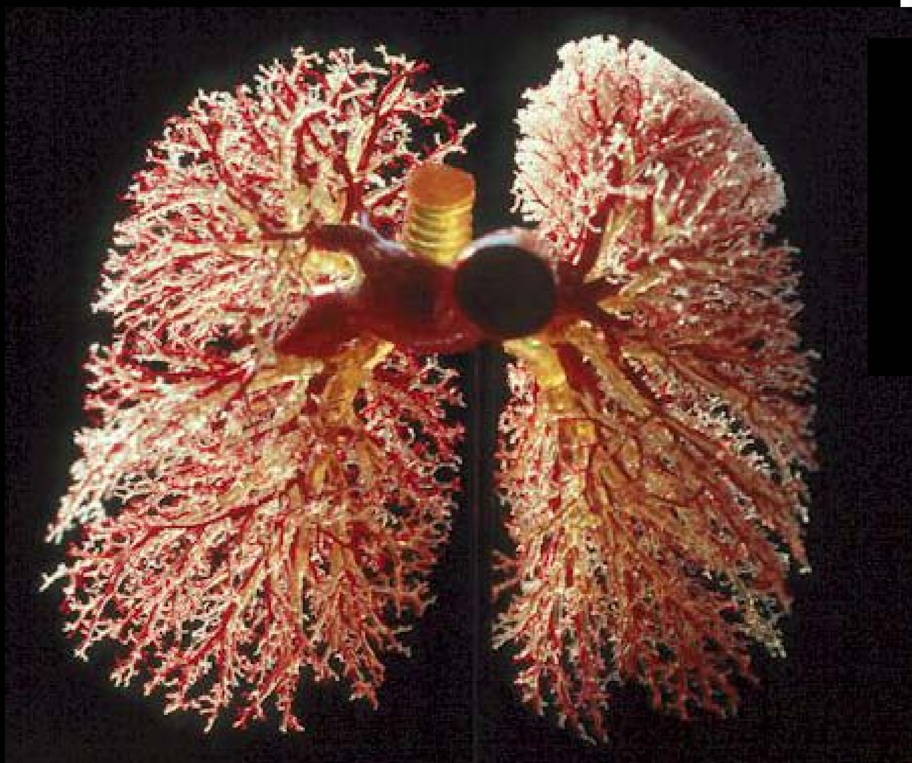
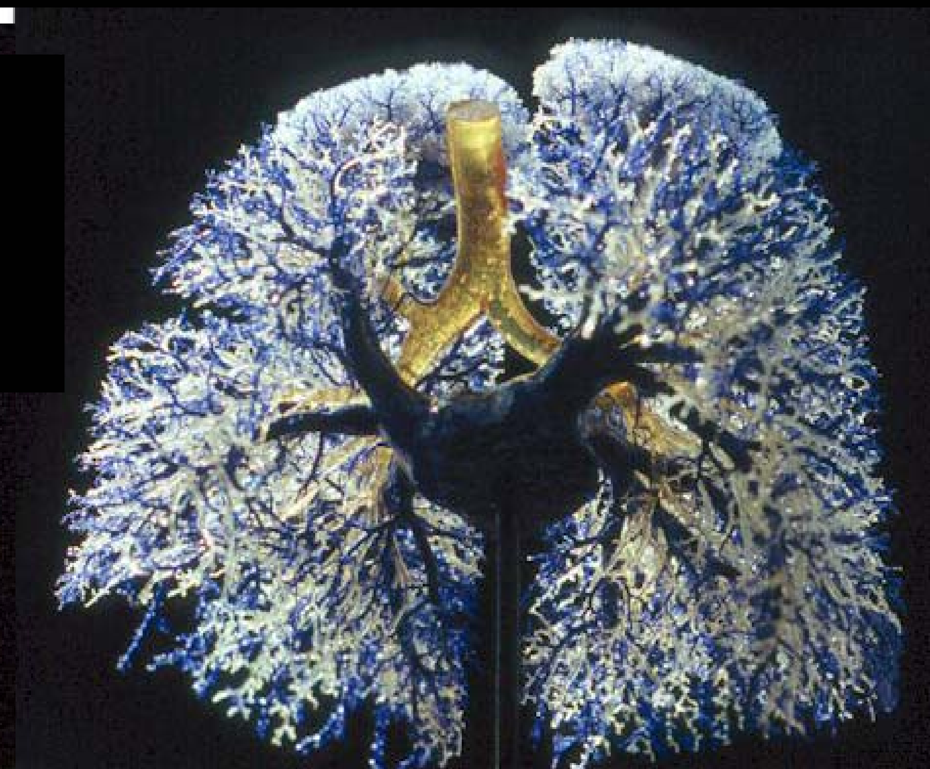
Pulmonary Circulation



resin cast of pulmonary arteries

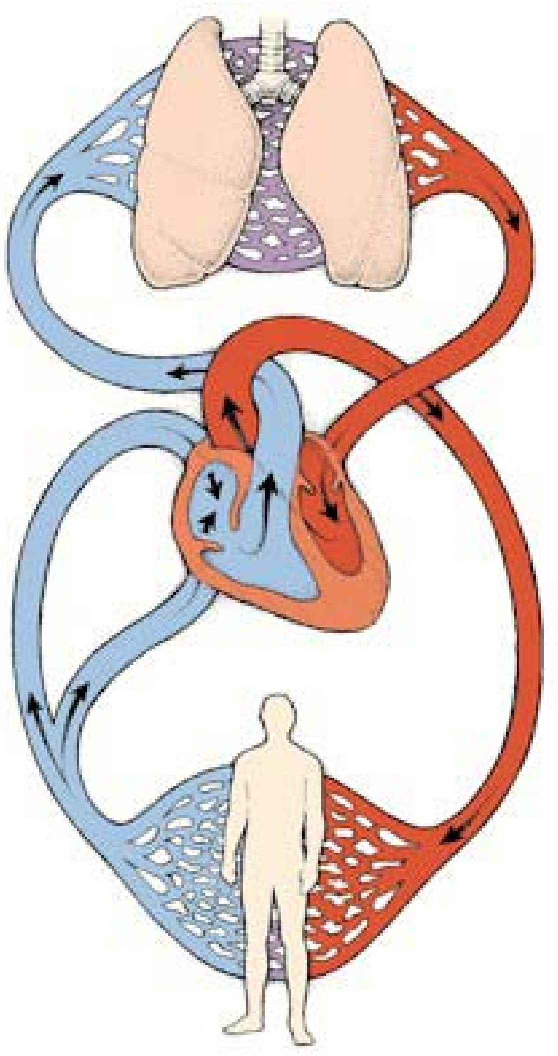


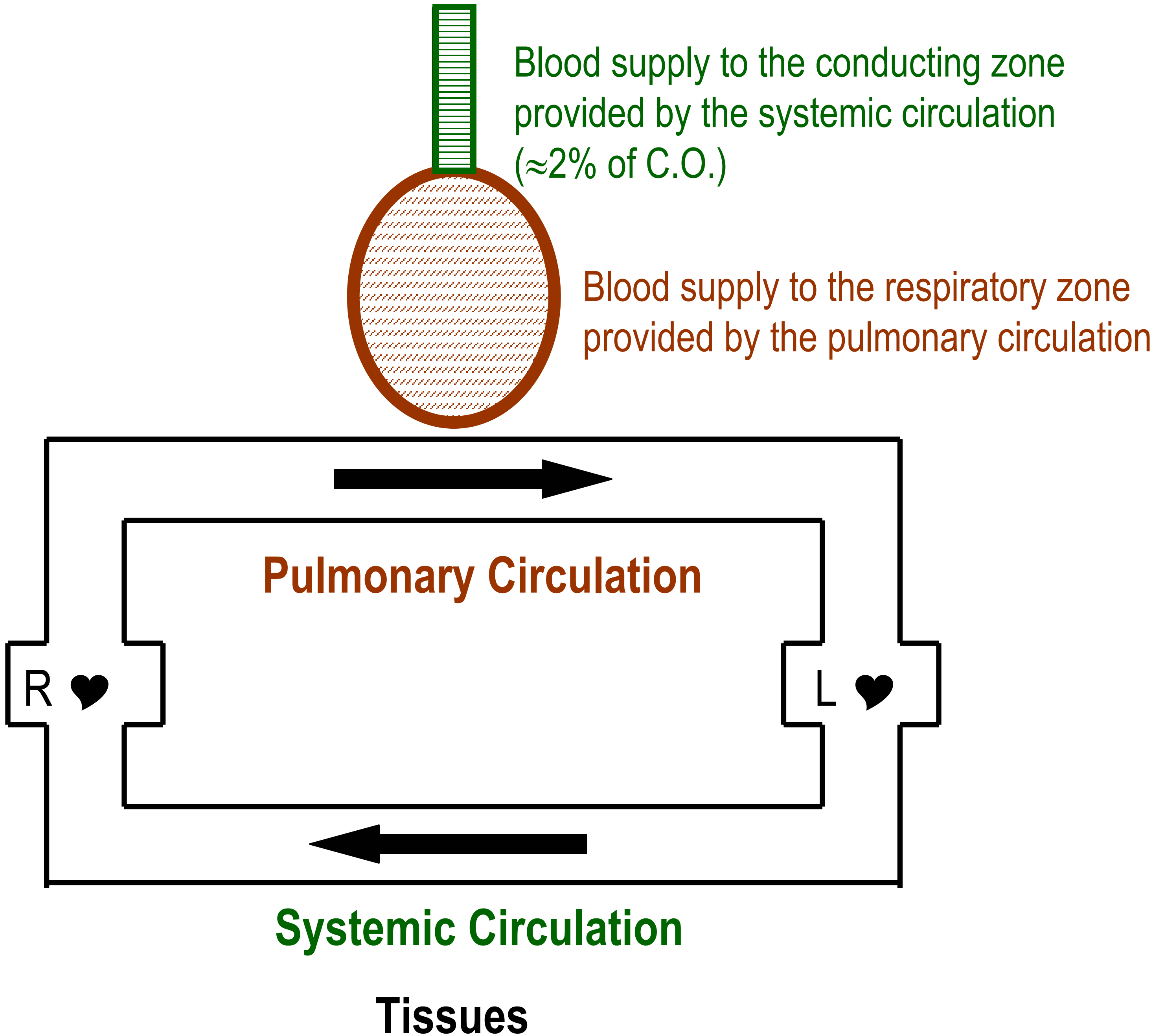
resin cast of pulmonary veins

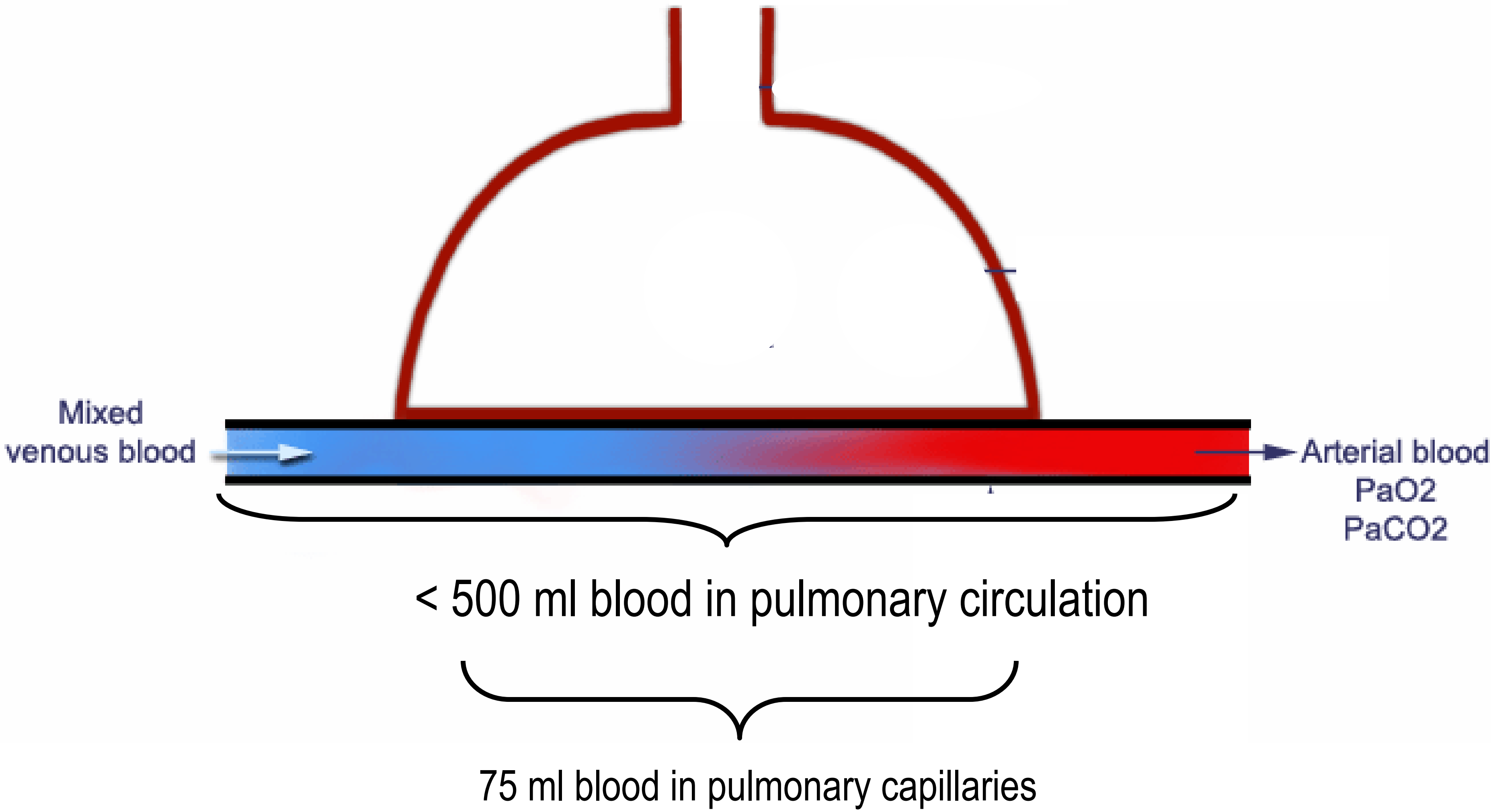
Blood Flow to the Lungs

Pulmonary Circulation

Systemic Circulation



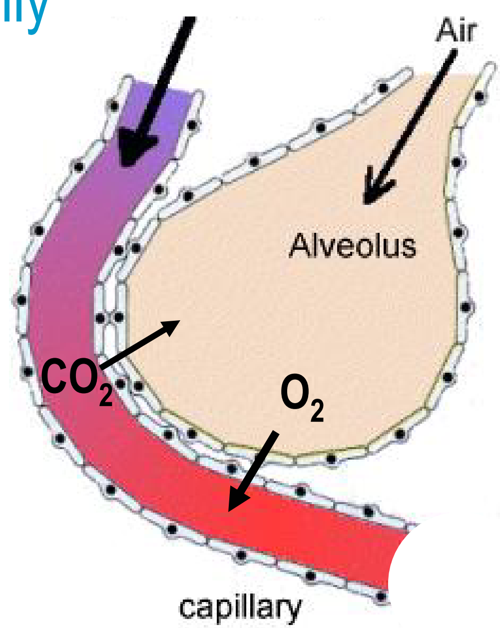

Blood supply to the conducting zone provided by the systemic circulation (≈2% of C.O.)
Blood supply to the respiratory zone provided by the pulmonary circulation
Pulmonary Circulation
R ♥
L ♥
Systemic Circulation
Tissues


Mixed
venous blood
Arterial blood
PaO2
PaCO2
< 500 ml blood in pulmonary circulation
75 ml blood in pulmonary capillaries

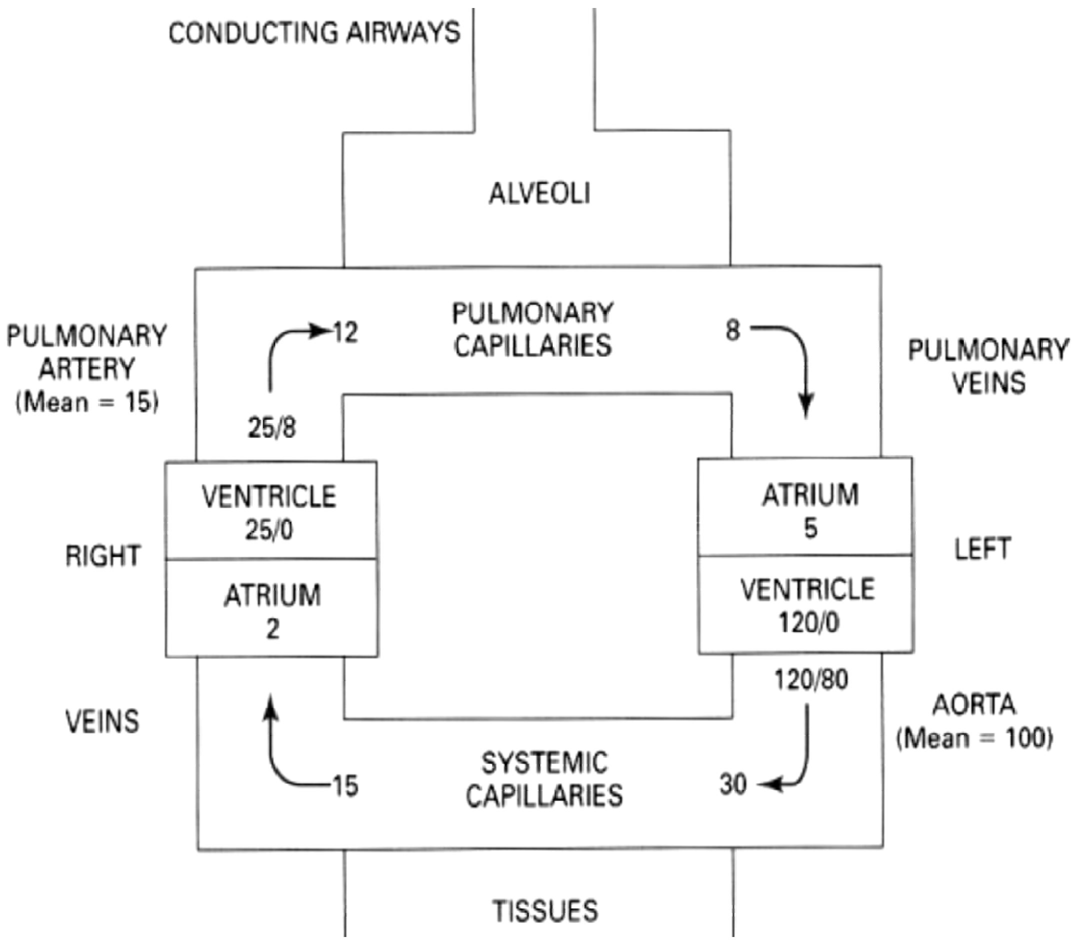
Gas Exchange in the Lungs Takes Place at the Respiratory Zone of the Airways [Airways with Alveoli]

- gas exchange: across small pulmonary arterial vessels [histologically not capillaries-functionally capillaries] & pulmonary capillaries

- there are about 280 billion pulmonary capillaries for about 300 million alveoli resulting in a gas exchange surface of about 60-100 m^2]

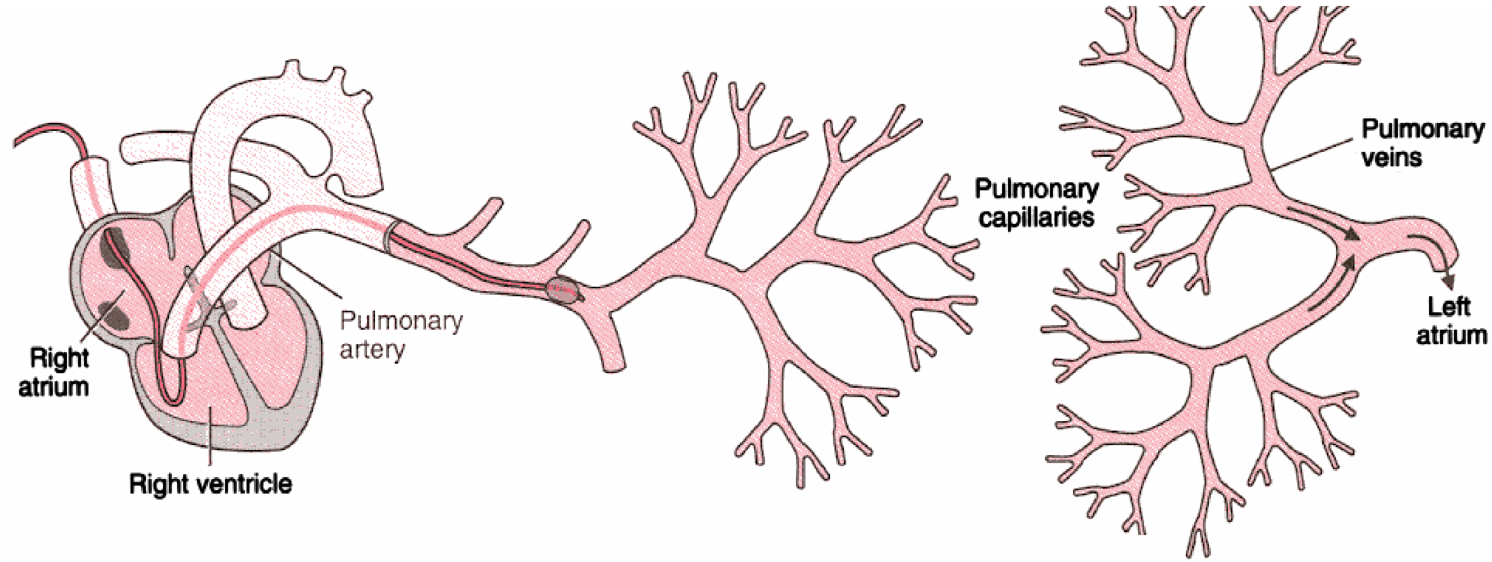


Comparison of Vascular Pressures
in the Systemic & Pulmonary Circulations



- 10 fold difference in mean arterial pressure
- structural basis: less smooth muscle in pulmonary vessels
  - greater distensibility + greater compressibility
- major drop in pressure in the pulmonary circulation is through capillaries
- major drop in pressure in the systemic circulation is through the arterioles

Right Heart Catheterization: Measuring R-side Pressures



Pulmonary Vascular Resistance

$$PVR = \Delta P/\Delta \dot{Q} = P_{PA} - P_{LA} / C.O.$$
$$= 15 - 5 / 5$$
$$= 2 \text{ mmHg/L/min}$$

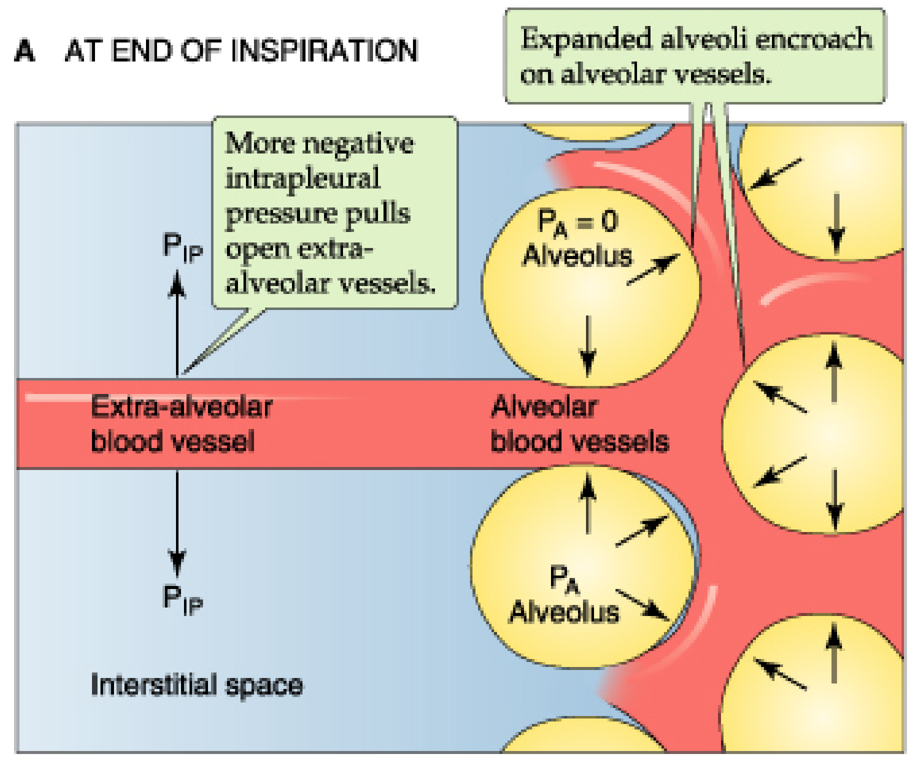
A Swan-Ganz catheter introduced through a peripheral vein(femoral/ brachial/ jugular), advanced toward the chest by normal flood flow, allows for RA, RV & pulmonary artery “wedge” [estimates LA] pressures.

Passive Influences on PVR
Difference in Surrounding Pressure

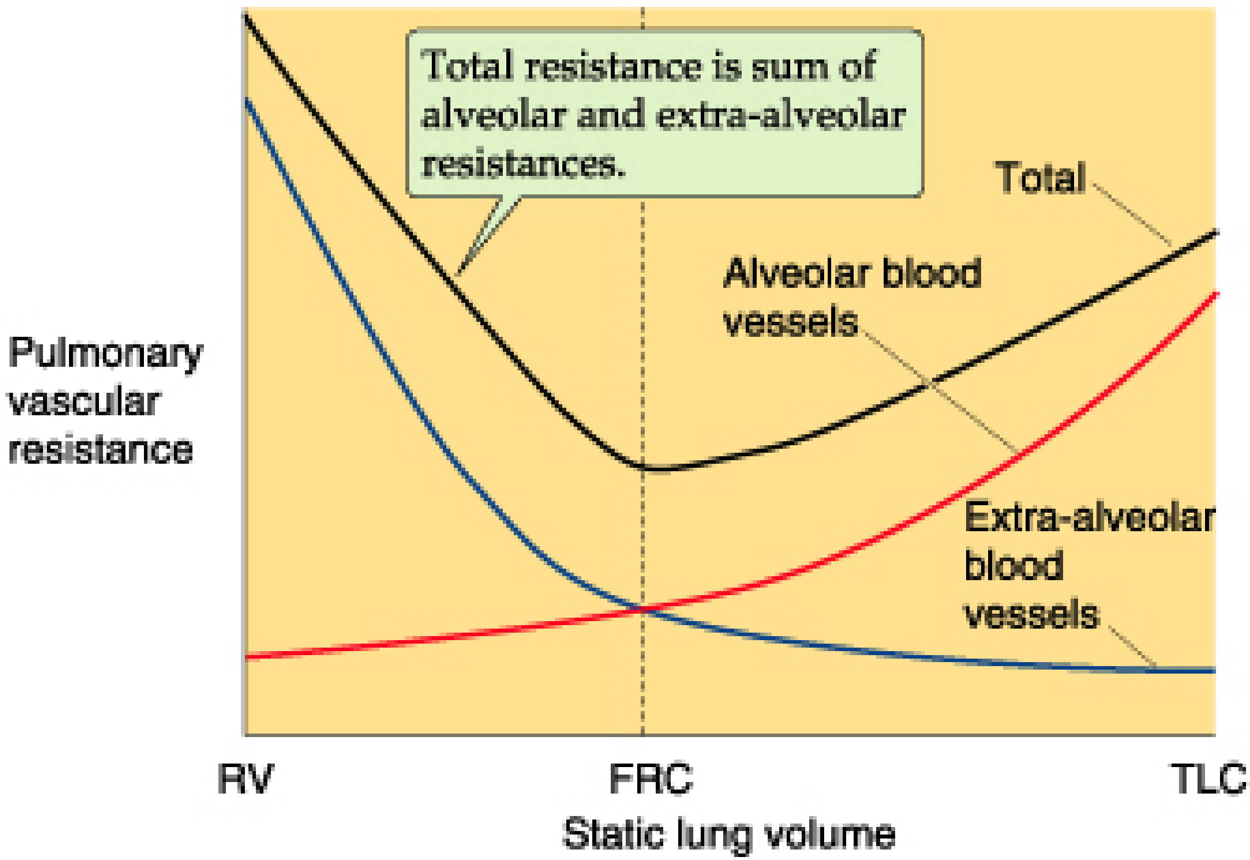
- Alveolar vessels [pulmonary capillaries] – alveolar pressure
- Extra-alveolar vessels [pulmonary arteries & veins]- intrapleural pressure

Lung inflation:

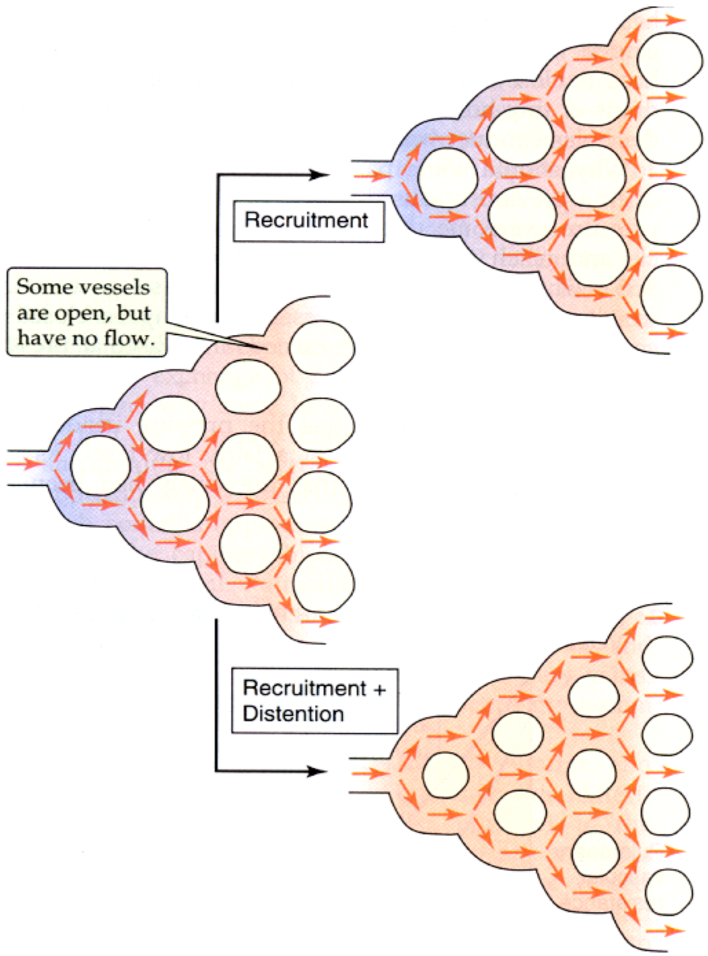
- collapses alveolar vessels via stretch of alveolar wall
- expands extra-alveolar vessels via radial traction



Lung Volume Affects Pulmonary Vascular Resistance



Passive Influences on PVR
Distention & Recruitment



Increase in perfusion pressure [pulmonary artery pressure] results in distension & recruitment $\Rightarrow$ decreasing PVR.

How can vessels be open but have no flow?

Consider very low pressure systems, e.g. garden hose with multiple small holes. At low enough pressure, only a few holes drizzle water: sufficient difference in resistance that flow is diverted to the path with least resistance.

Active Influences on Pulmonary Vascular Resistance

Increase	Decrease
Alveolar Hypoxia	
Alveolar Hypercapnia	
humoral: NE / E	*humoral: Ach*
humoral: Histamine	*humoral: Bradykinin*
humoral: PGF2α / PGE2	*humoral: PGE1*
humoral: Thromboxane	*humoral: nitric oxide*
humoral: Angiotensin	

- *physiologic role of humoral factors ?*
- There is sparse sympathetic & parasympathetic innervation of the pulmonary vasculature and the effect of stimulation of these nerves is controversial.

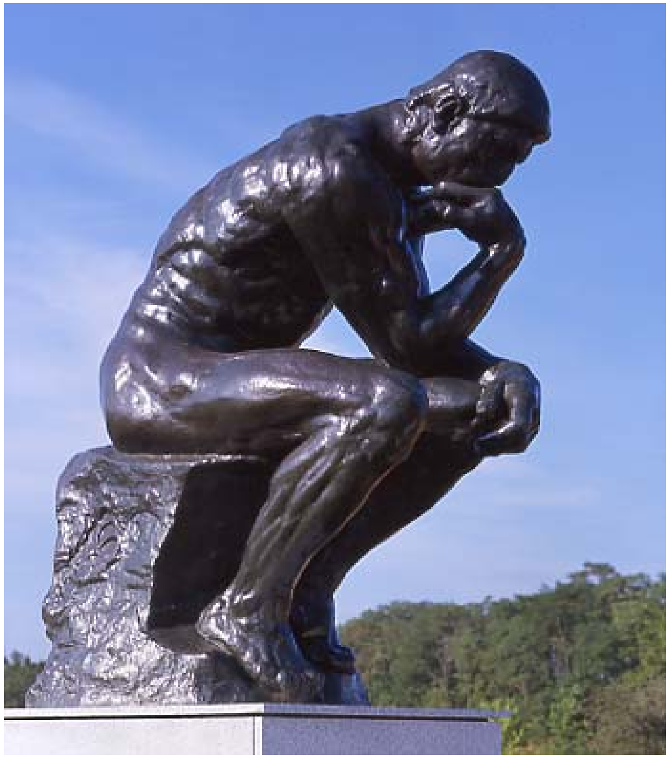
Summary & Query

- Consider the factors that affect pulmonary vascular resistance (PVR). How do these differ from factors that affect systemic vascular resistance (TPR)

- Contrast the effect of low oxygen on vessel diameter in the pulmonary versus systemic circulation.

  How is this difference useful?

  When is it not beneficial?



Regional Distribution of Pulmonary Blood Flow

There is a hydrostatic pressure difference of about 23 mmHg from the top to bottom of the lungs (30 cm height)

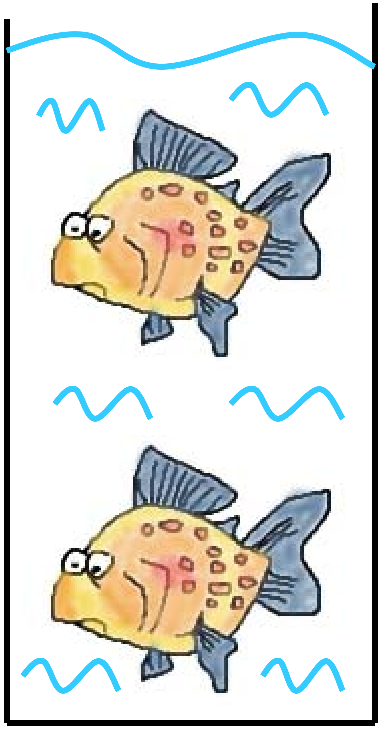
<u>Hydrostatic Pressure (P)</u>

$P = \rho h g$

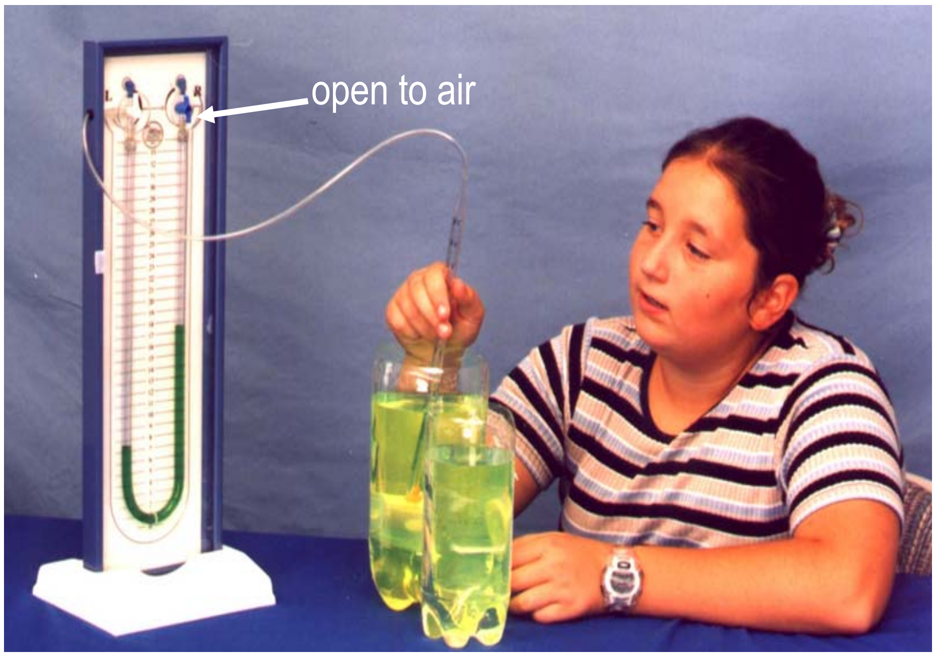
ρ = density of the fluid

h = height (depth) of fluid column

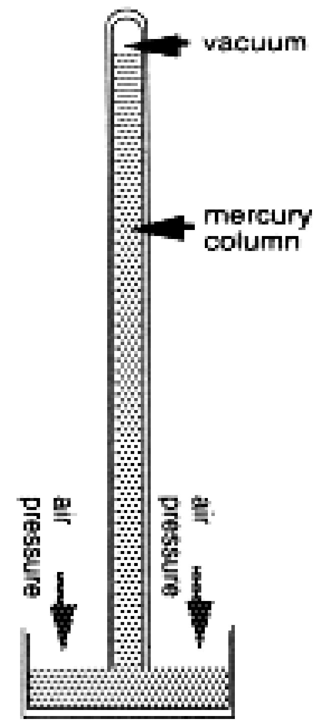
g = acceleration of gravity



Measuring Pressure- a Relative Difference
units: cm H_2O vs mmHg



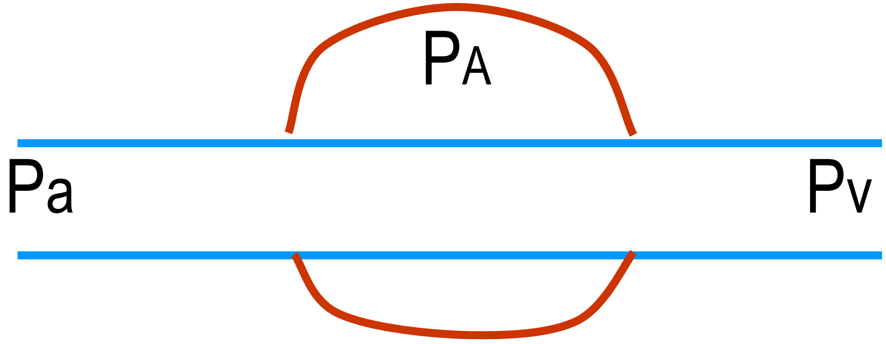
water manometer



mercury barometer

There are 13.6 mm H_2O (or 1.36 cm H_2O) for every 1 mm Hg pressure

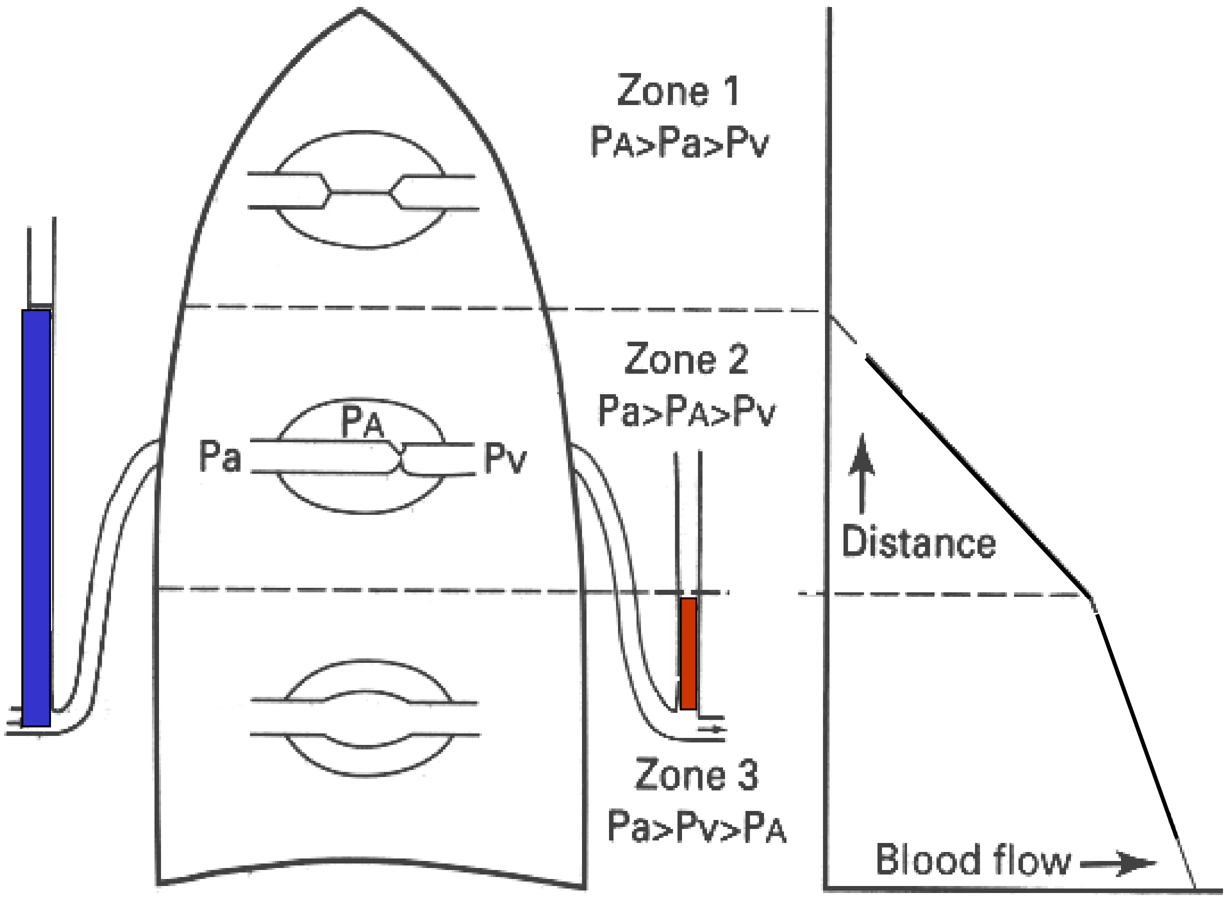
The Starling Resistor Again!



If $P_v > P_A$, the driving pressure = $P_a - P_v$

If $P_A > P_v$, the driving pressure = $P_a - P_A$

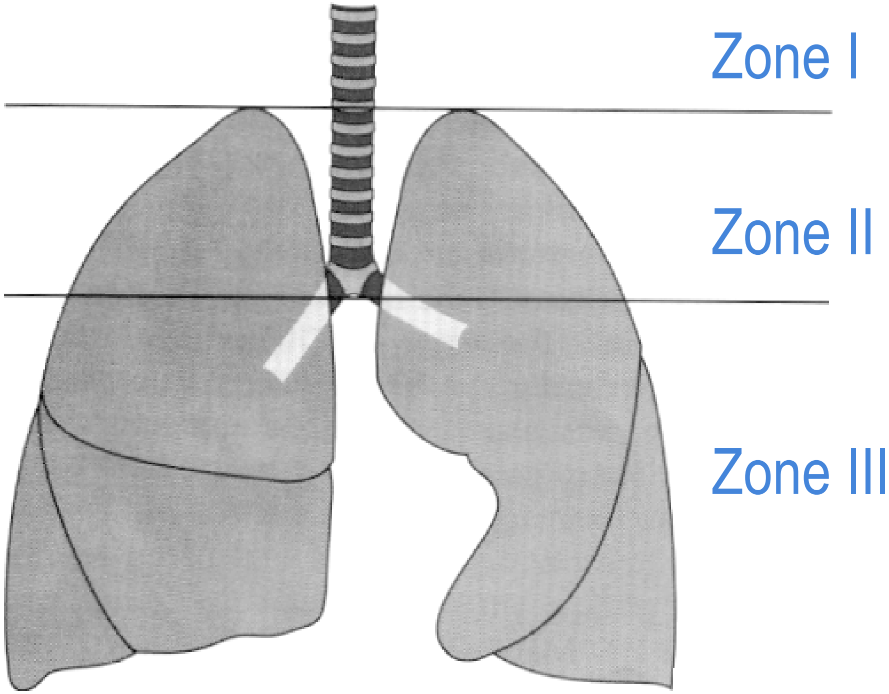
The "Zones" of the Lung: The Interaction of Gravity & Extravascular Pressures



- ↑arterial & venous hydrostatic pressures from the tip to the base due to gravity
- constant alveolar pressure

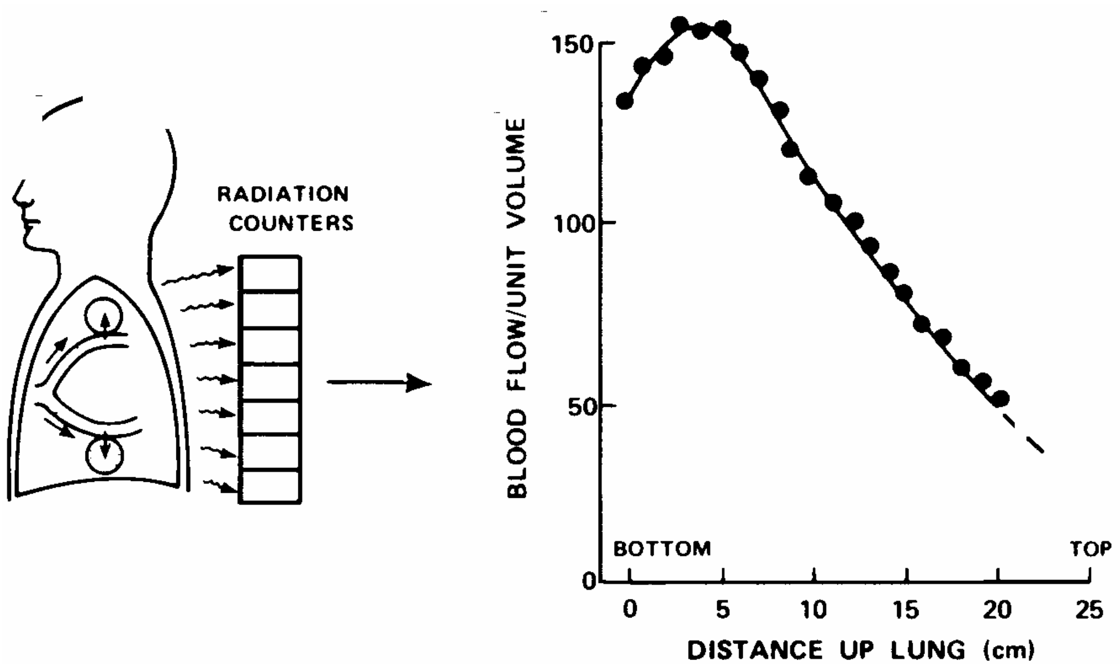
- the pulmonic valve ≈15 cm below the tip of the lungs, Pa ≈ 15 mmHg
- note the relative alveolar, arterial & venous pressure in each "zone" + determine the driving pressure
- zone III: additional contributing factor distention & recruitment of vessels

Zone Model versus Reality



- Zone I: at rest, during systole Pa>PA. Potential to function as alveolar dead space ventilated but not perfused when PA>Pa e,g, patient on high PEEP; after hemorrage; low Pa (anesthesia)
- Zone II: exercise leads to an increase in C.O. & Pa, boundary between Zone II & III shifts up.
- consider changes in body position

Region of Reduced Flow near the Bottom of the Lungs
Zone 4



- At the base of the lungs, radial traction on extra-alveolar vessels is less [less negative pleural pressure] hence there is greater contribution to resistance to flow.

Matching of Ventilation & Perfusion at Alveolar Level Affects Gas Exchange

Consider the average range of total alveolar ventilation and blood flow (perfusion) to through the pulmonary circulation and their ratio and compare it to regional lung units.

$\dot{Q}c$ = 4-6 L/min

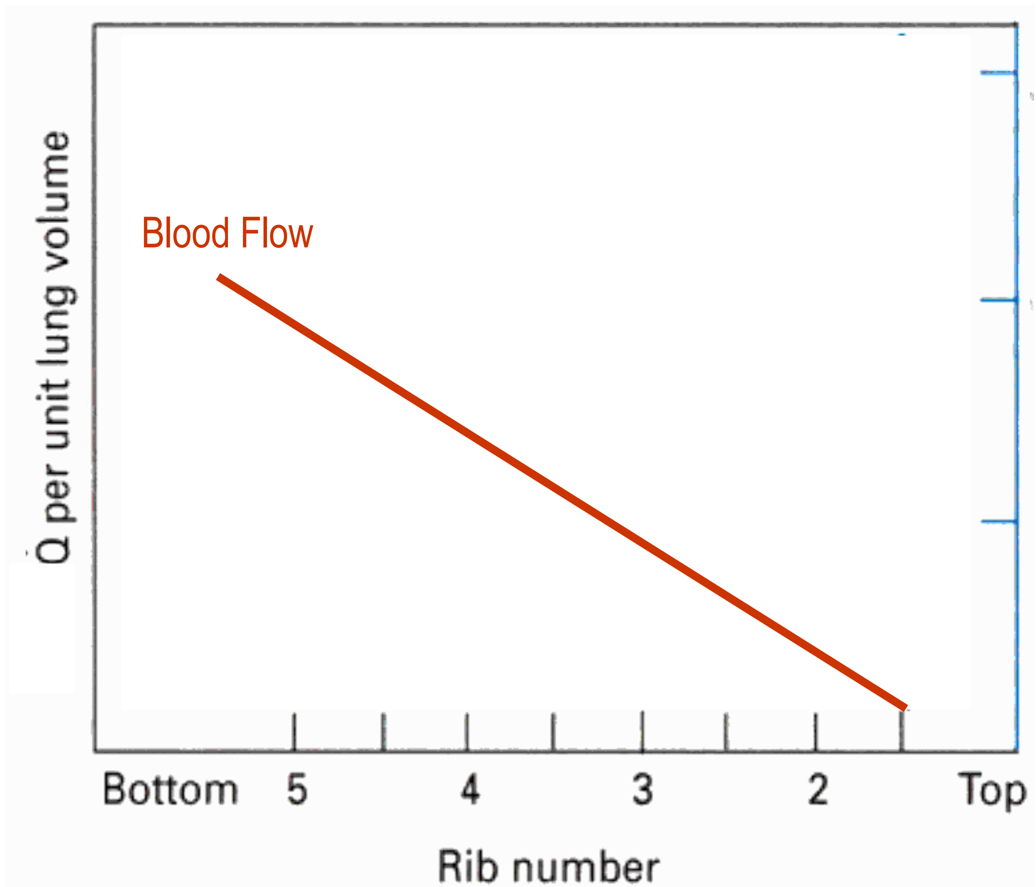
$\dot{V}A$= 4-6 L/min

$\dot{V}A/\dot{Q}c$ = 0.8-1.0

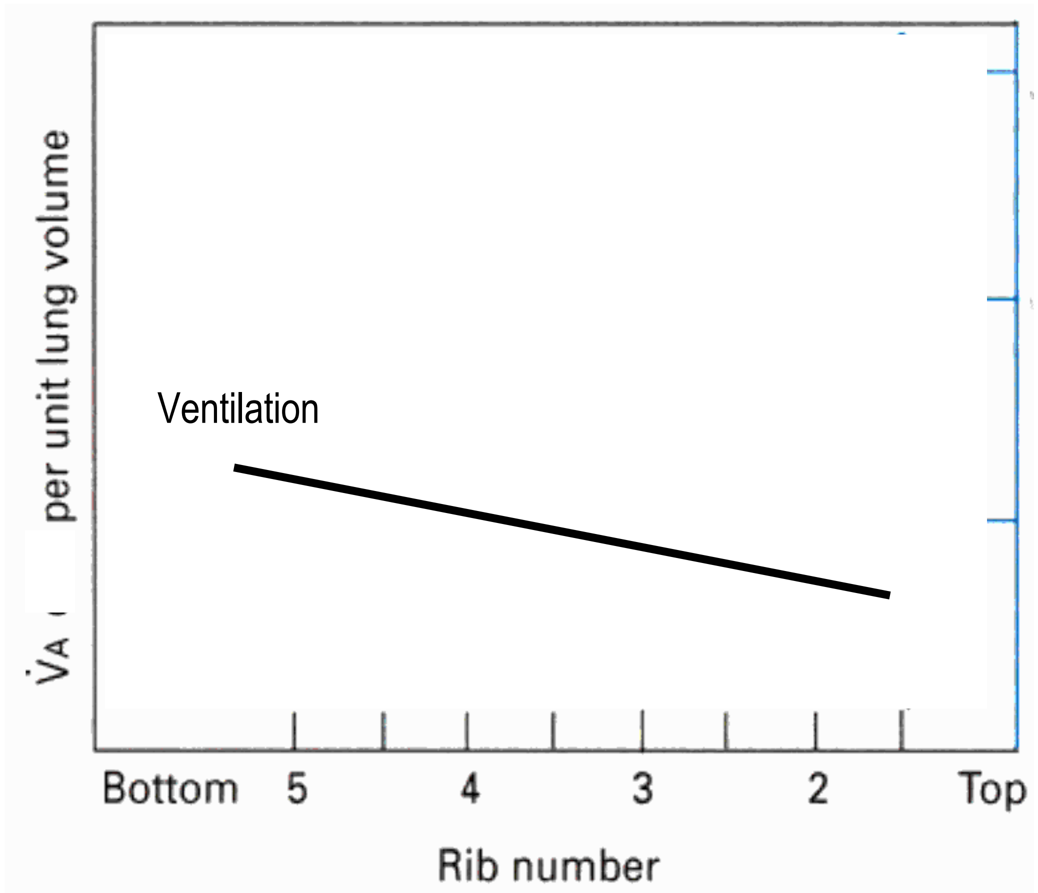
The consequence of $\dot{V}/\dot{Q}$ matching at alveolar level is important to gas exchange.

To appreciate the importance of V/Q matching at alveolar level, consider a scenario where there is perfusion to only the L-lung & ventilation to only the R-lung. What would the V/Q be?

Regional Distribution of Blood Flow

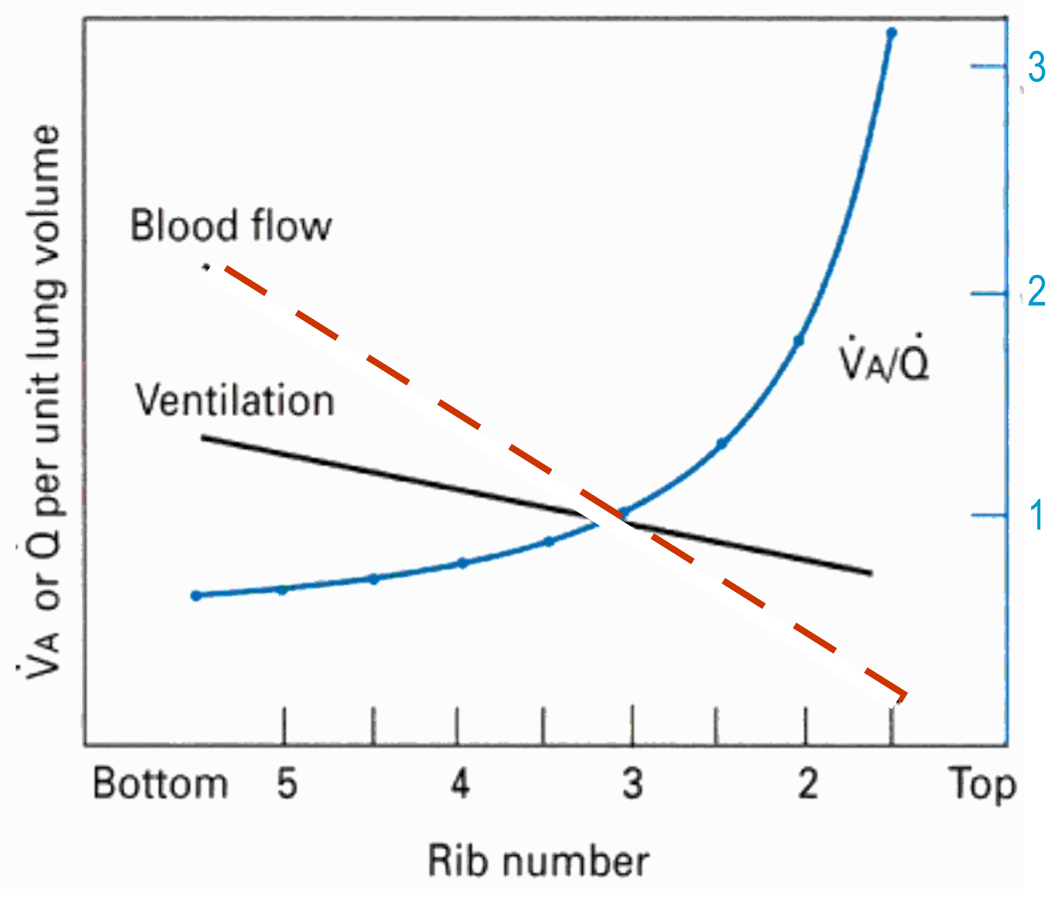


Regional Distribution of Alveolar Ventilation

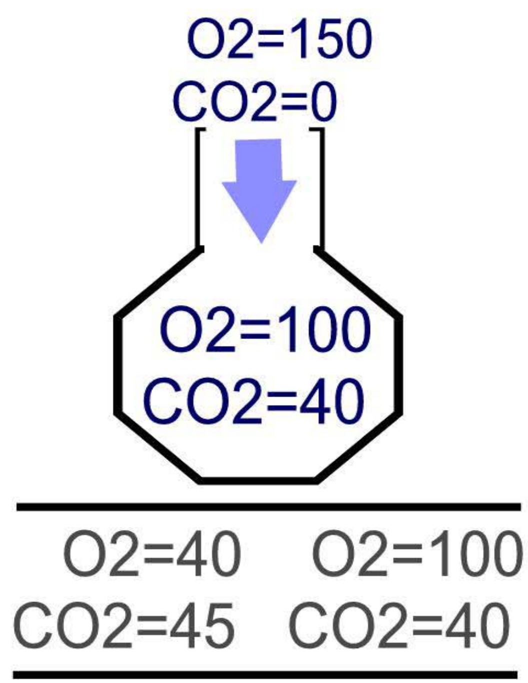


Ventilation-Perfusion Mismatch

note the greater gradient for blood flow relative to ventilation



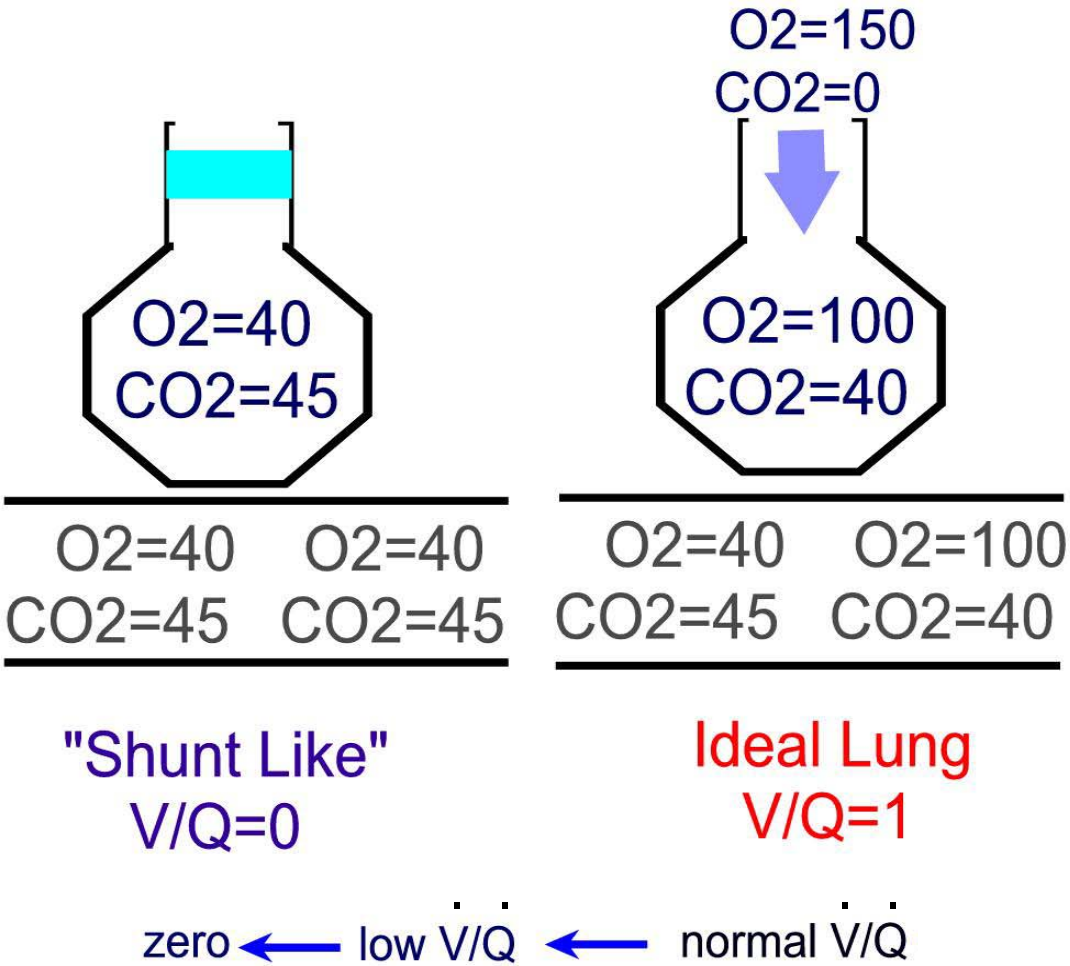
Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units



Ideal Lung
V/Q=1

normal $\dot{V}/\dot{Q}$

Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units



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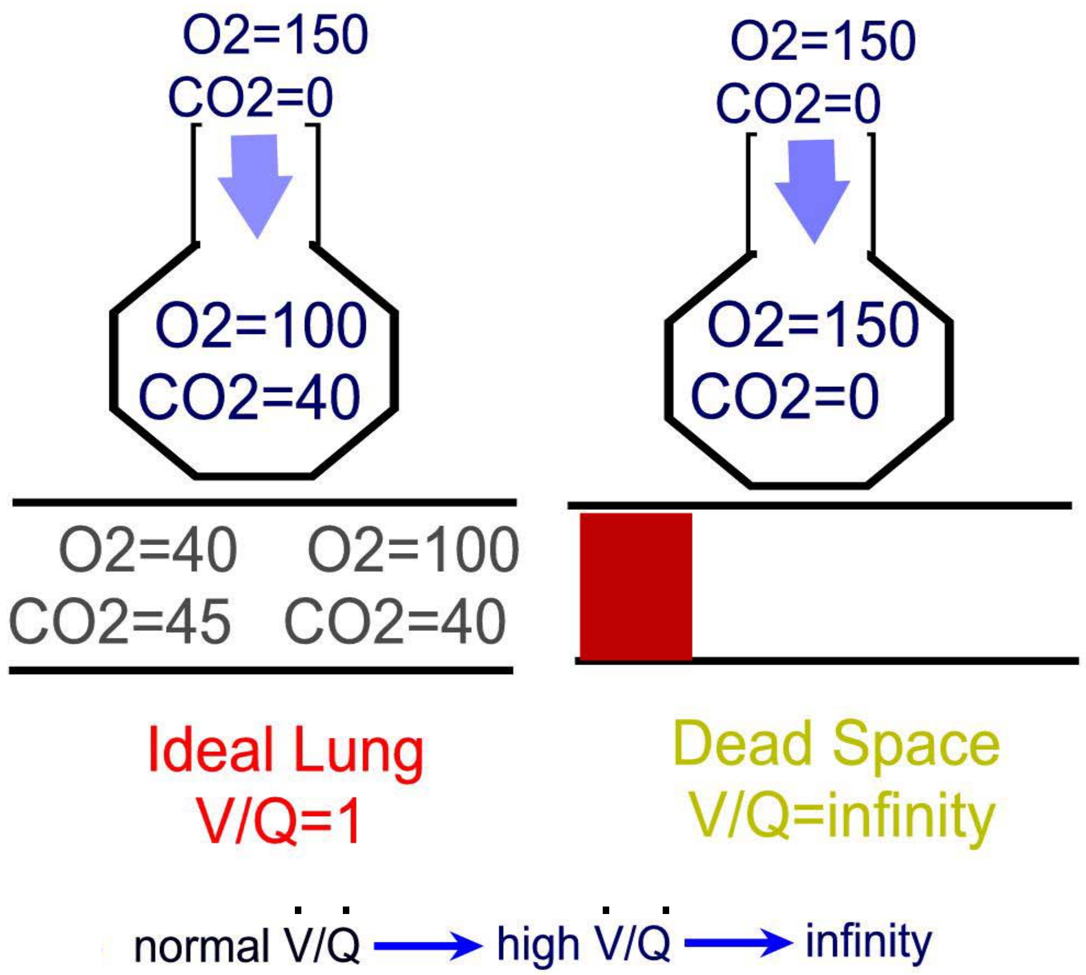
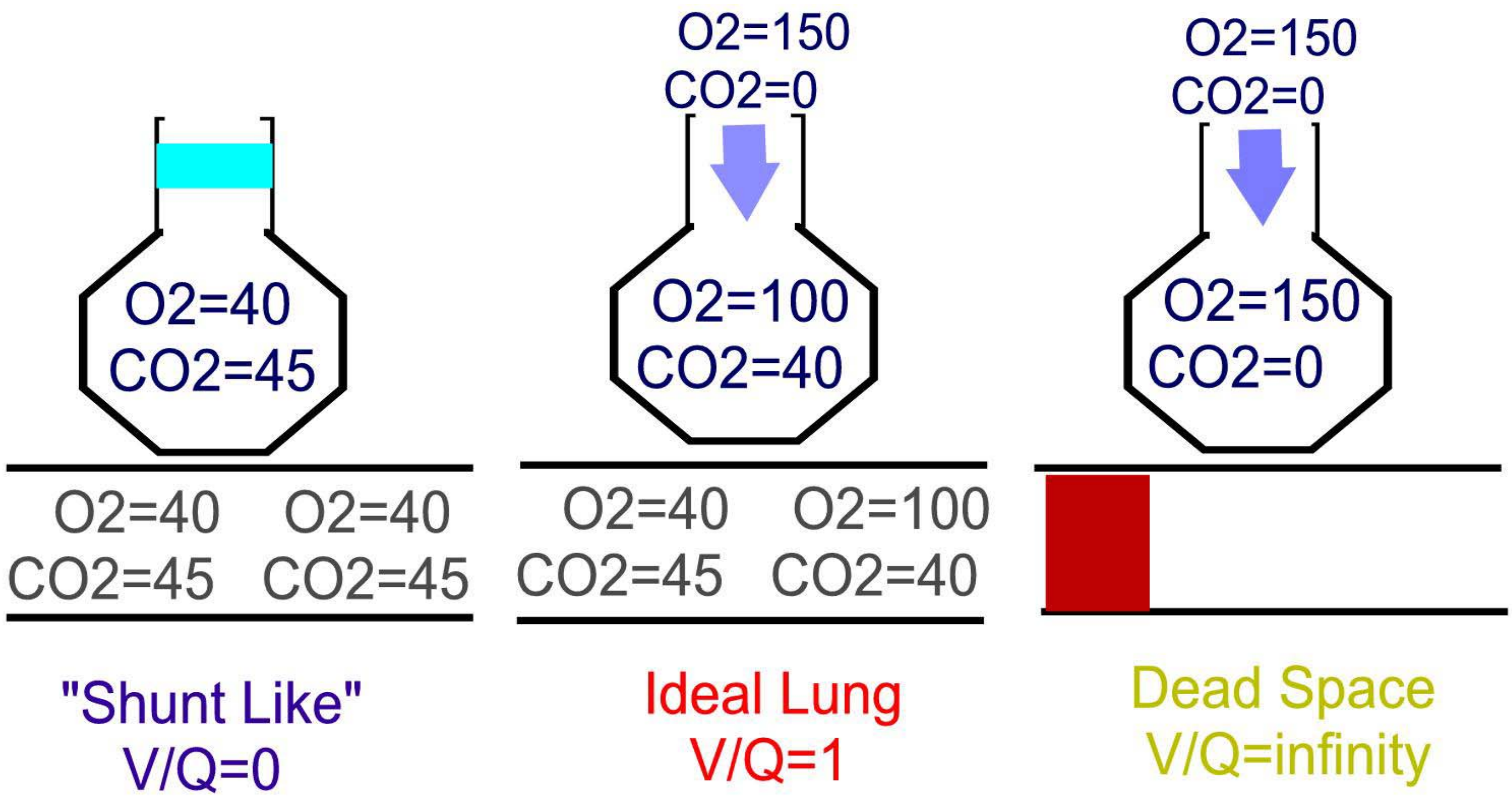
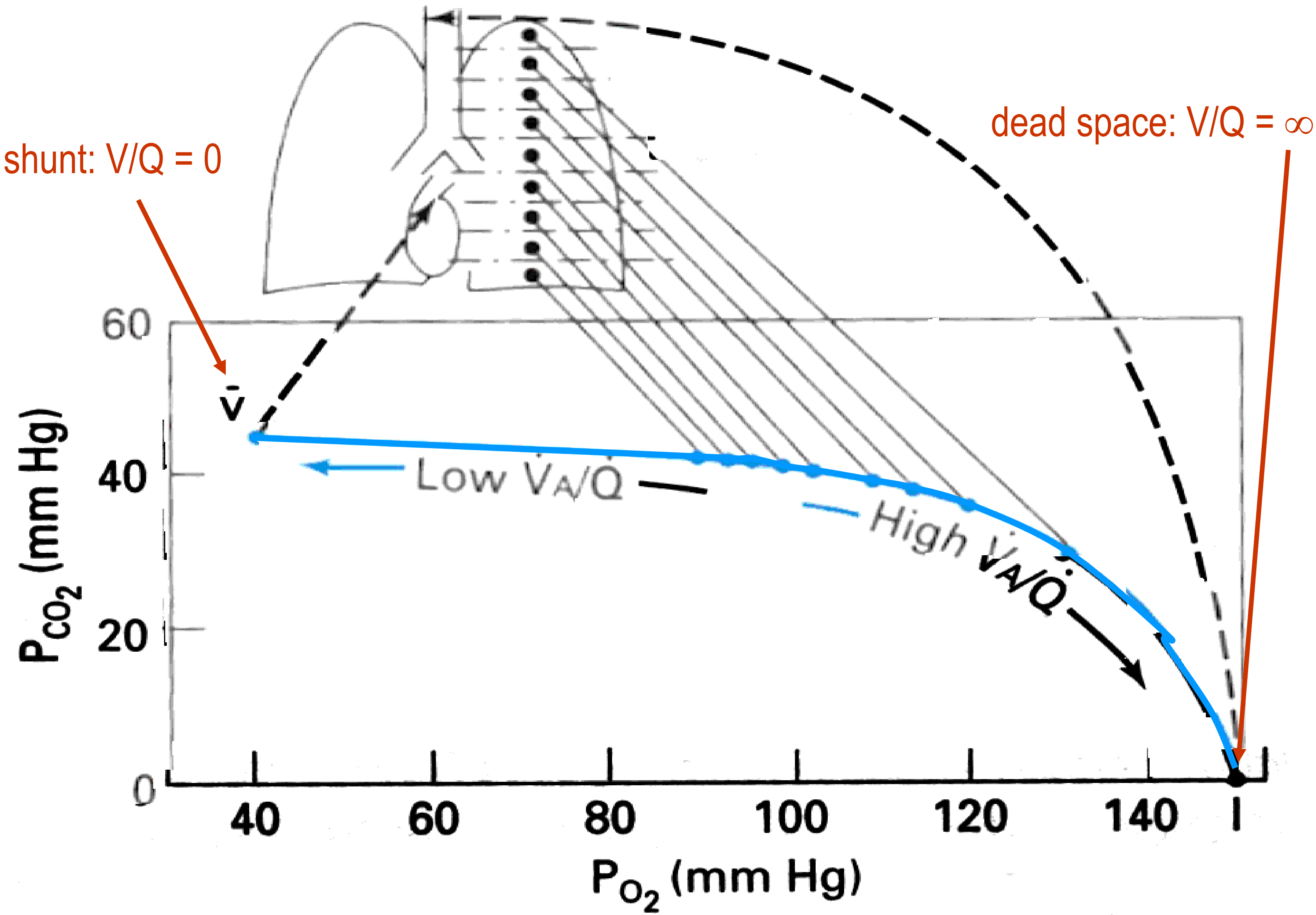


Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units



zero ← low $\dot{V}/\dot{Q}$ ← normal $\dot{V}/\dot{Q}$ → high $\dot{V}/\dot{Q}$ → infinity

V̇/Q̇ Mismatch & Partial Pressure of O2 & CO2

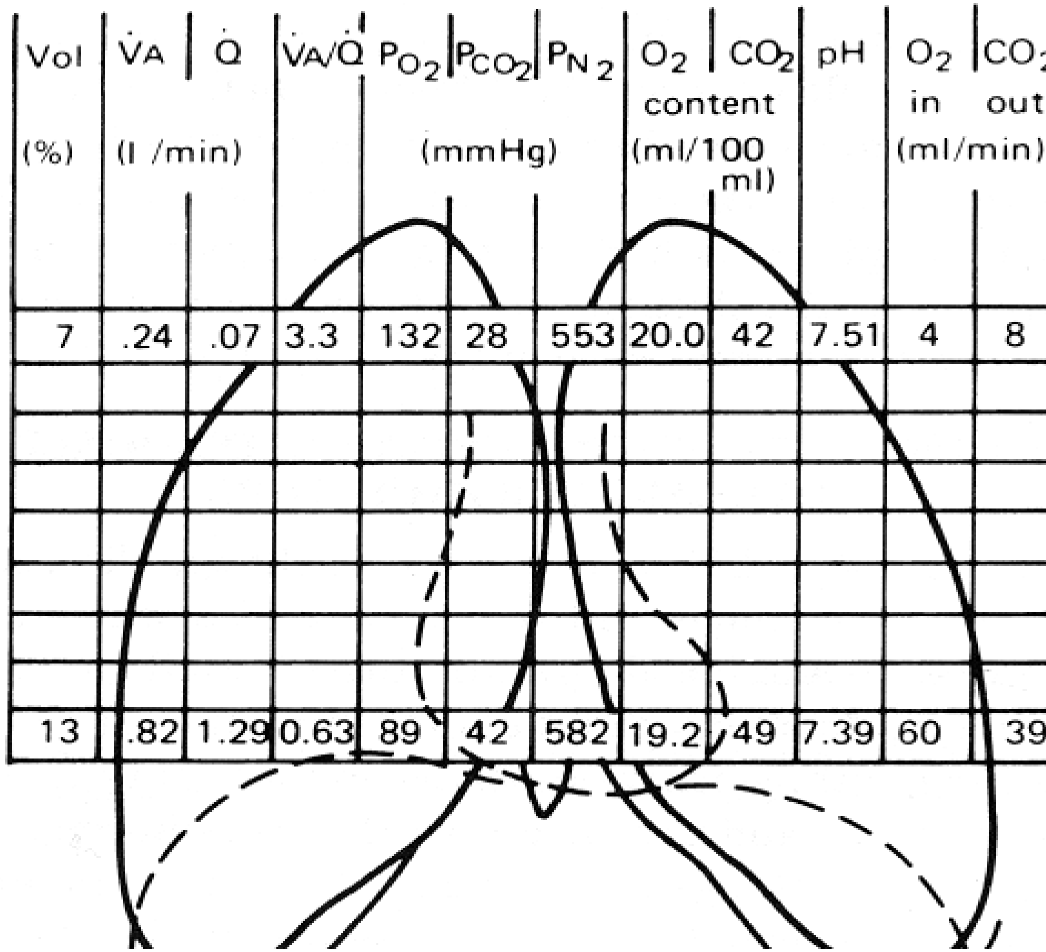


Regional Differences in Gas Exchange

Differentiate between the apex & the base:

- the site with highest V/Q lowest P_{CO_2} + highest P_{O_2}

- the site with the greatest quantity of gas exchange



Vol (%)	$\dot{V}_A$ (l/min)	$\dot{Q}$	$\dot{V}_A/\dot{Q}$	P_{O_2} (mmHg)	P_{CO_2}	P_{N_2}	O_2 content (ml/100 ml)	CO_2	pH	O_2 in (ml/min)	CO_2 out
7	.24	.07	3.3	132	28	553	20.0	42	7.51	4	8
13	.82	1.29	0.63	89	42	582	19.2	49	7.39	60	39