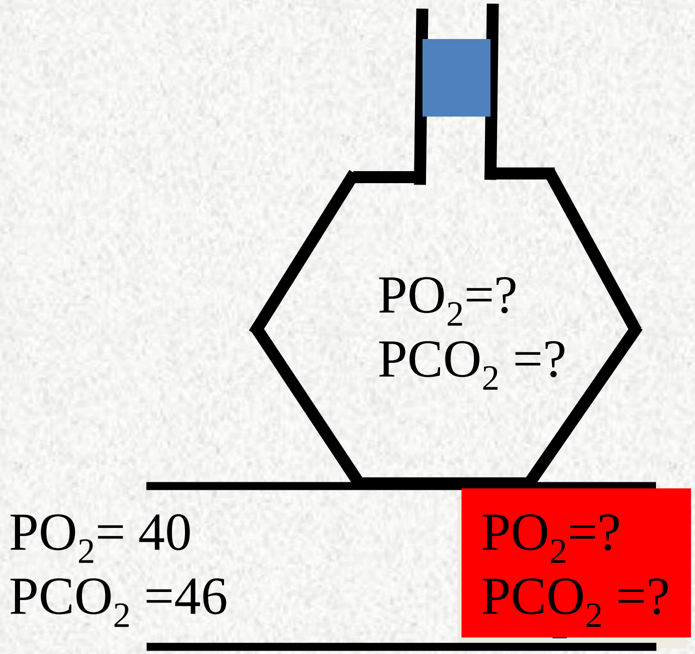
Movement of Air in and Out of Lungs

- Pleural Pressures
  - Resting -4 mmHg
  - Inspiration -6 mmHg
  - In the upright position at rest the basal intrapleural P is

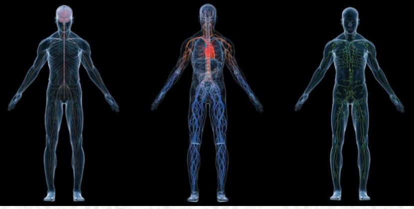
–2 mm Hg, while apical intrapleural P equals –7 mm Hg.

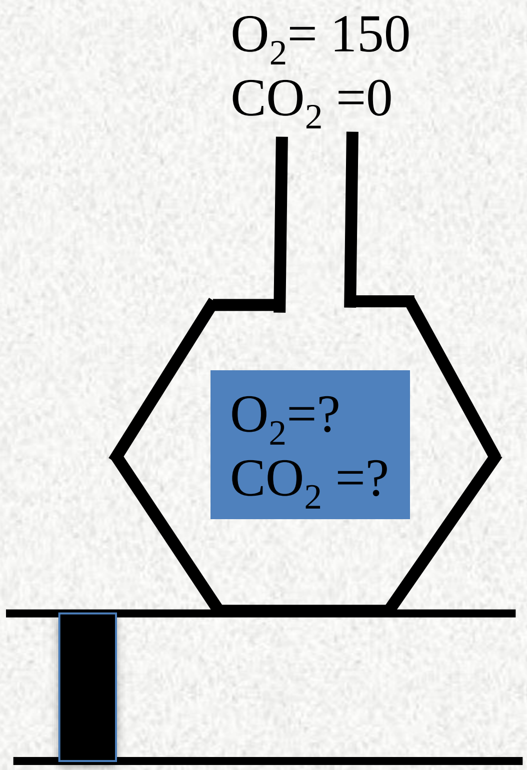


V/Q =0.8

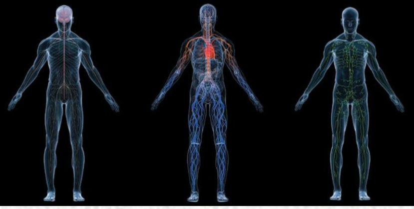


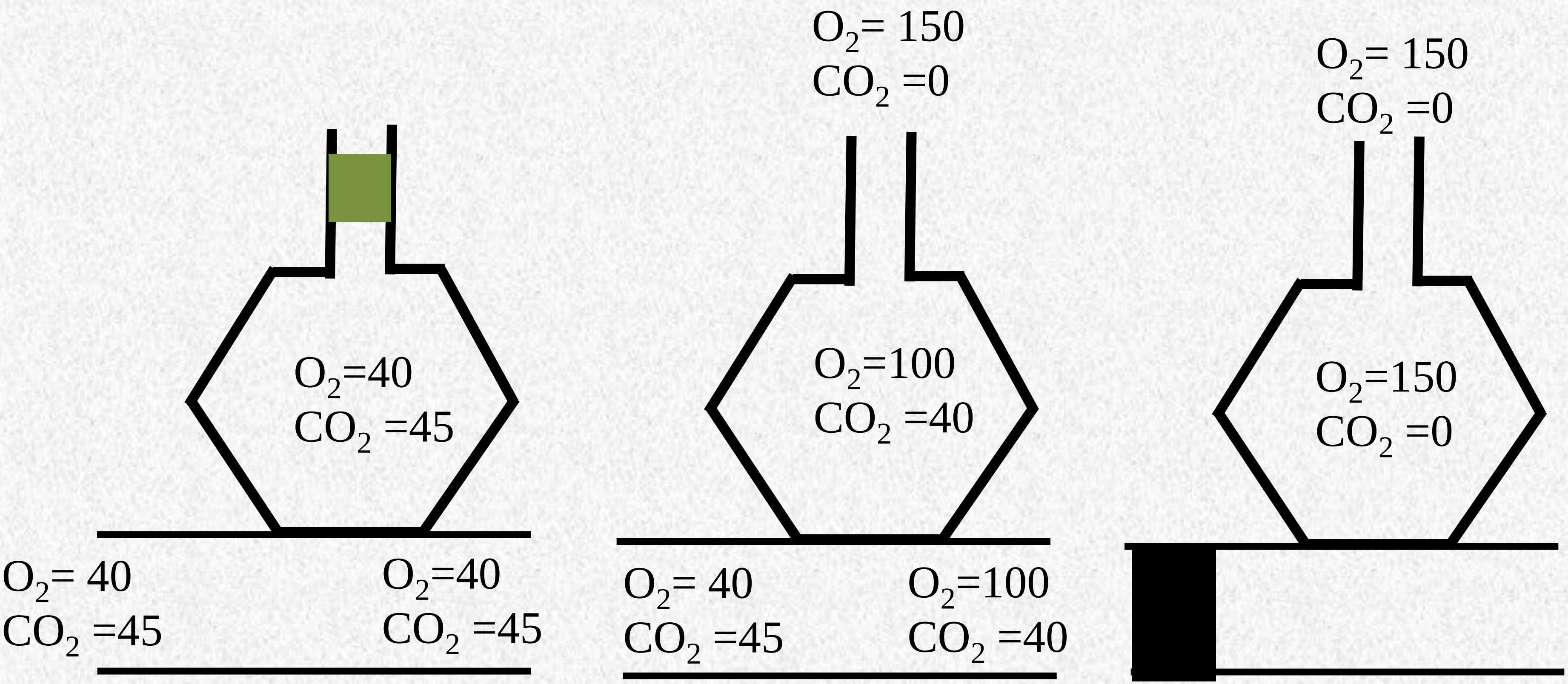
$V/Q = 0$





$$V/Q = \infty$$



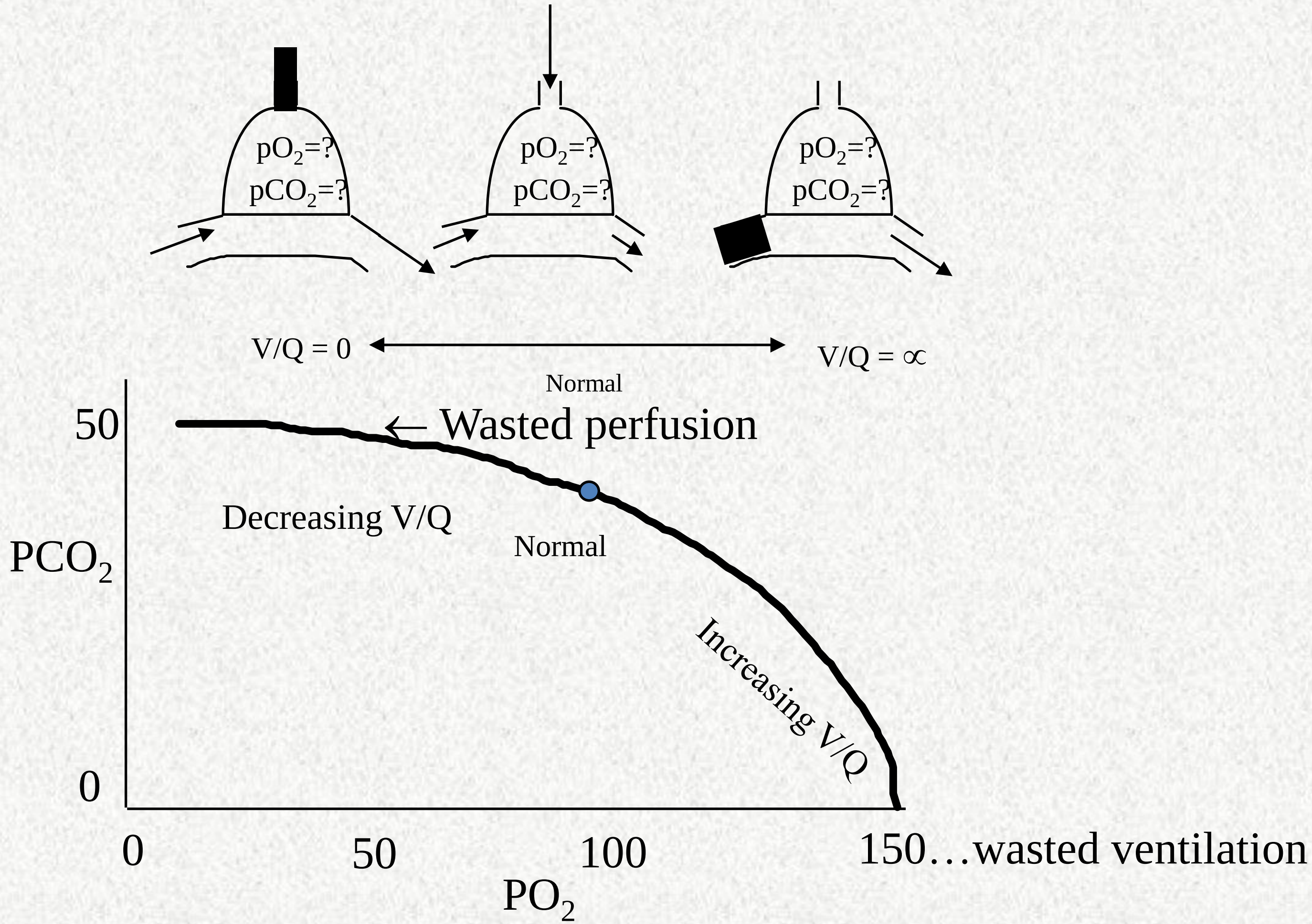


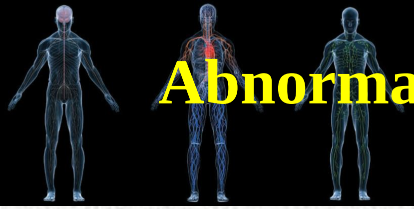
V/Q = 0

V/Q =normal

V/Q = ∞

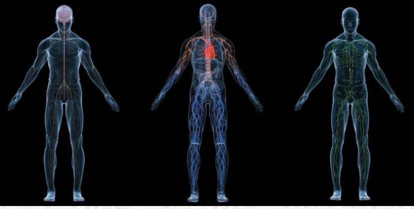
Ventilation/perfusion





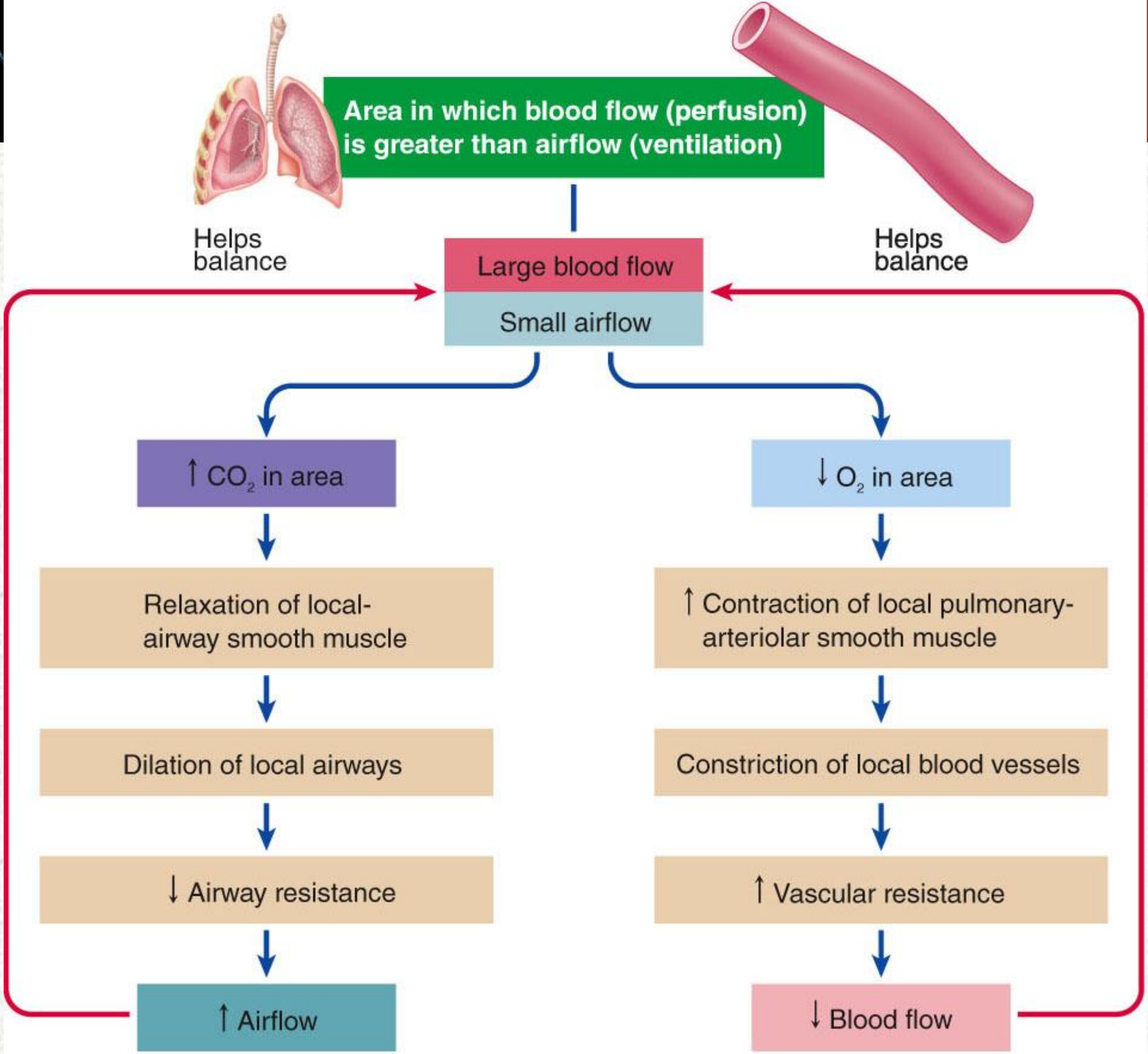
Abnormal VA/Q in the Upper and Lower Normal Lung.

- **Upper part of the lung**
  - Less blood flow and less ventilation; but blood flow is considerably less than ventilation.
  - Therefore, V/Q is 3.4 times higher than the normal value
  - This causes a moderate degree of *physiologic dead space*.
- **The bottom of the lung**
  - Slightly too little ventilation in relation to blood flow
  - Va/Q as low as 0.6 times the normal value.
  - A small fraction of the blood fails to become normally oxygenated, and this represents a *physiologic shunt*.
  - Assuming perfusion is adequate … hyperventilation makes alveolar air like atmospheric air …. Hypoventilation makes alveolar air like venous blood.



V/Q ratio

- Physiologic shunt
  - – V/Q ration is less than normal bcs of low ventilation
- Physiologic dead space…alveolar wasted volume
  - – V/Q > normal
- Abnormalities
  - – Upper lung V/Q =3
  - – Lower lung V/Q =0.5



(a) Local controls to adjust ventilation and perfusion to lung area with large blood flow and small airflow

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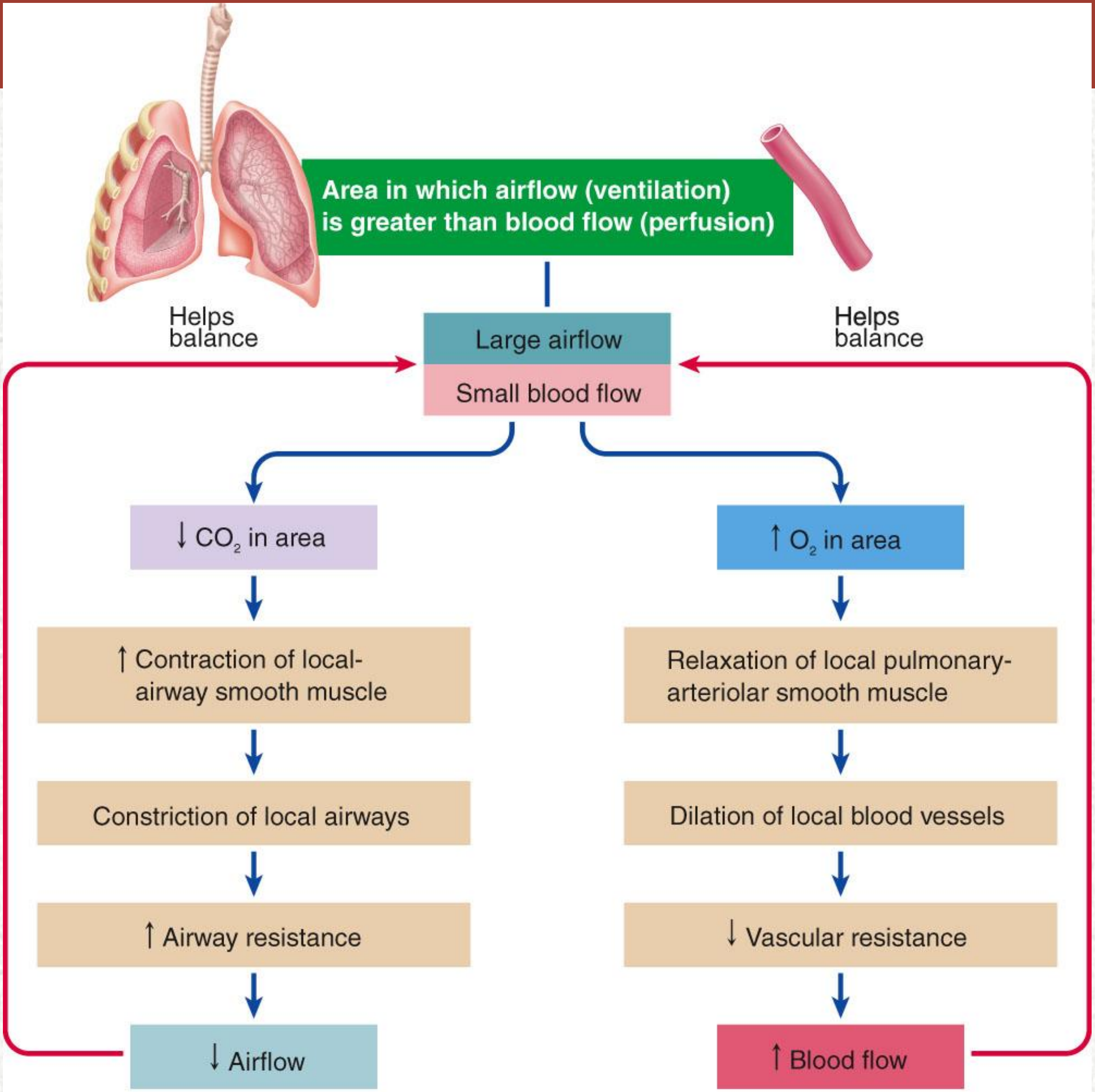
Figure 13.23: Local controls to match airflow and blood flow to an area of the lung.

CO_2 acts locally on bronchiolar smooth muscle and O_2 acts locally on arteriolar smooth muscle to adjust ventilation and perfusion, respectively, to match airflow and blood flow to an area of the lung

Figure 13.23: Local controls to match airflow and blood flow to an area of the lung. CO_2 acts locally on bronchiolar smooth muscle and O_2 acts locally on arteriolar smooth muscle to adjust ventilation and perfusion, respectively, to match airflow and blood flow to an area of the lung.



(b) Local controls to adjust ventilation and perfusion to a lung area with large airflow and small blood flow

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