Respiratory Mechanics and Introduction to Respiratory Physiology

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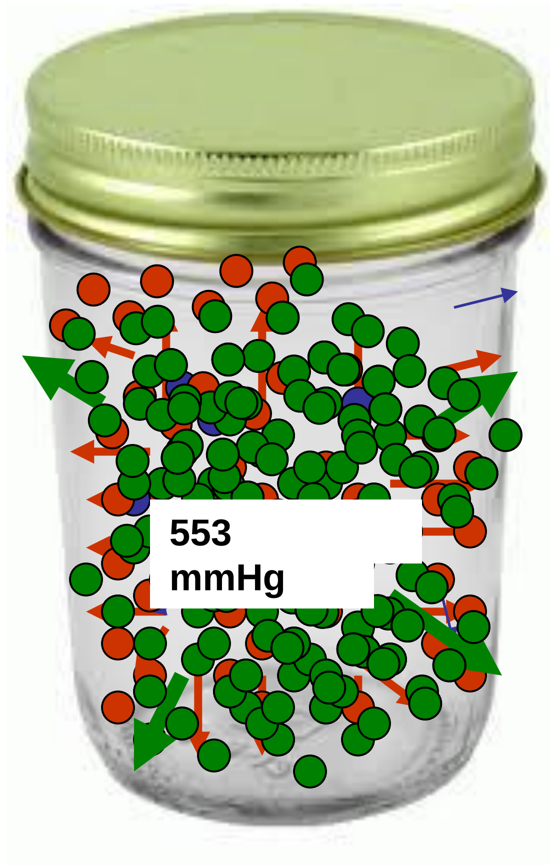
Disclosures

- Dr Burchfield has nothing to disclose

Basic Concept of Gas Pressures

- Atmosphere is filled with gas that applies a pressure of 760 mmHg pressure on it's surroundings
  - 20.8% oxygen (160 mmHg)
  - Some gaseous water (47 mmHg)
  - Nitrogen (553 mmHg)

Basic Concept of Gas Pressures



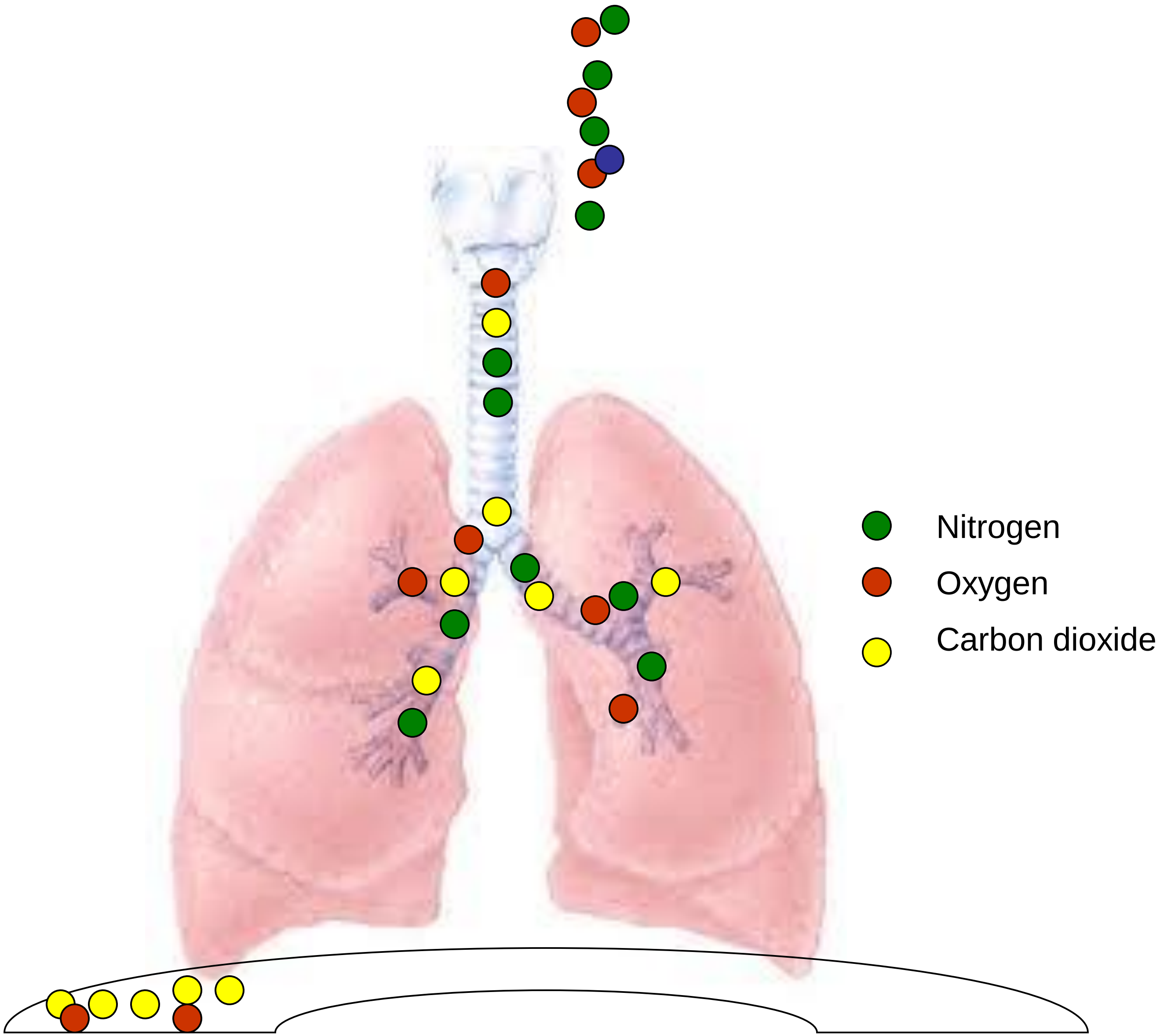
Gaseous water (Humidity)

Oxygen

Nitrogen

$Press_{Total} = \text{press } H_20 + \text{press } O_2 + \text{press } N_2$

Gas Pressure Relationships in the Lung



Gas Pressure Relationships in the Lung

- Alveolar gas equation
  - Calculation of the amount of oxygen at the alveoli

- Alveolar $pO_2 = P_AO_2 = [(P_B - P_{H_2O}) \times FiO_2] - P_{CO_2}$

- $P_AO_2 = [(760-47) \times FiO_2] - (pCO_2)/R$
  - Newborn, $R \approx 1$

- $P_AO_2 = [(760-47) \times FiO_2] - pCO_2$

Calculate P_AO_2

- Inspired oxygen 50%
- Barometric pressure 760
- Water vapor pressure 47
- ABG 7.40/45/65

- $P_AO_2 = [(760\text{-}47) \times FiO_2] - pCO_2$
- $P_AO_2 = (713 \times 0.5) - 45 = 317$ torr

Calculate P_AO_2

- You are hiking in Leadville, CO at an elevation of 10,000 ft. with a barometric pressure of 525 mmHg. The water vapor pressure is 47 mmHg. Since you are hyperventilating due to fatigue, your pCO2 is 33 torr. What is your alveolar oxygen concentration?
- $P_AO_2 = [(525-47) \times FiO_2] – pCO_2/R$
- $P_AO_2 = (478 \times 0.21)- 33/0.8 = 59$ torr
  - Would be 67 torr if you ignore respiratory quotient

A-a Gradient (AaDO2)

- Alveolar - arterial gradient
- Alveolar oxygen (calculated) – arterial oxygen (measured)

ARS Question 1

- Gas flow in normal respiration occurs due to:

1. Boyles Law
2. Charles law
3. LePlace Law
4. Starling Law

Gas Flow

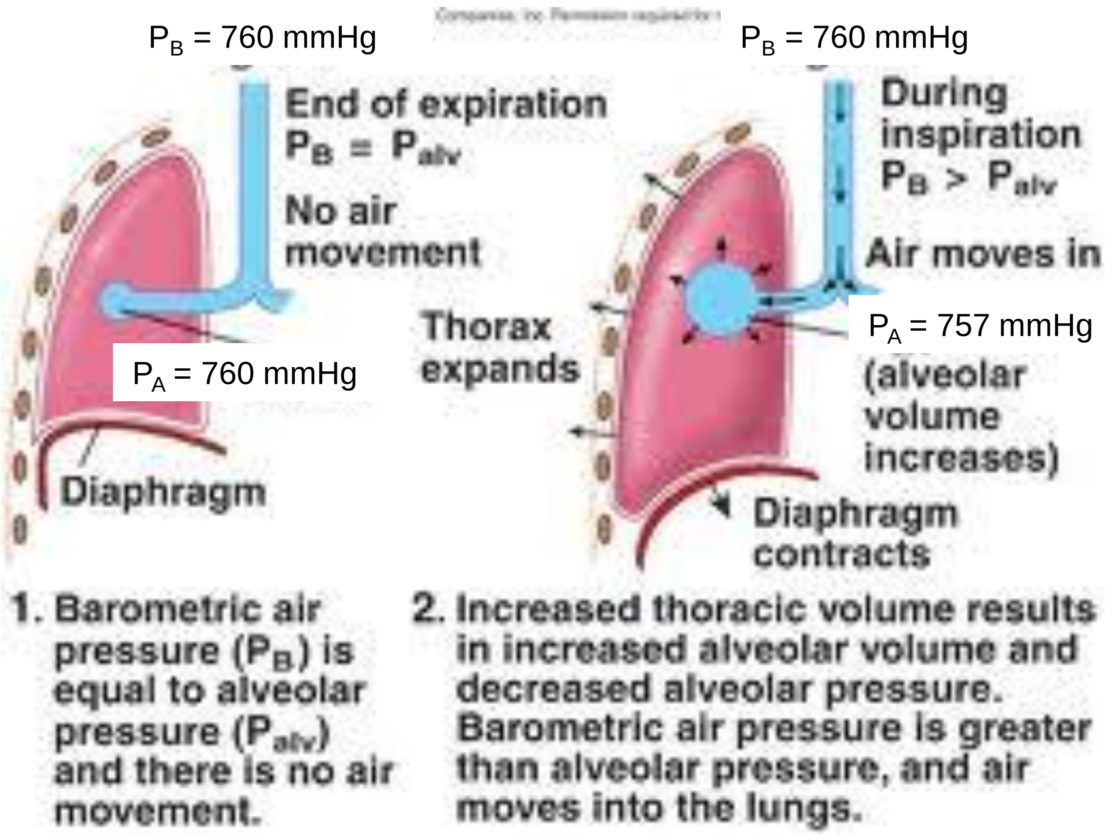
- Boyles Law
  - The pressure of a gas decreases as the volume that it is contained in increases
  - $P \infty 1/V$
  - $P_1 V_1 = P_2 V_2$

Atmospheric Pressure

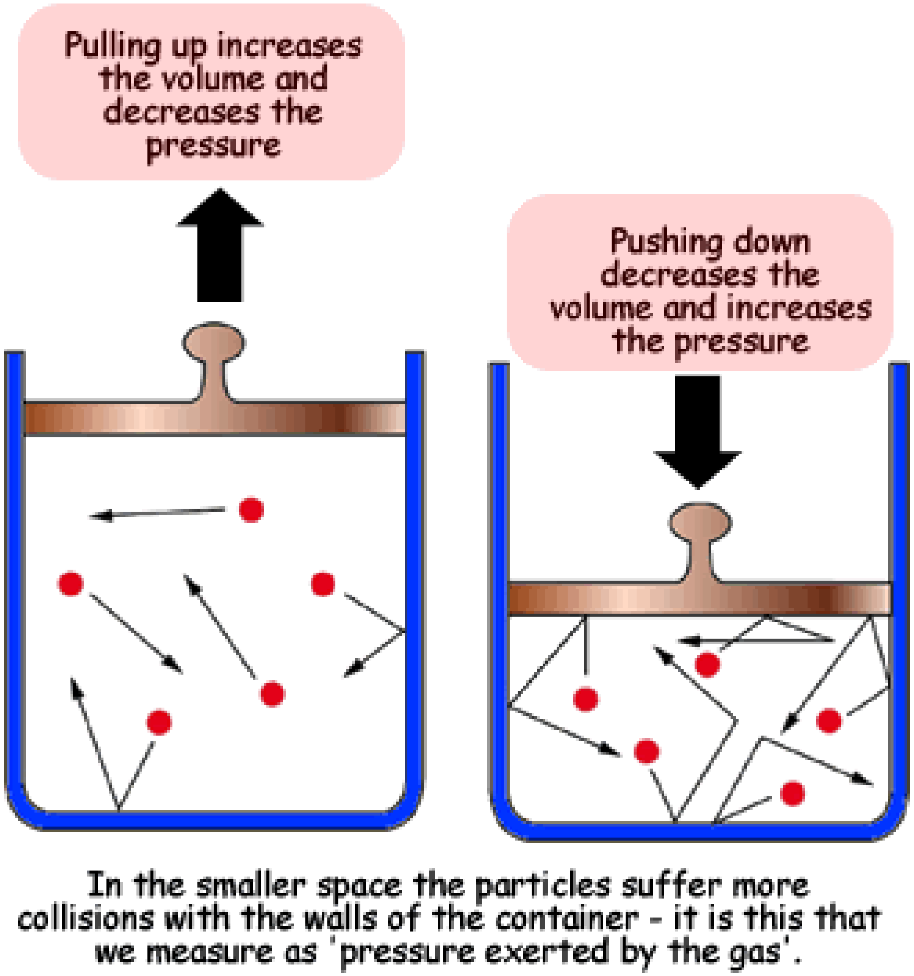
End expiration

Chest wall expansion

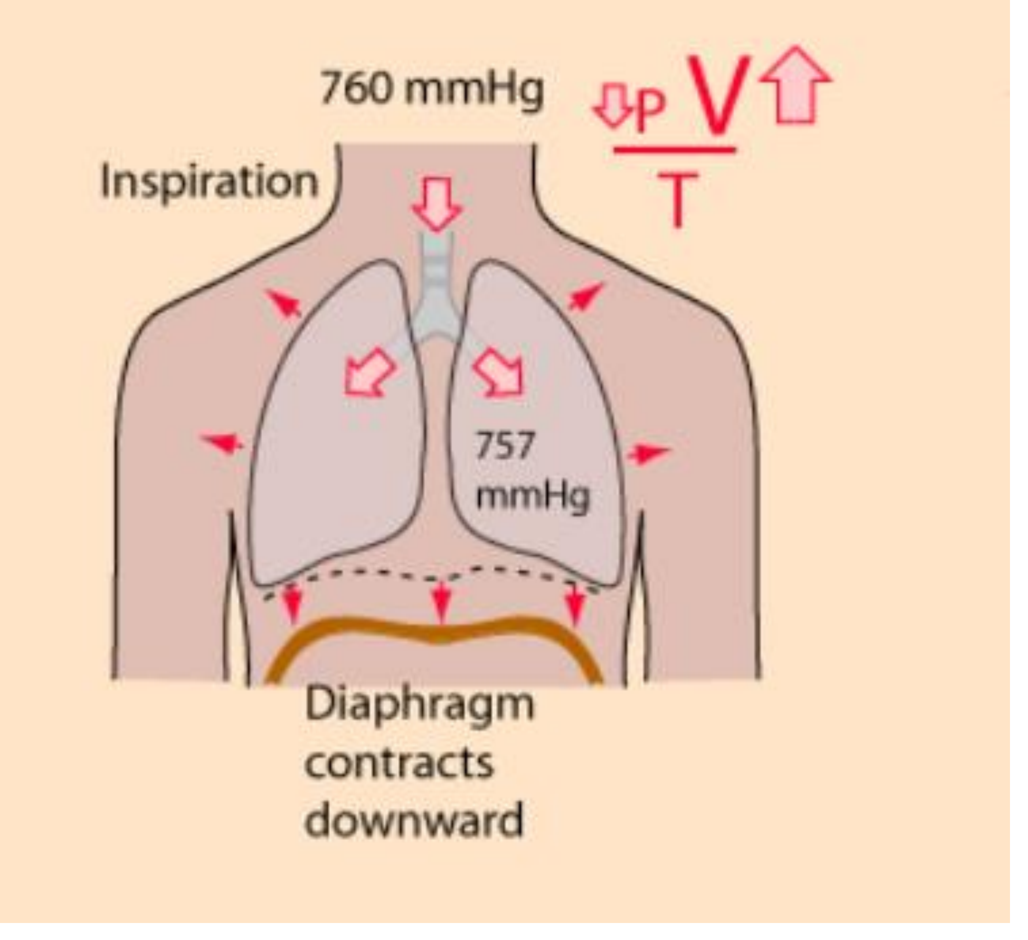
Pulmonary Mechanics-Chest Wall



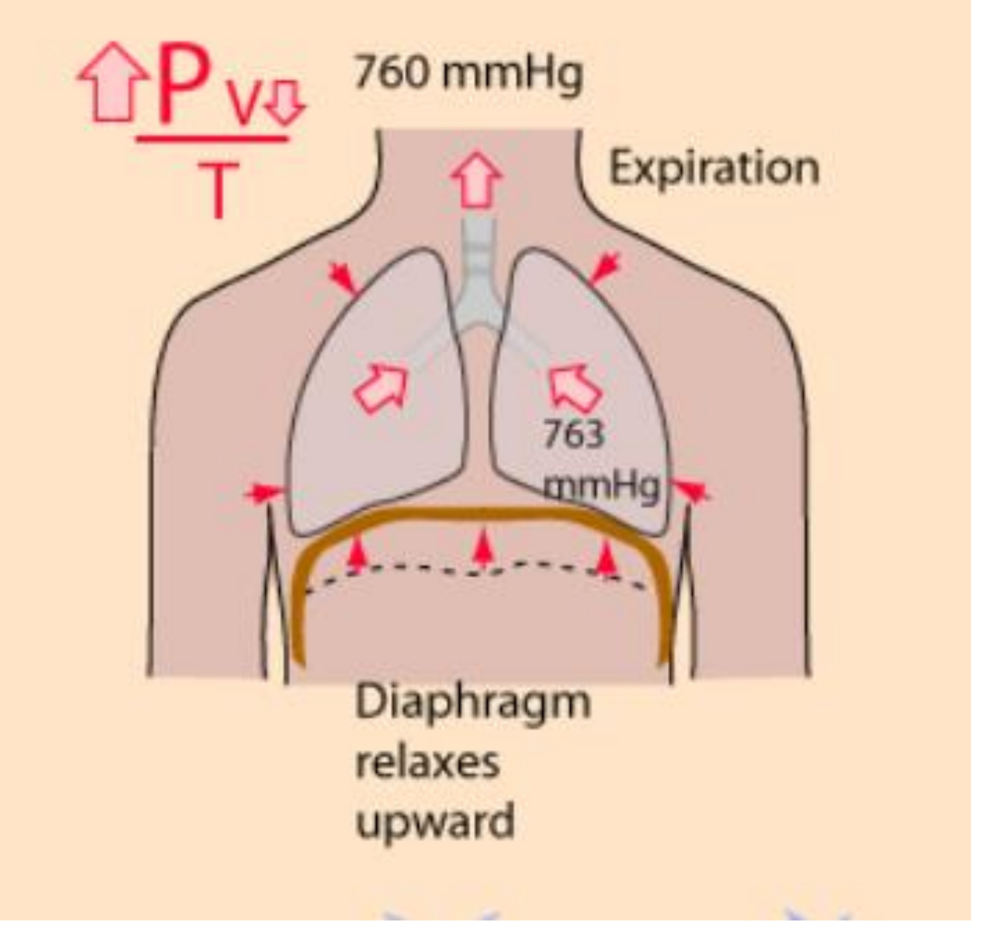
Boyles Law


Pulling up increases the volume and decreases the pressure
Pushing down decreases the volume and increases the pressure
In the smaller space the particles suffer more collisions with the walls of the container - it is this that we measure as 'pressure exerted by the gas'.

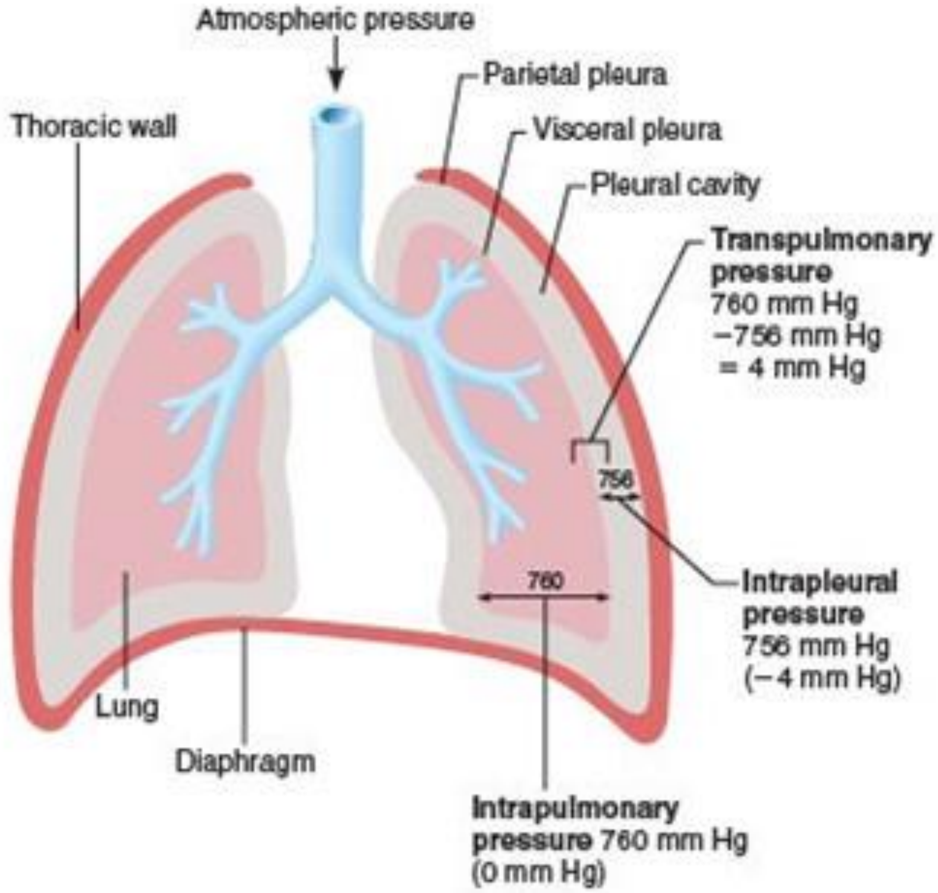
Boyles Law and Ventilation



Boyles Law and Ventilation

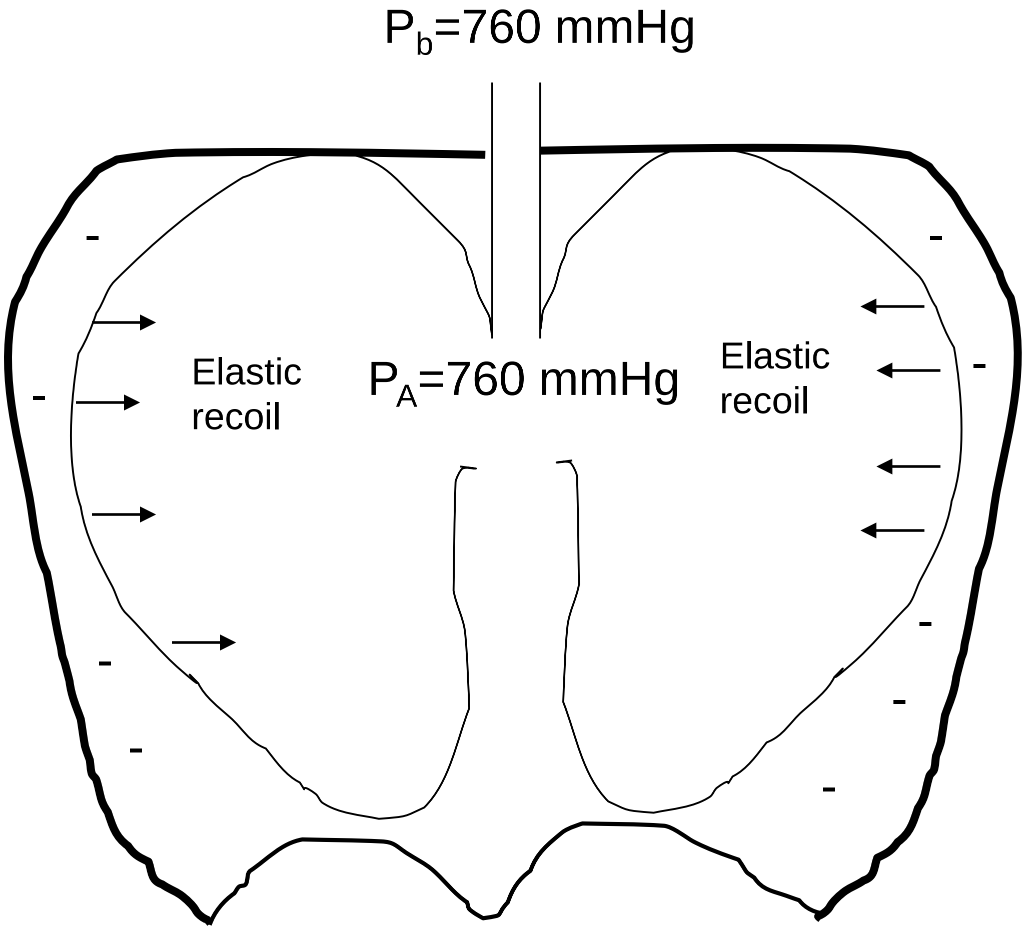


Static Lung Forces



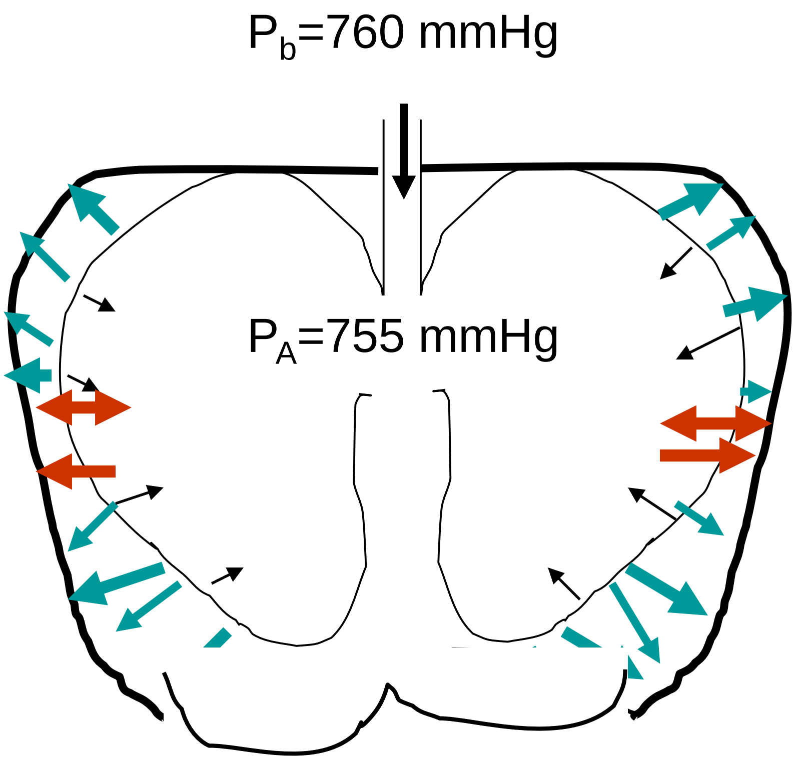
Pressures listed are
relative and absolute

Pulmonary Mechanics-Chest wall



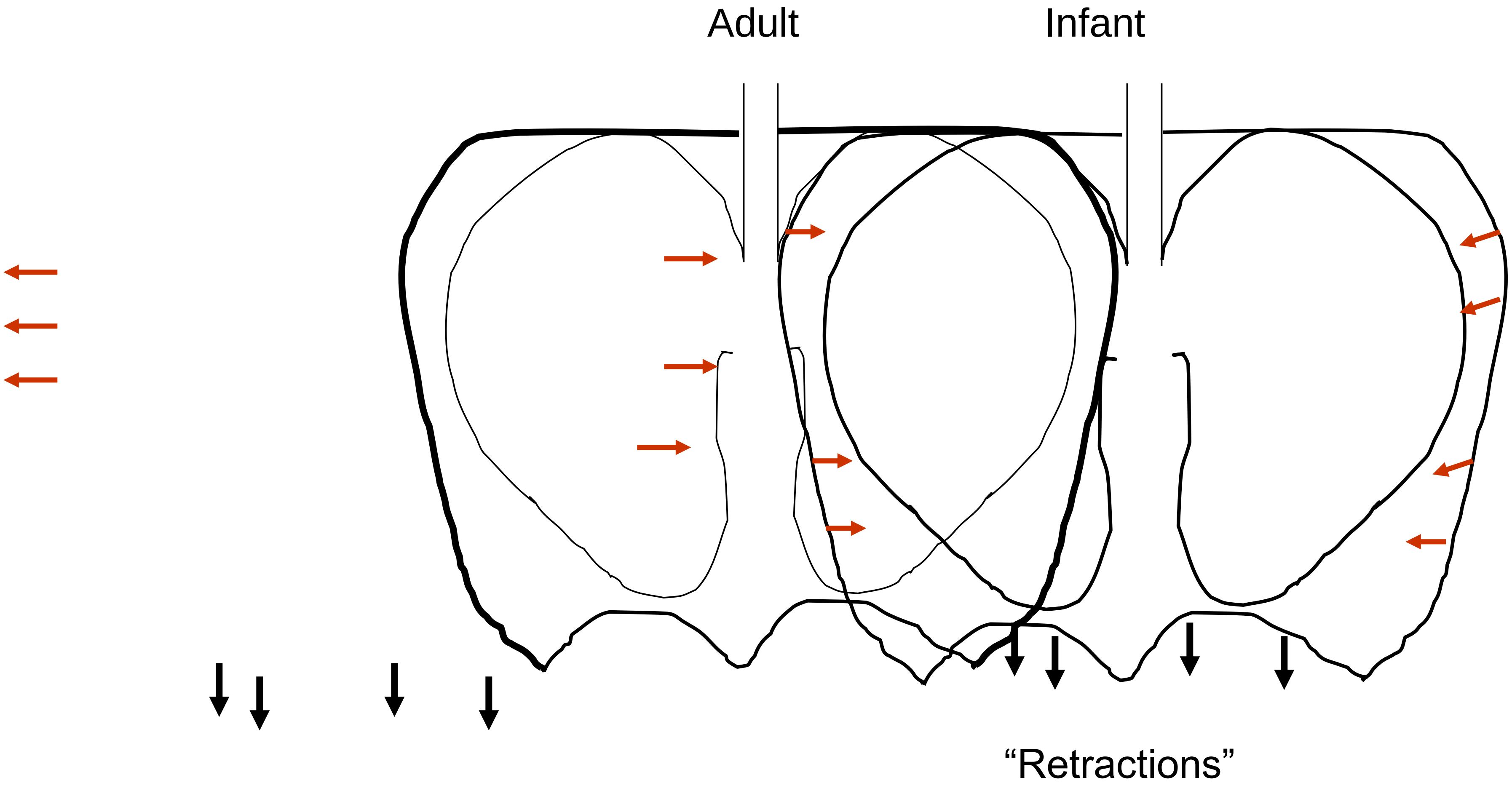
Negative pressure due to chest wall stability balances elastic recoil…leads to FRC

Pulmonary Mechanics-Chest Wall



Chest Wall Expansion increases the (-) intrapleural pressure, with lung expansion and decrease in intrapulmonary pressure

Adult vs Infant Mechanics



Deadspace

- Anatomical
  - gas in the conducting areas of the respiratory system
  - air does not come into contact with the alveoli
- Alveolar dead space
  - air contacting alveoli without blood flow in their adjacent pulmonary capillaries
  - ventilation without perfusion
- Physiological deadspace = anatomic + alveolar
- Can be calculated by the Bohr equation

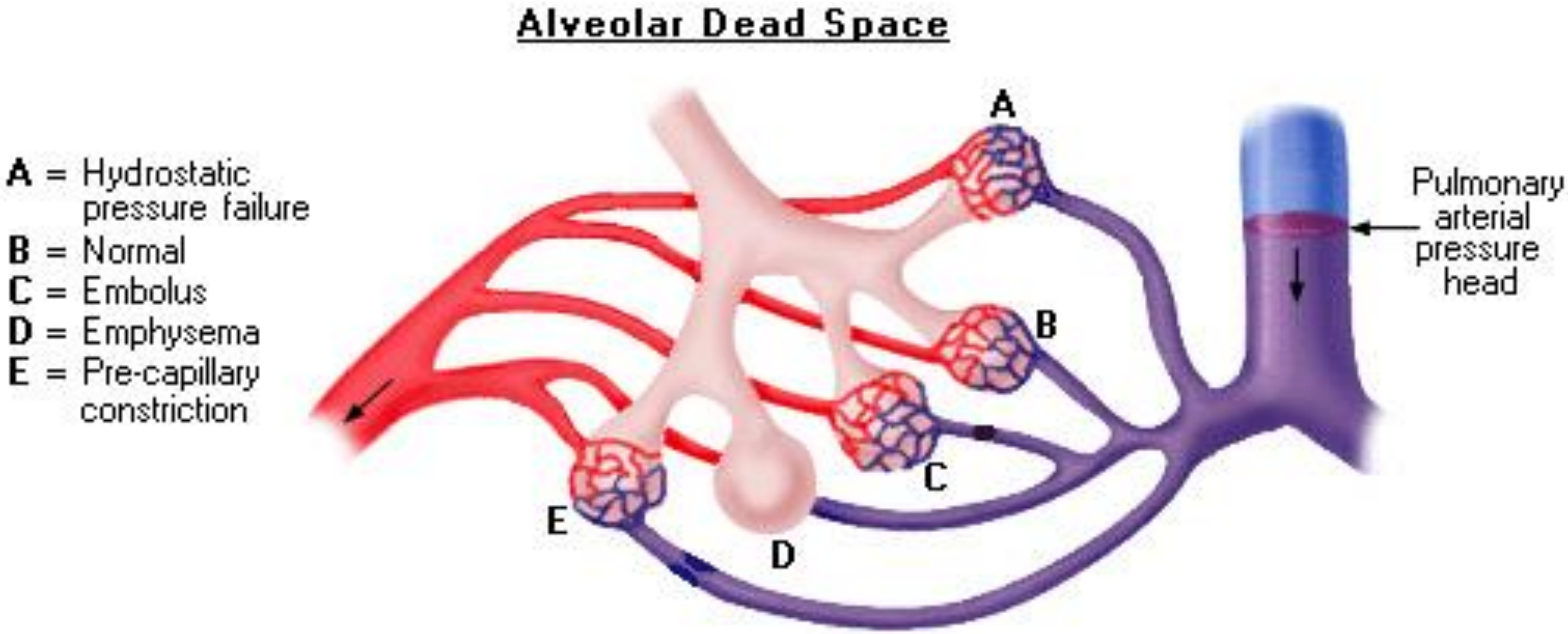
Deadspace Calculation

Estimated with capnography

$$\frac{V_d}{V_t} = \frac{P_aCO_2 - P_eCO_2}{P_aCO_2}$$

Vd is dead space volume
Vt is tidal volume
PaCO2 is the carbon dioxide in the arterial blood
PeCO2 is the partial pressure of carbon dioxide in the expired air.

Alveolar Dead Space



ARS Question 2

- Compliance is

1. Change in volume/change in resistance
2. Change in resistance/change in volume
3. Change in volume/change in resistance
4. Change in volume/change in pressure
5. An office that makes sure I bill correctly

Compliance

- A measure of elasticity or distensibility
- Compliance = ΔVolume/ ΔPressure
- **Compliance** = ΔVolume/ ΔPressure
- Compliance = ΔVolume/ ΔPressure

Compliance

- Static Compliance
  - Measured during no gas flow (i.e., no ΔV)
  - Reflects the elastic properties of the lung
    - Tendency to recoil toward its original dimensions after removing distending pressure
- Dynamic Compliance
  - Measured during continuous breathing
  - Reflects elastic as well as resistive components
  - Measures from end of expiration to the end of inspiration for a given volume

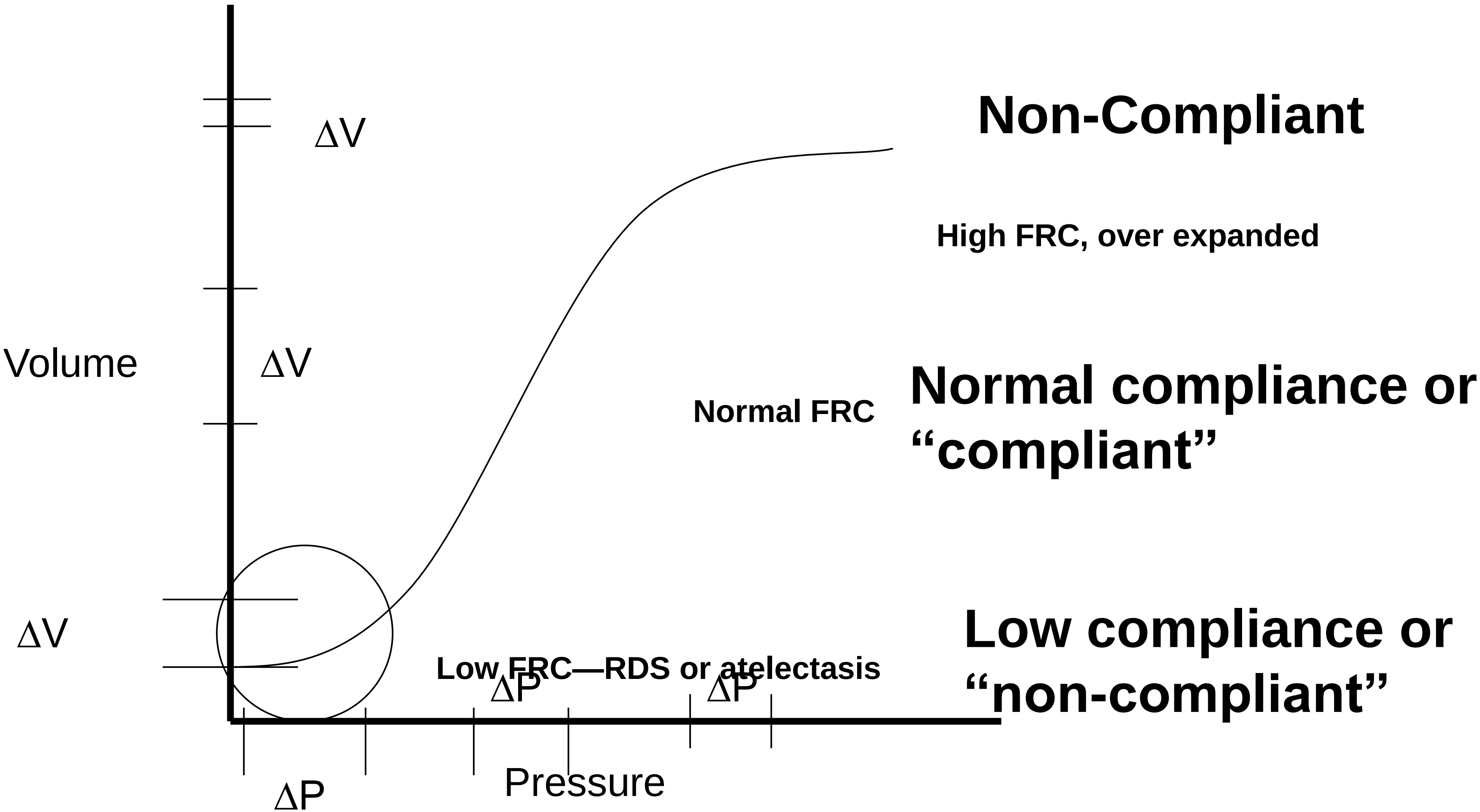
Compliance

So, what is the net affect of decreased compliance in a neonate with RDS?

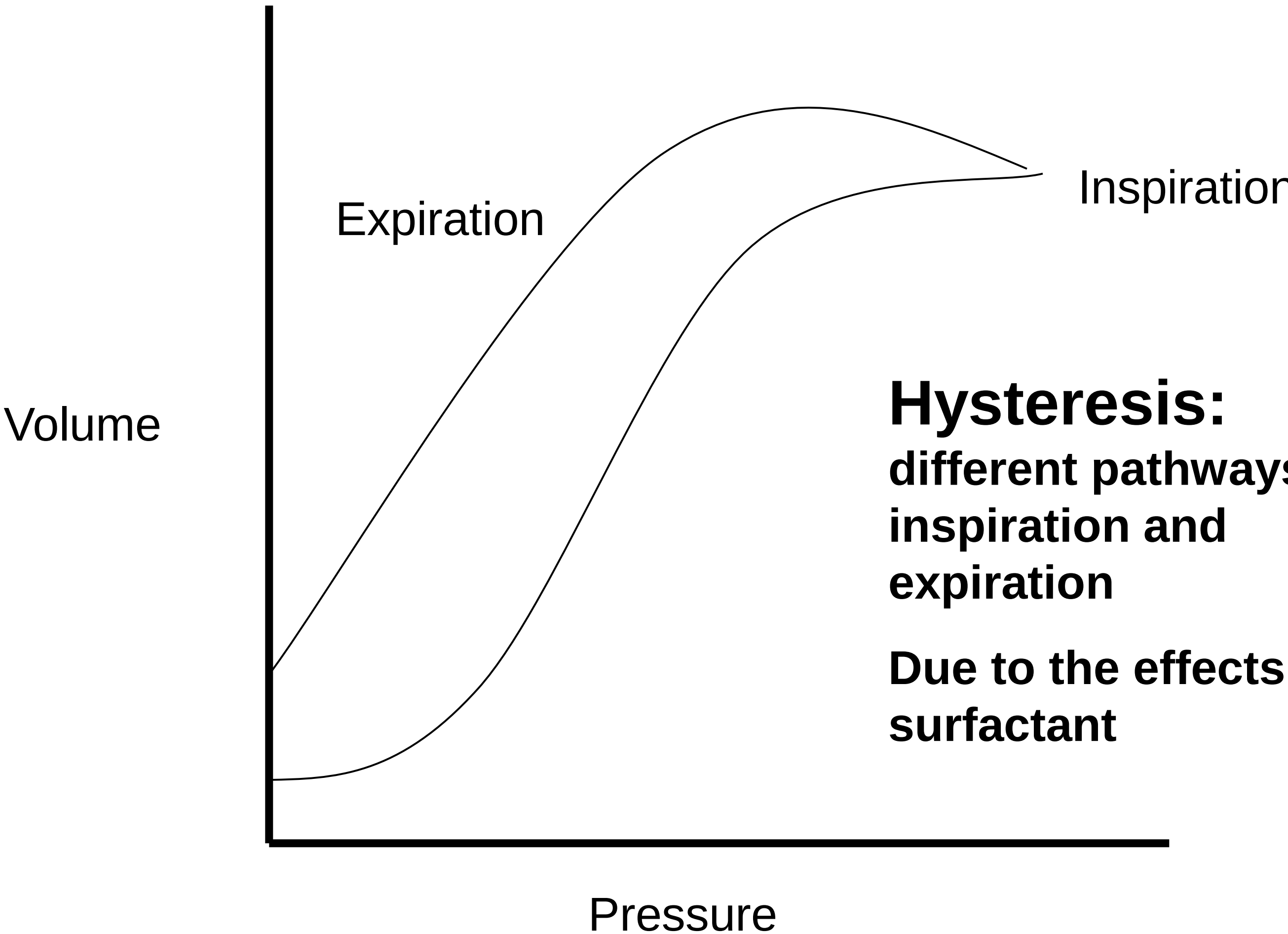
Compliance = Δ *Volume*/ Δ *Pressure*

1. For same pressure gradient, the tidal volume will be reduced
2. …or to maintain a tidal volume, the pressure gradient must increase

Pressure-Volume Relationships



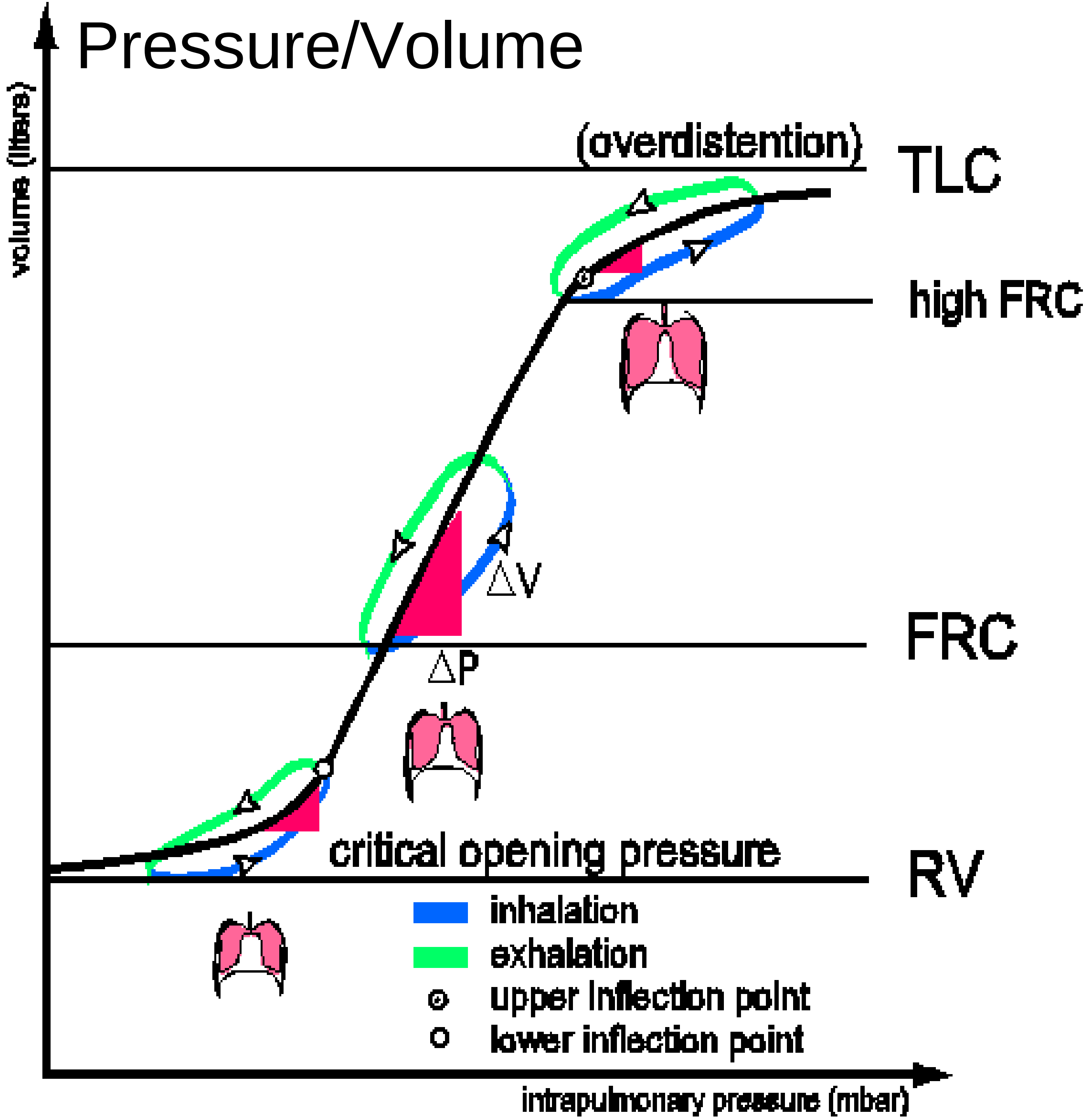
Pressure-Volume Relationships



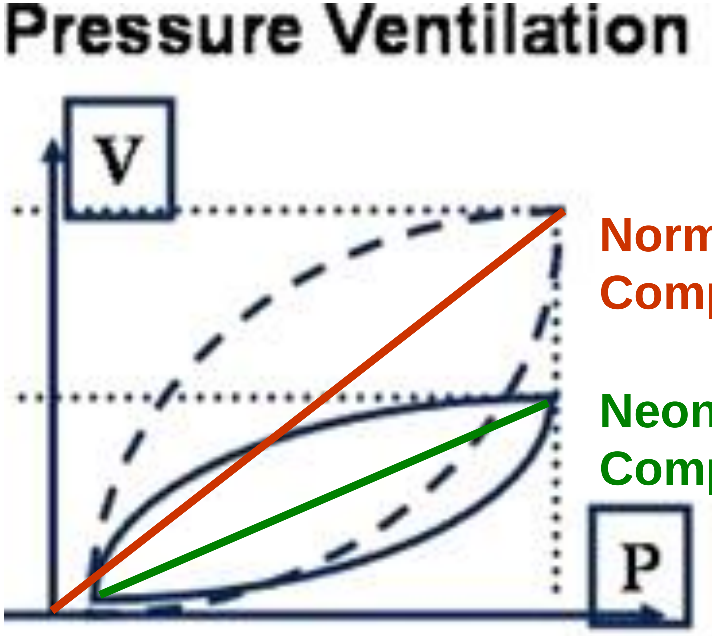
Hysteresis:

different pathways for inspiration and expiration

Due to the effects of surfactant


Pressure/Volume
volume (liters)
(overdistention)
TLC
high FRC
ΔV
FRC
ΔP
critical opening pressure
RV
inhalation
exhalation
upper Inflection point
lower inflection point
intrapulmonary pressure (mbar)

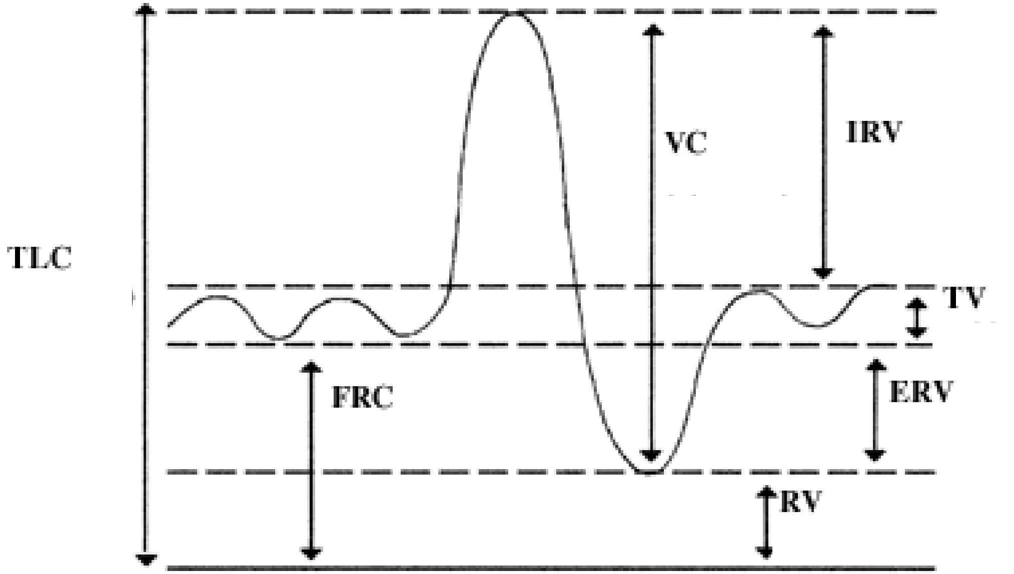
Pressure Volume Relationships



Normal Lung and Compliance

Neonatal RDS—Decreased Compliance

Lung Volumes



Lung Volumes measured with a spirometer during quiet breathing with one maximum breath. Values shown are for an average-sized healthy young male.

RV	*Residual volume*	*FRC*	*Functional residual capacity*
ERV	*Expiratory reserve volume*	*TV*	*Tidal vlume*
IRV	*Inspiratory reserve volume*	*VC*	*Vital capacity*
TLC	*Total lung capacity*		

Fig 1

Comparison of Lung Mechaics

- Neonate
  - ↑ RR
  - ↑ Minute ventilation
    - TV x RR
  - ↑Alveolar ventilation
    - (TV-Deadspace) x RR
  - ↑Oxygen consumption
- Adult
  - ↑TV
  - ↑Total lung capacity
  - ↑Inspiratory capacity
  - ↑Vital capacity

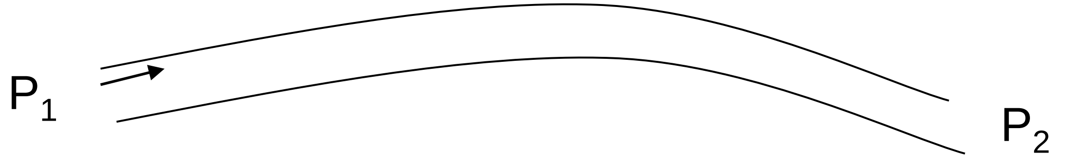
ARS Question 3

- All of the following are true about Resistance EXCEPT:

1. It is a property typically dealing with flow through tubes
2. Is directly related to length
3. Goes up to the 4^{th} power with changing the radius
4. Involves the viscosity of the substance

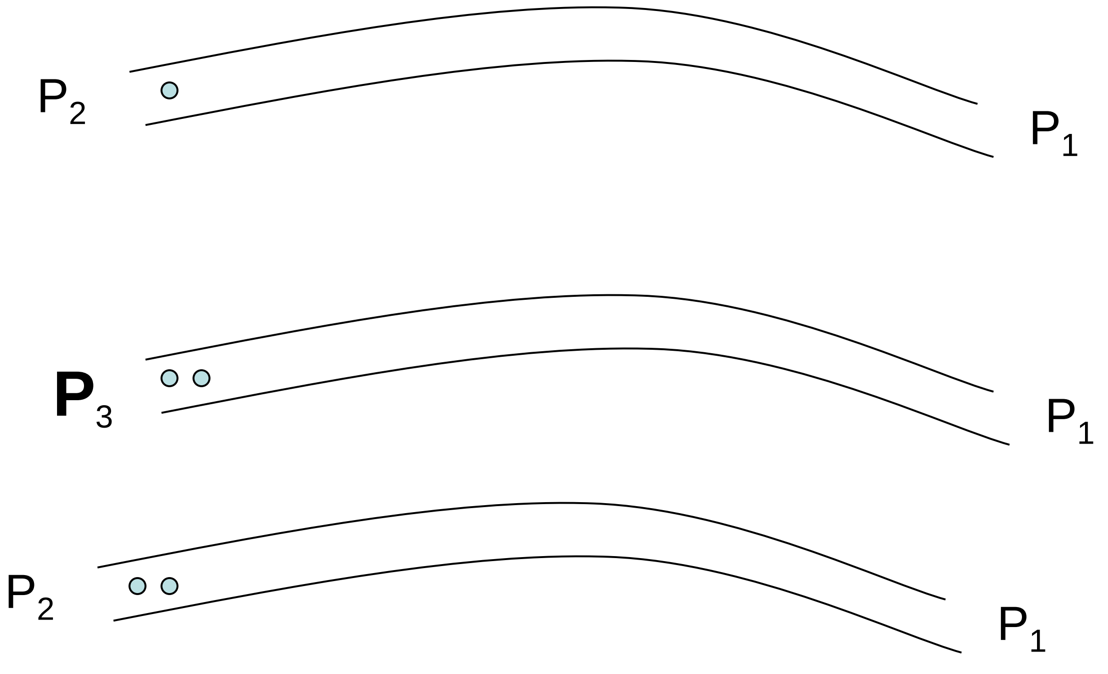
Resistance

- $R = \Delta P/\dot{V}$
- Typically think of the effects of resistance on either flow or pressure



Resistance

$R = \Delta P/\dot{V}$ ⟶ ⟶ $\dot{V} = \Delta P/R$



Resistance

$$R \infty L \times \eta / r^4$$

Length of tube

Length of airway

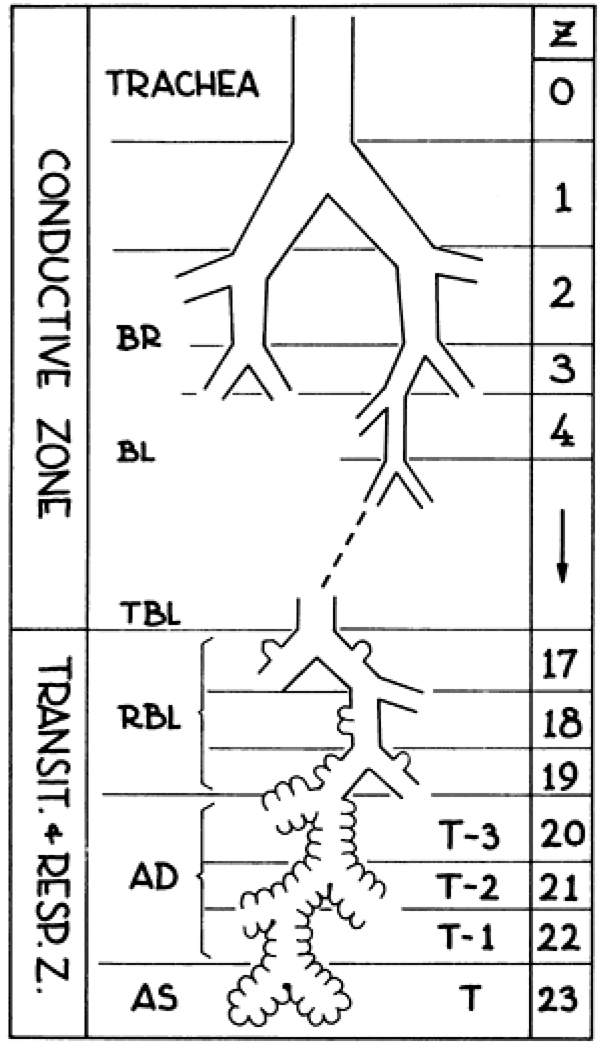
Viscosity

- Air
- Helium

Radius

- ET Tube
- Airways

Resistance

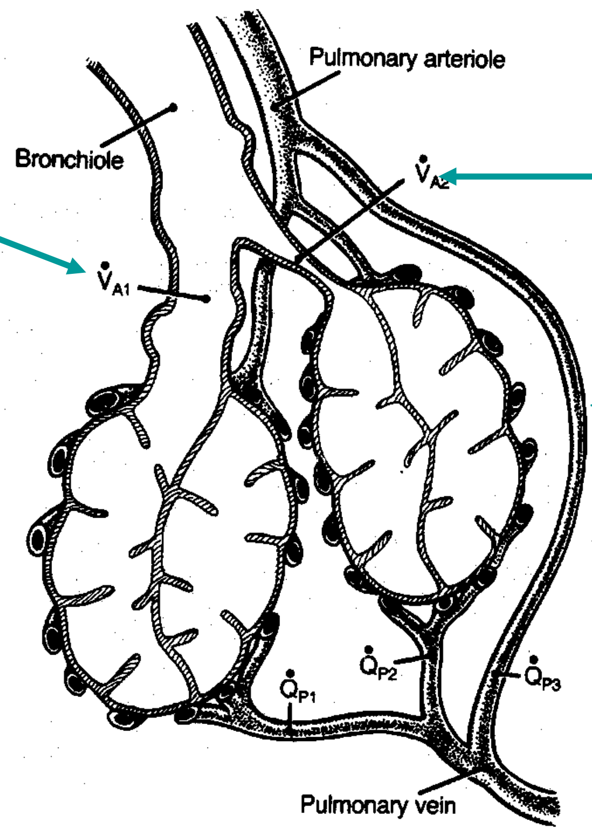


CONDUCTIVE ZONE
TRANSIT. + RESP. Z.
TRACHEA
BR
BL
TBL
RBL
AD
AS
T-3
T-2
T-1
T
Z
0
1
2
3
4
17
18
19
20
21
22
23

Lung Anatomy and Shunts

Normal

$\dot{V}_A / \dot{Q}_P$



Low

$\dot{V}_A / \dot{Q}_P$

Shunt

Three Alveoli And Gas Exchange

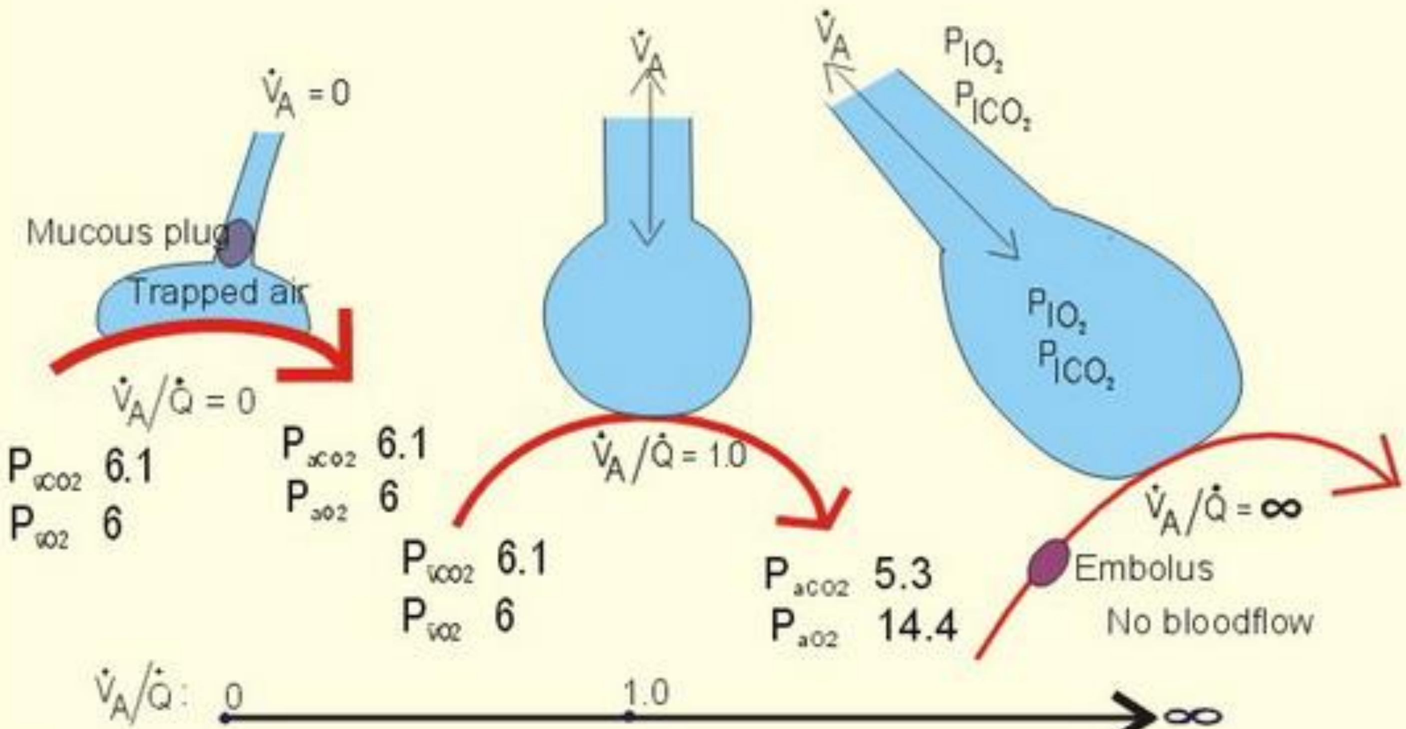
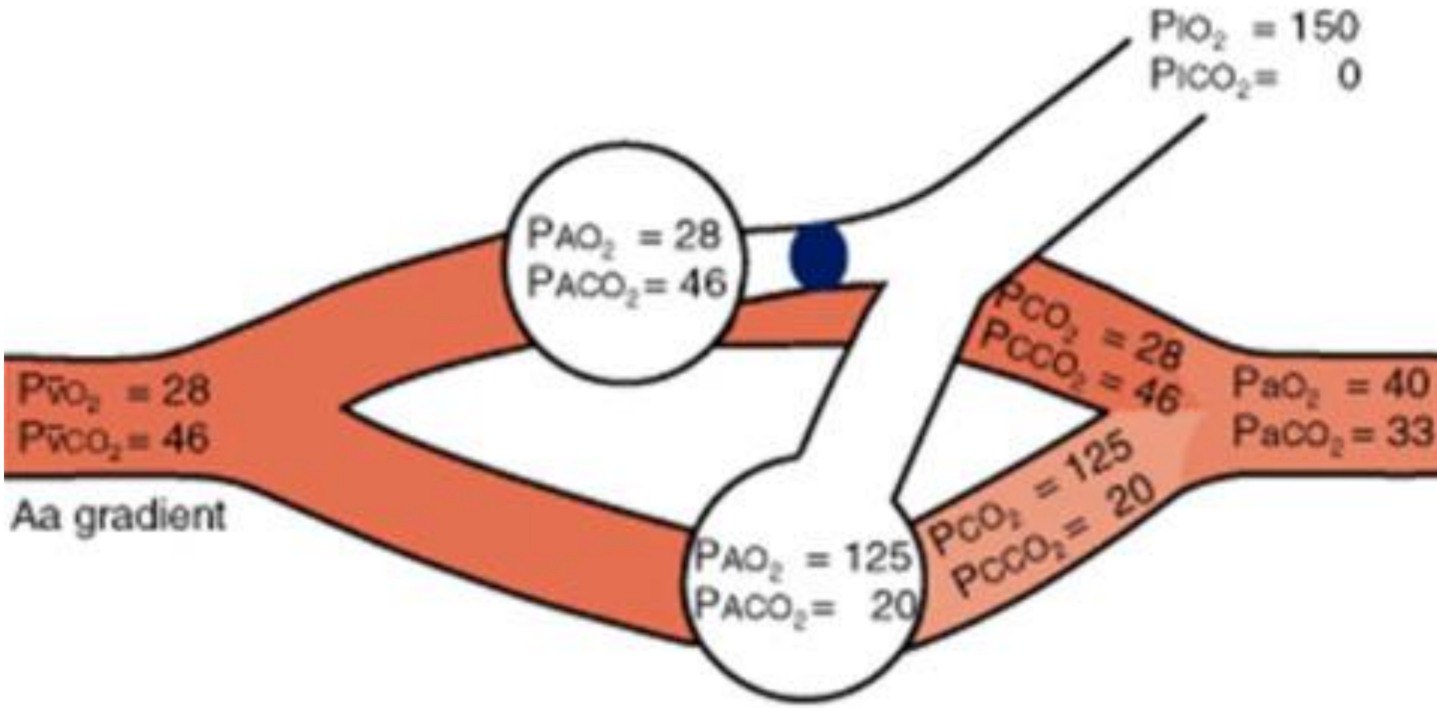


Fig. 14-2

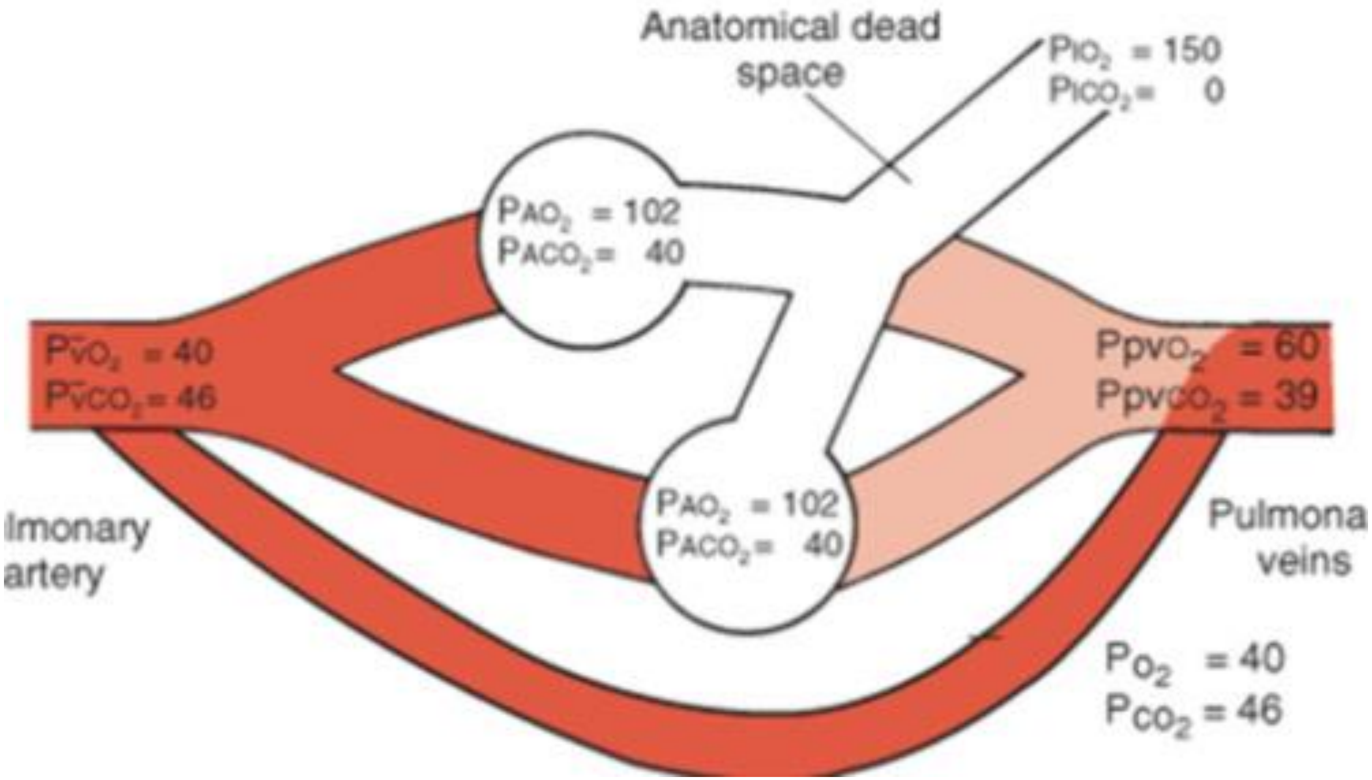
KMc

Physiologic Shunt or Intrapulmonary shunt

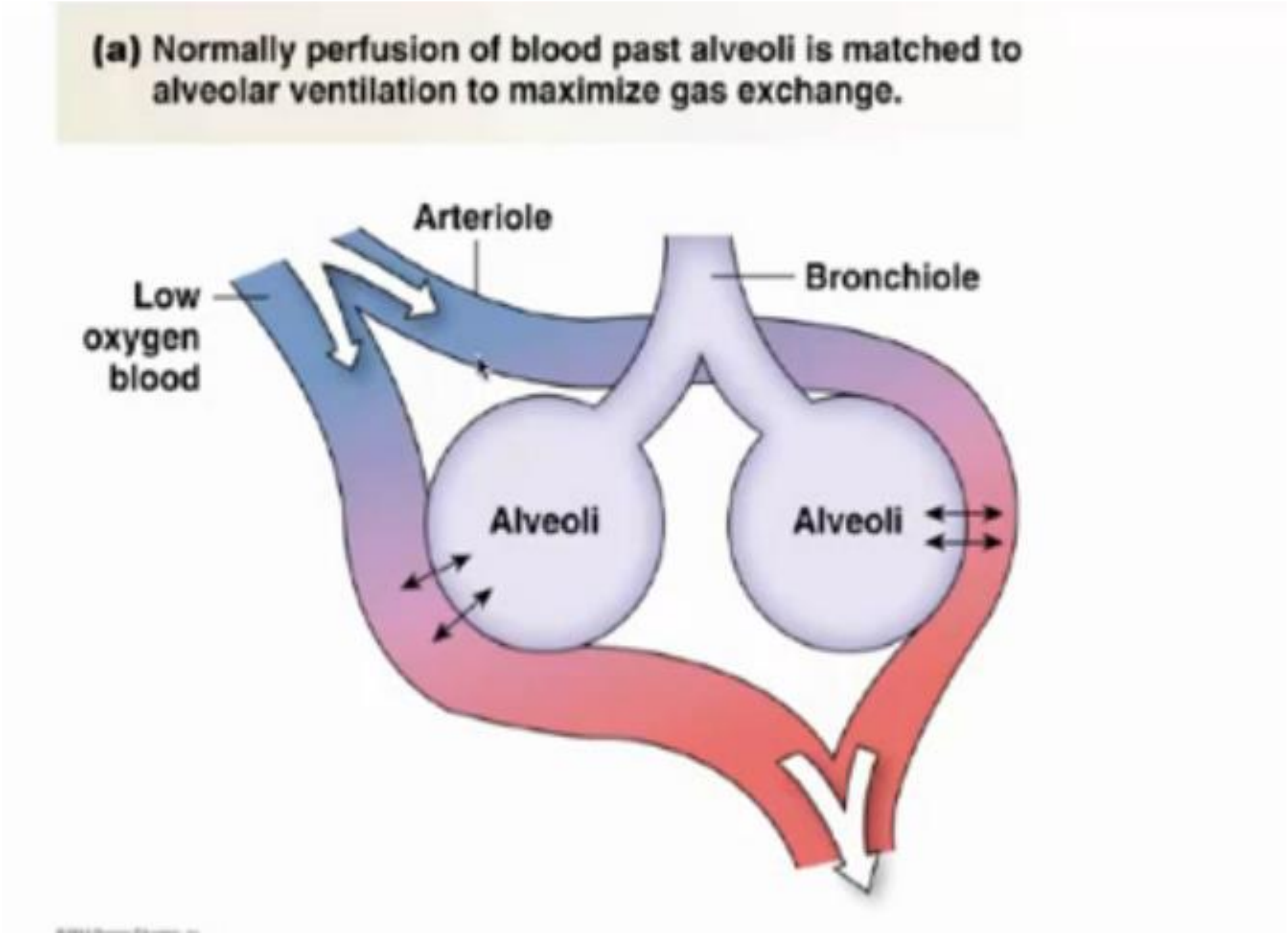


$AaDO_2 = 125 - 40 = 85$ mmHg

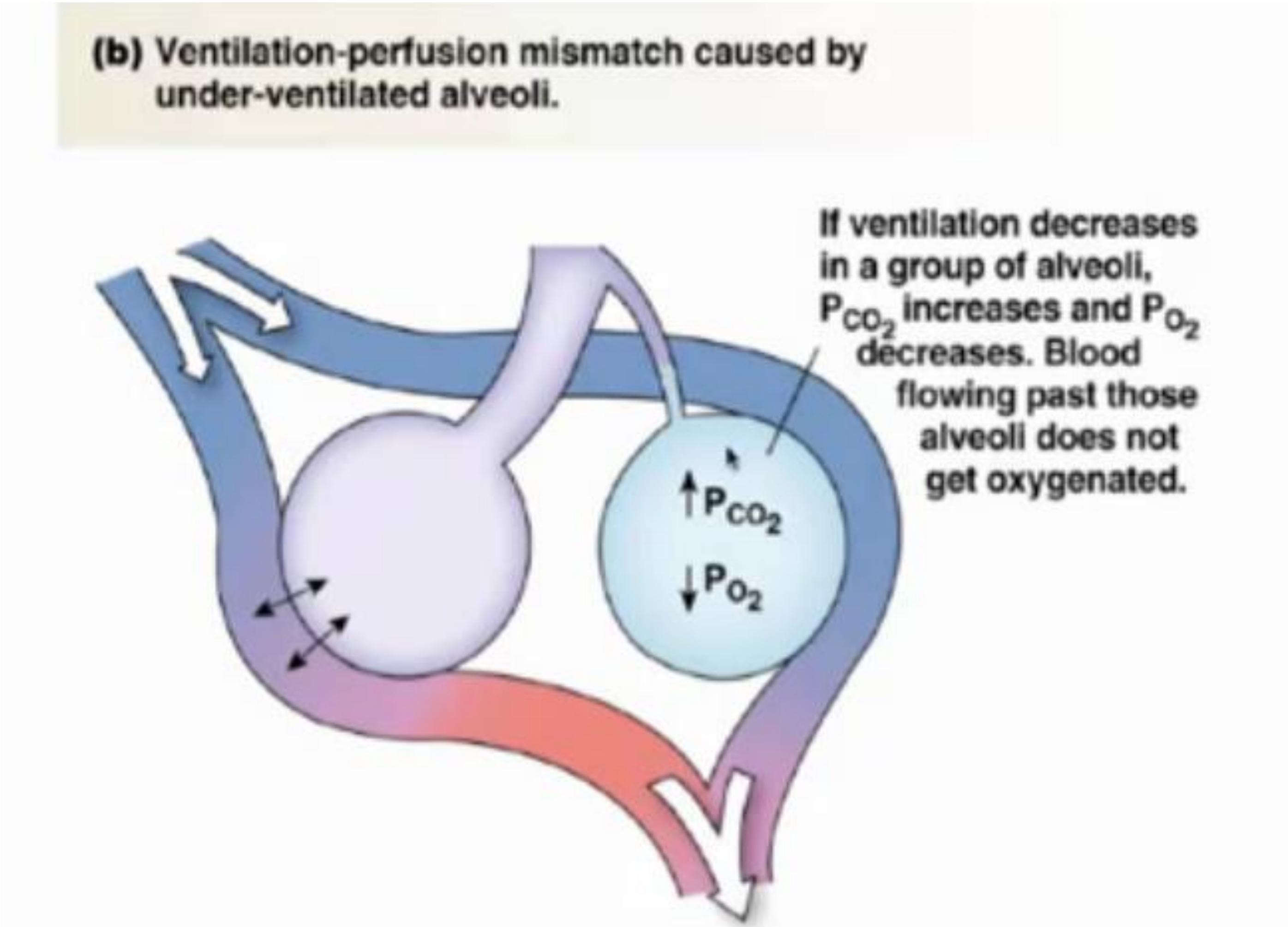
Venous-Arterial Shunt



Ventilation Perfusion Matching

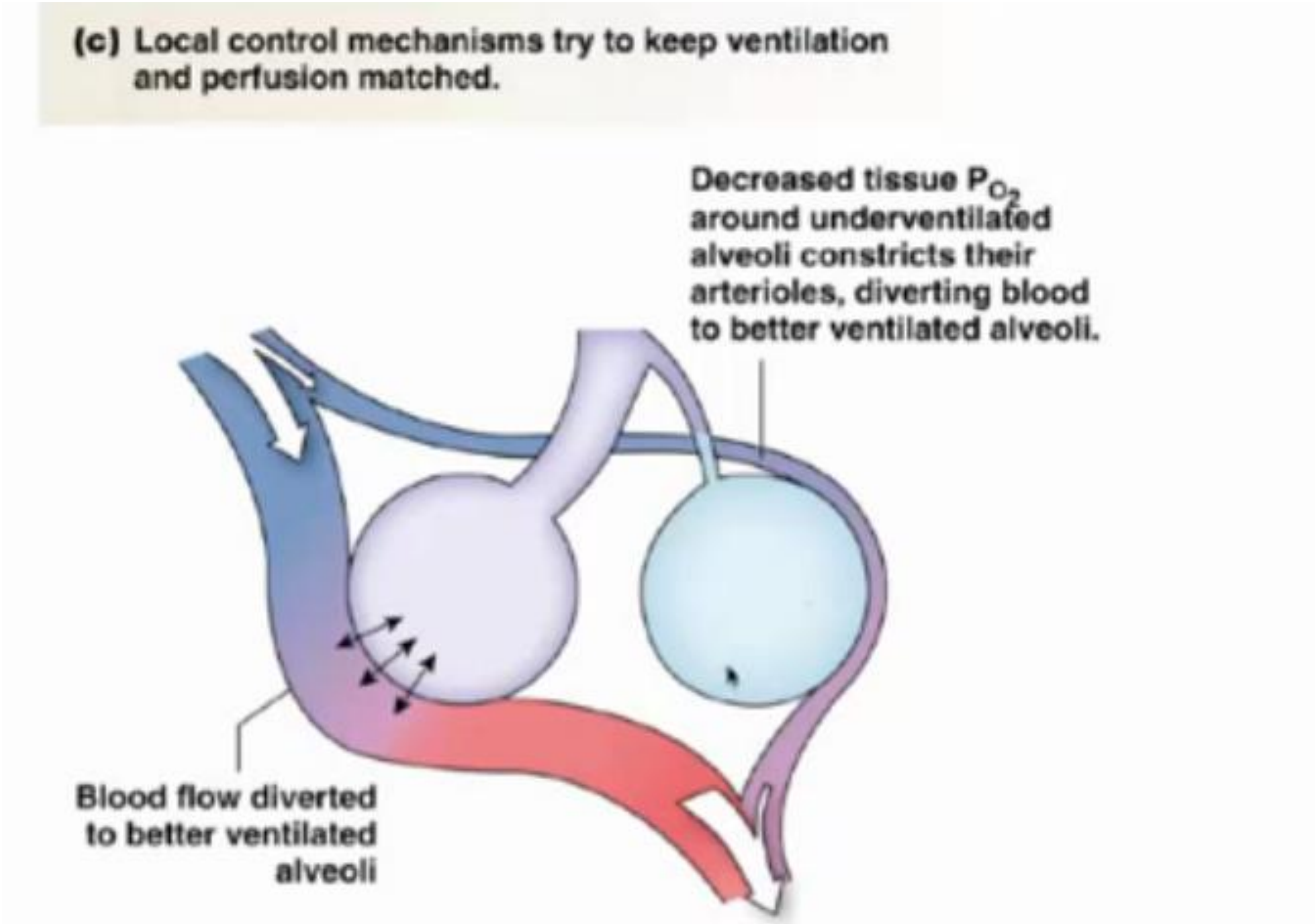


Low V/Q

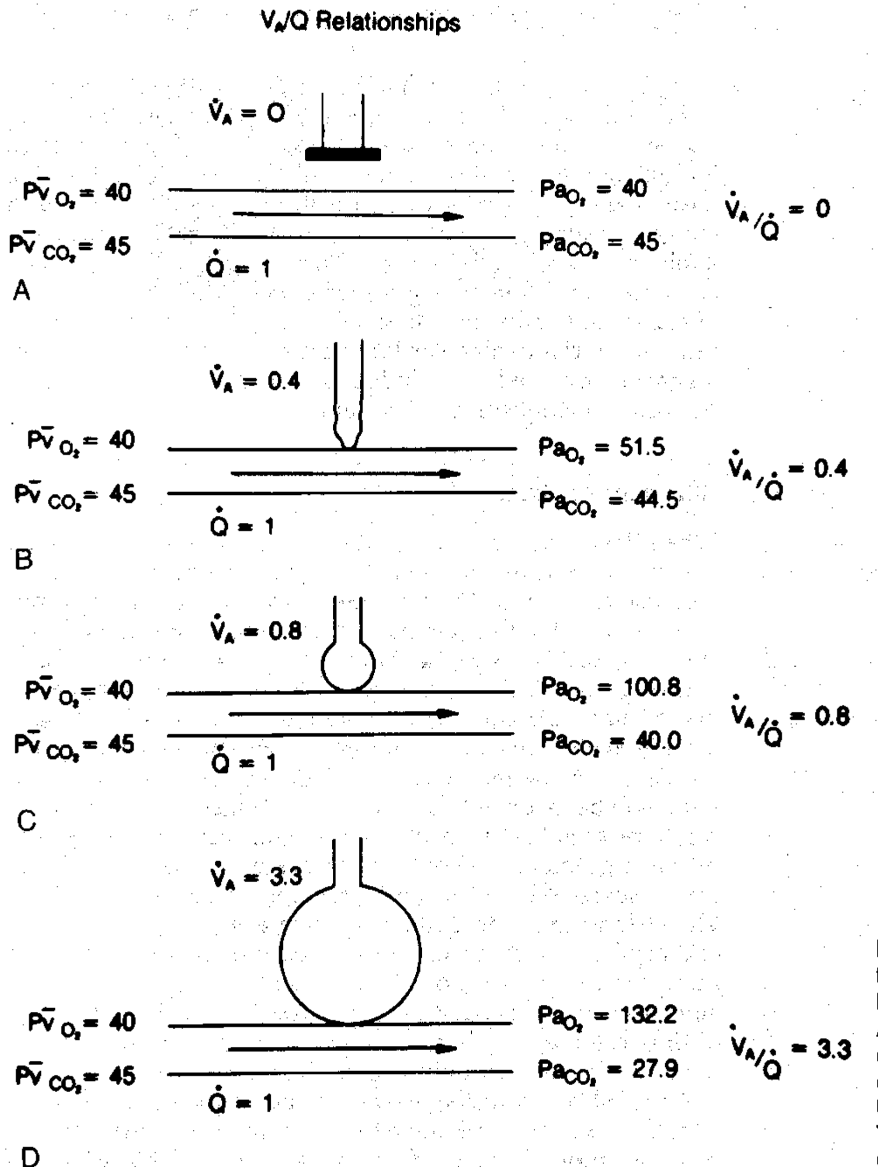


(b) Ventilation-perfusion mismatch caused by under-ventilated alveoli.
If ventilation decreases in a group of alveoli, P_{CO_2} increases and P_{O_2} decreases. Blood flowing past those alveoli does not get oxygenated.
↑P_{CO_2}
↓P_{O_2}

Hypoxic Pulmonary Vasoconstriction



Ventilation/Perfusion Relationships



Shunt

R-->L at PDA, foramen ovale

Hypoventilated lung unit

Normal

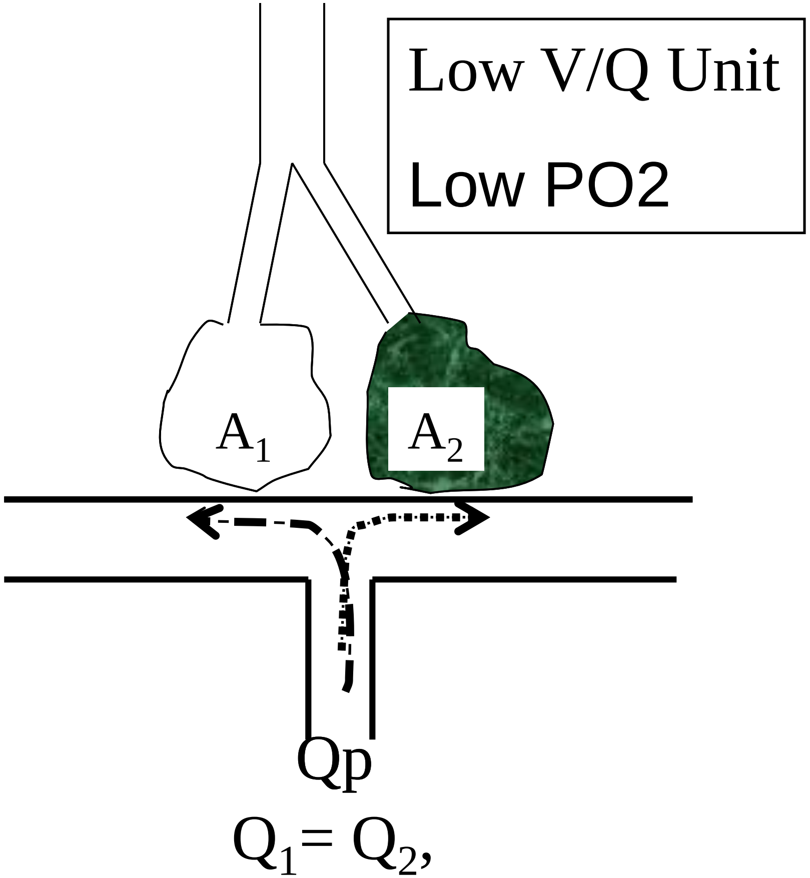
Hyperventilation

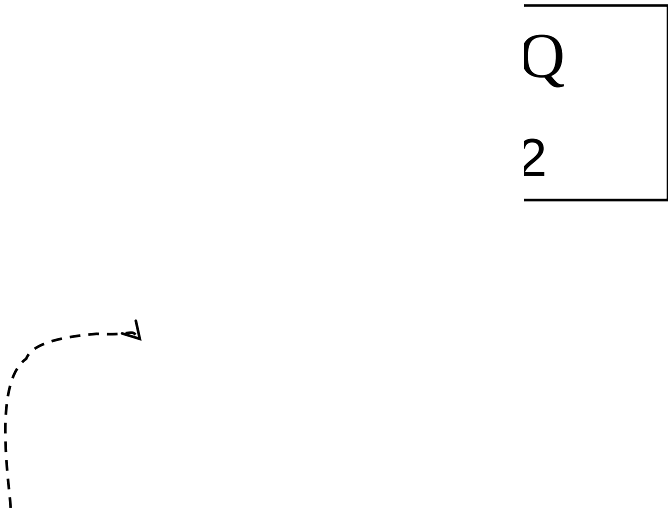
Factors Regulating Ventilation-Perfusion Matching

- Changes in Pulmonary Artery Pressure
  - Hypoxic Pulmonary Vasoconstriction and V/Q matching
  - Pulmonary vasoconstriction and V/Q mismatching
- Distribution of Ventilation

Hypoxic Pulmonary Vasoconstriction

- Occurs at higher PAO_2 than adults
- More vigorous response than adults





ARS Question 4

- Time constant of the lung is

1. Compliance x resistance
2. Is high in acute RDS
3. Is low in meconium aspiration syndrome
4. Is important only in the weaning phase of mechanical ventilation

Time Constants

- Compliance = ΔVolume/ ΔPressure

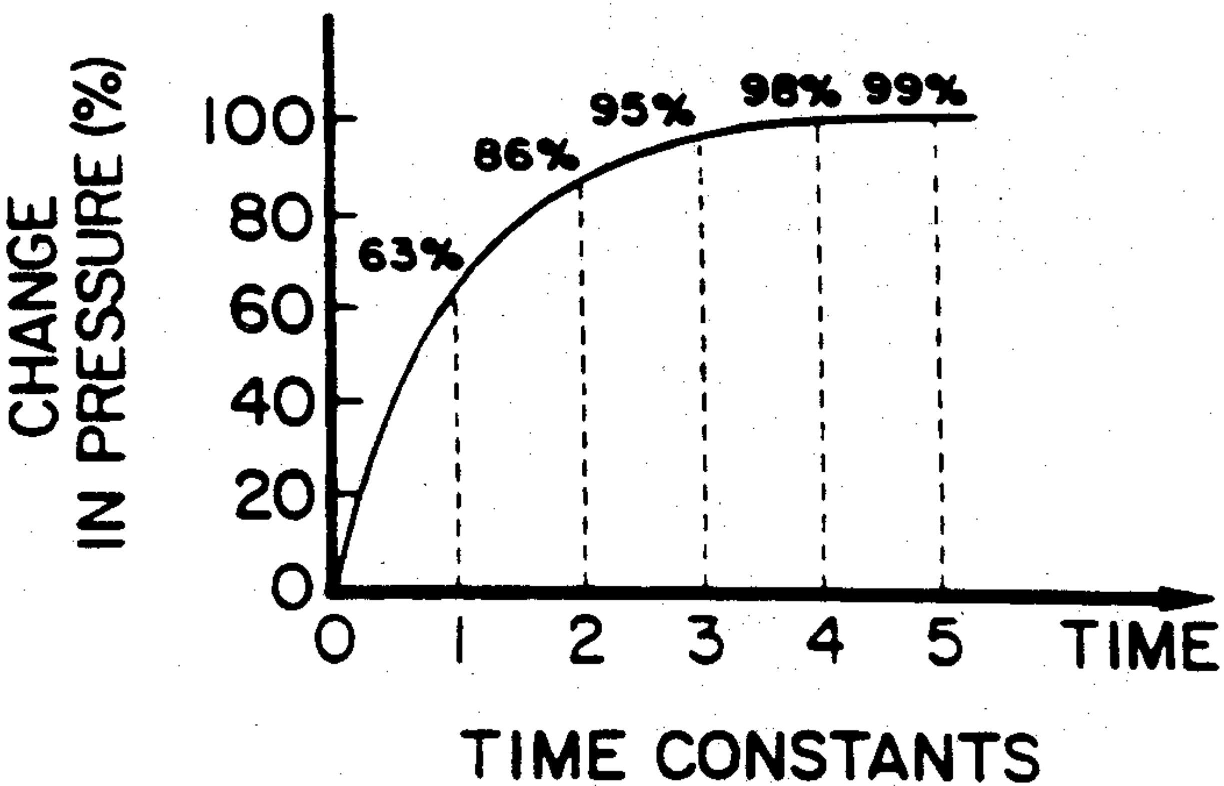
- ΔVolume = Compliance x ΔPressure
  - However, there must be a TIME element involved for the ΔVolume to occur.

- The time necessary to deflate 63% of its volume is called the time constant

Time Constant

<u>Mathematical Product :</u>

time constant = compliance x resistance



Time Constant

- $TC = R \times C$
  - $R = P/\dot{V} =$ /Time
  - $C = V/P = V/$ $_2$
  - TC = time

Time Constant

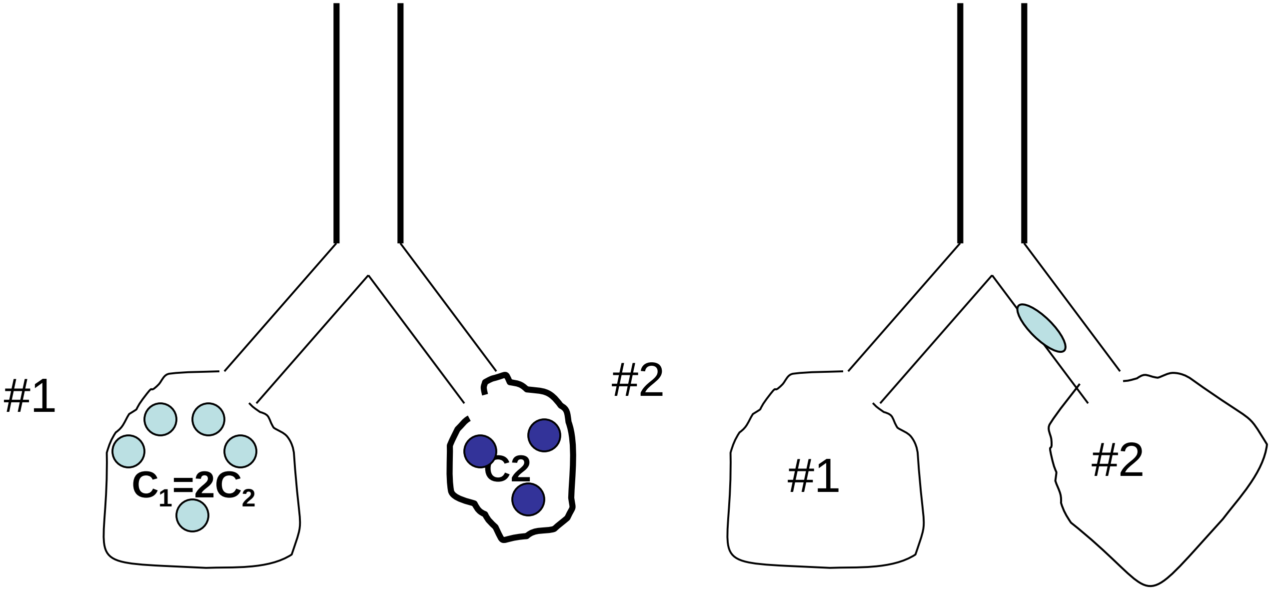
- Assume healthy infant
  - Resistance 30 cm H_2O/L
  - Compliance 0.004 L/ cm H_2O

1 TC = 0.12 sec

5TC = 0.6 sec

Thus, inspiratory or expiratory phase needs to be 0.6 sec (assuming phases are equivalent)

Time Constants



TC_1 = R x **$2C_2$**

TC_2 = R x **C_2**

$TC_1 = R_1 \times C_1$

$TC_2 = R^4 \times C_1$

$TC_2 = (TC_1)^4$

Time Constants

- Normal TC = 0.12-0.15 sec
  - TC = 63% emptying
  - 2 TC = 84% emptying
  - 3 TC = 95 % emptying

- RDS
  - TC ≈ 0.05 sec

Summary

- Think about flow through pipes
- Hypoxia can come from VQ mismatch or shunt
- Need adequate time for gas exchange to take place from the mouth to the alveoli