Respiratory Physiology & Mechanics

Primary Functions of the respiratory system

Breathing

VENTILATION

RESPIRATION

Other functions

- Acid-Base balance

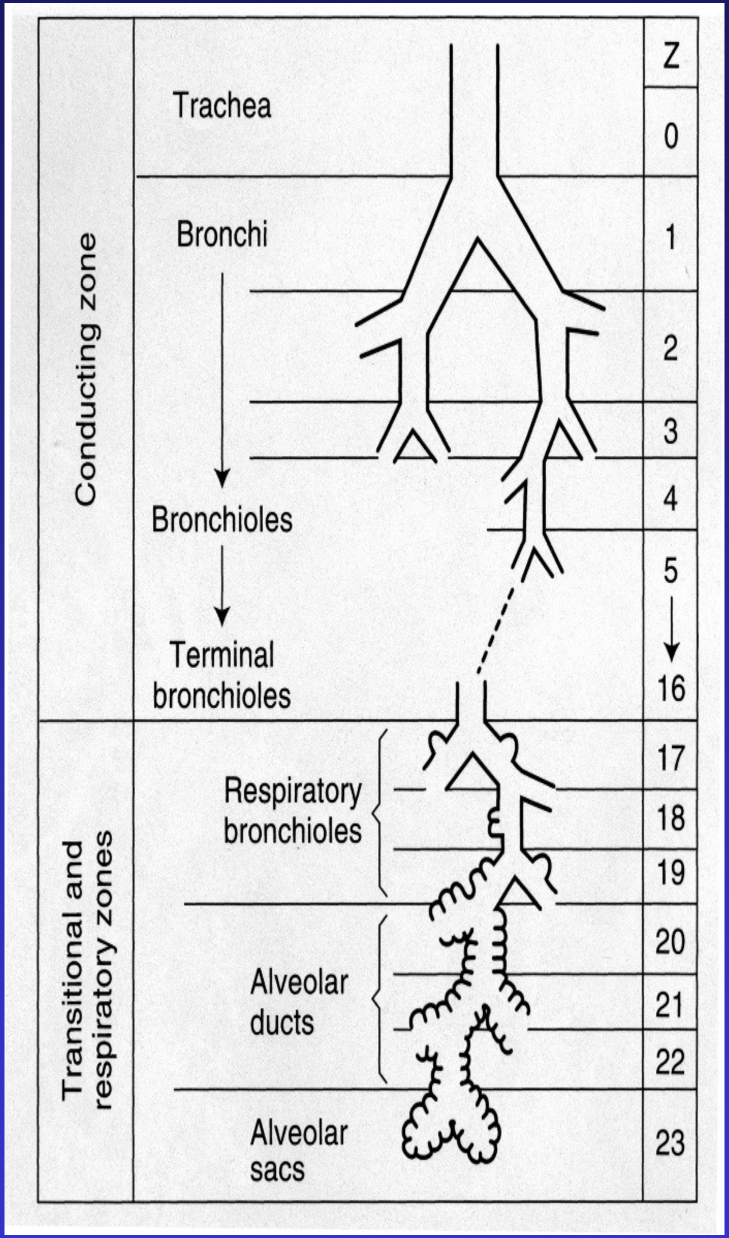
$$CO_2 + H_2O \rightleftharpoons H2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

- Phonation
- Pulmonary Defense mechanisms

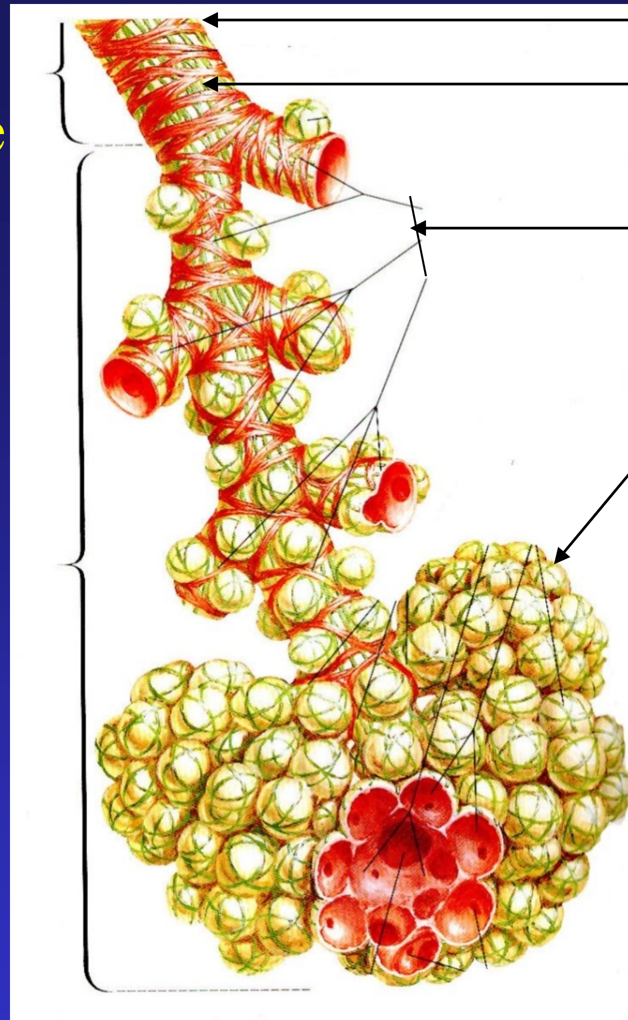
-Filtration, humidify and warm air, macrophages

Pulmonary Ventilation

- Is the physical movement of air in and out of respiratory tract
- Provides alveolar ventilation

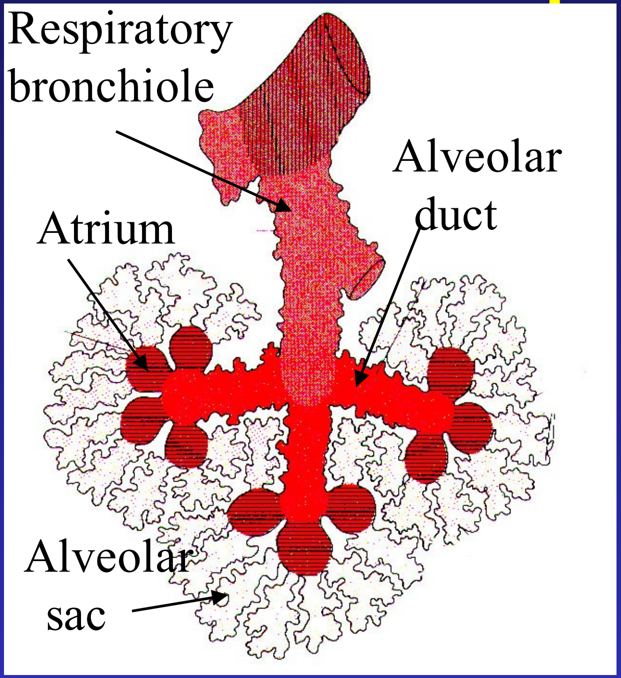


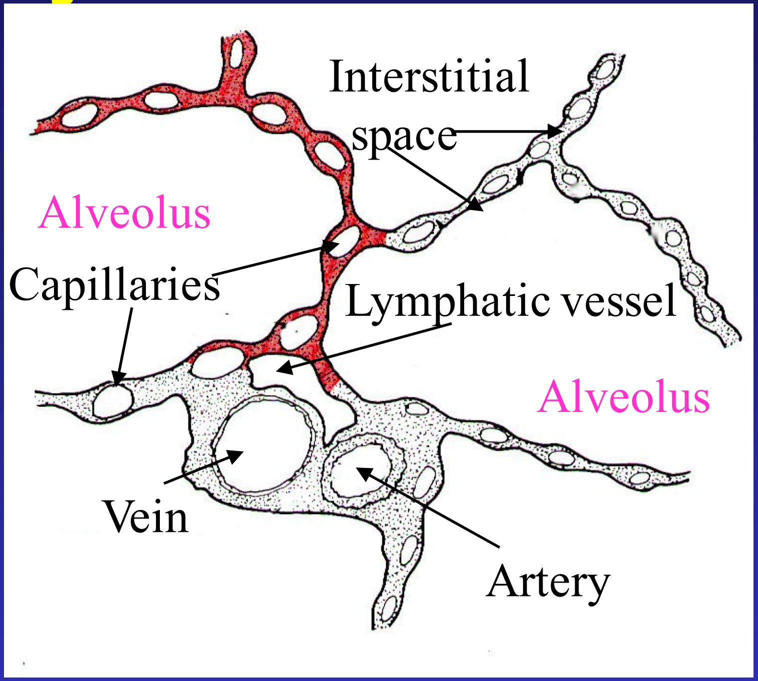
- Airways consist of branching tubes
- Conducting zone functions to lead inspired air to the gas exchange areas
- Conducting zone is the anatomical dead space –no gas exchange occurs
- Volume dead space = 150 ml
- Volume of the alveolar region = 2.5 – 3 liters.



- Lung tissue is very elastic
- Elastic force is also generated by the surface tension in the fluid lining the alveoli

Respiratory unit





- 300 million alveoli in 2 lungs
- Walls of the respiratory unit are very thin and surrounded by capillaries.
- Known as respiratory membrane

مکانیک تهویه

- به مجموعه عواملی اطلاق می شود که موجب تهویه می گردد

۱) فشارهای تنفسی الف) داخل ریوی ب) داخل جنبی

۲) چرخه تنفسی الف) دم ب) بازدم

۳) پذیرش ریوی

۴) حجم ها ریوی و تعداد تنفس

۵) مقاومت ریوی

۶) کار تنفسی

Intrapulmonary Pressure

- Also called intra-alveolar pressure
- Is relative to P_{atm}
- In relaxed breathing, the difference between P_{atm} and intrapulmonary pressure is small:
  - about —1 mm Hg on inhalation or +1 mm Hg on expiration

Intrapleural Pressure

- Pressure in space between parietal and visceral pleura
- Averages —4 mm Hg
- Maximum of —18 mm Hg
- Remains below P_{atm} throughout respiratory cycle

Tip:
The Respiratory Pump

- Cyclical changes in intrapleural pressure operate the respiratory pump:
  - which aids in venous return to heart

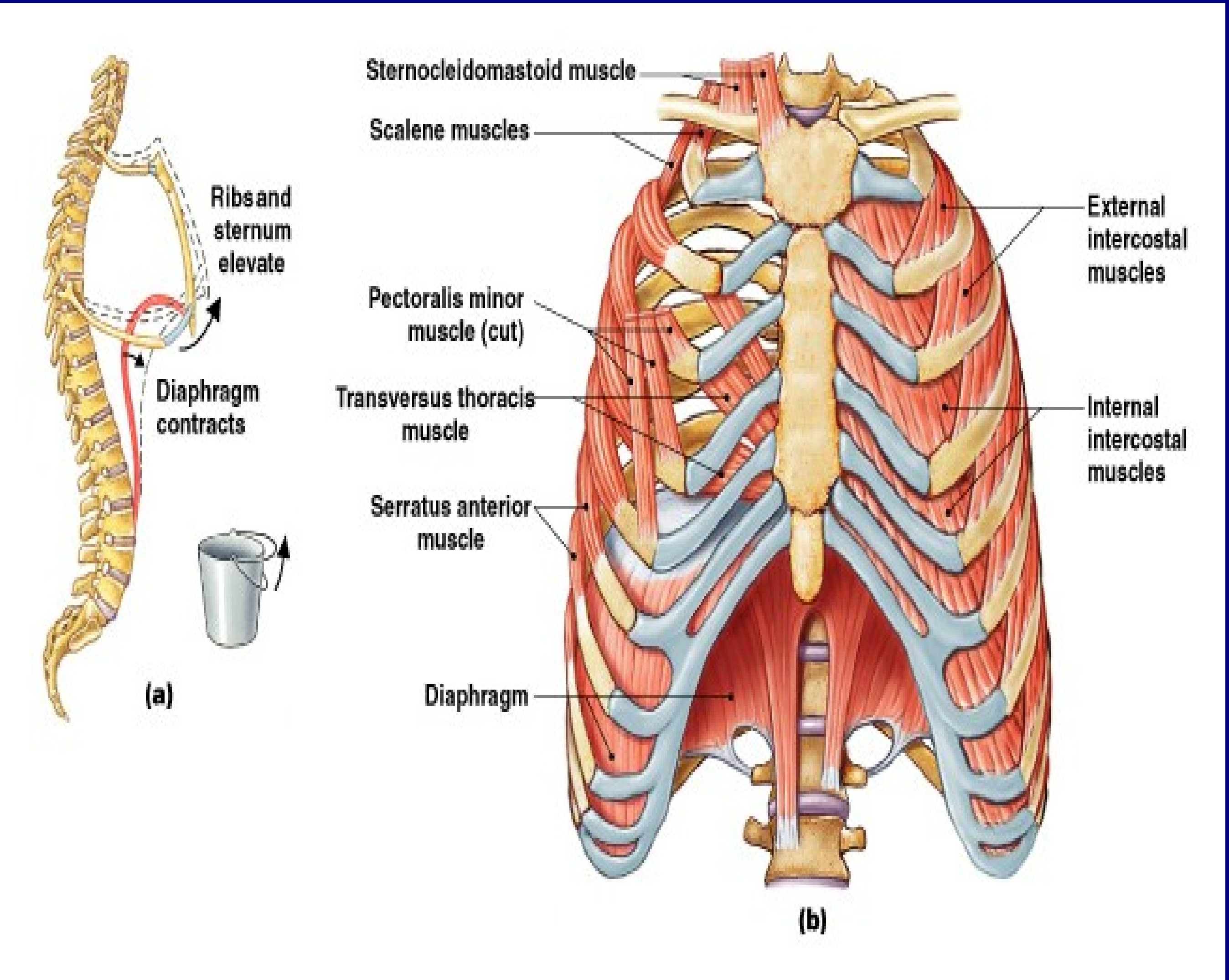
A Respiratory Cycle

- Consists of:
  - an inspiration (inhalation)
  - an expiration (exhalation)

Respiration

- Causes volume changes that create changes in pressure
- Volume of thoracic cavity changes:
  - with expansion or contraction of diaphragm or rib cage

The Respiratory Muscles



Most important are:
- the diaphragm
- external intracostal muscles of the ribs
- accessory respiratory muscles:
  - activated when respiration increases significantly

Figure 23-16a, b

The Respiratory Muscles

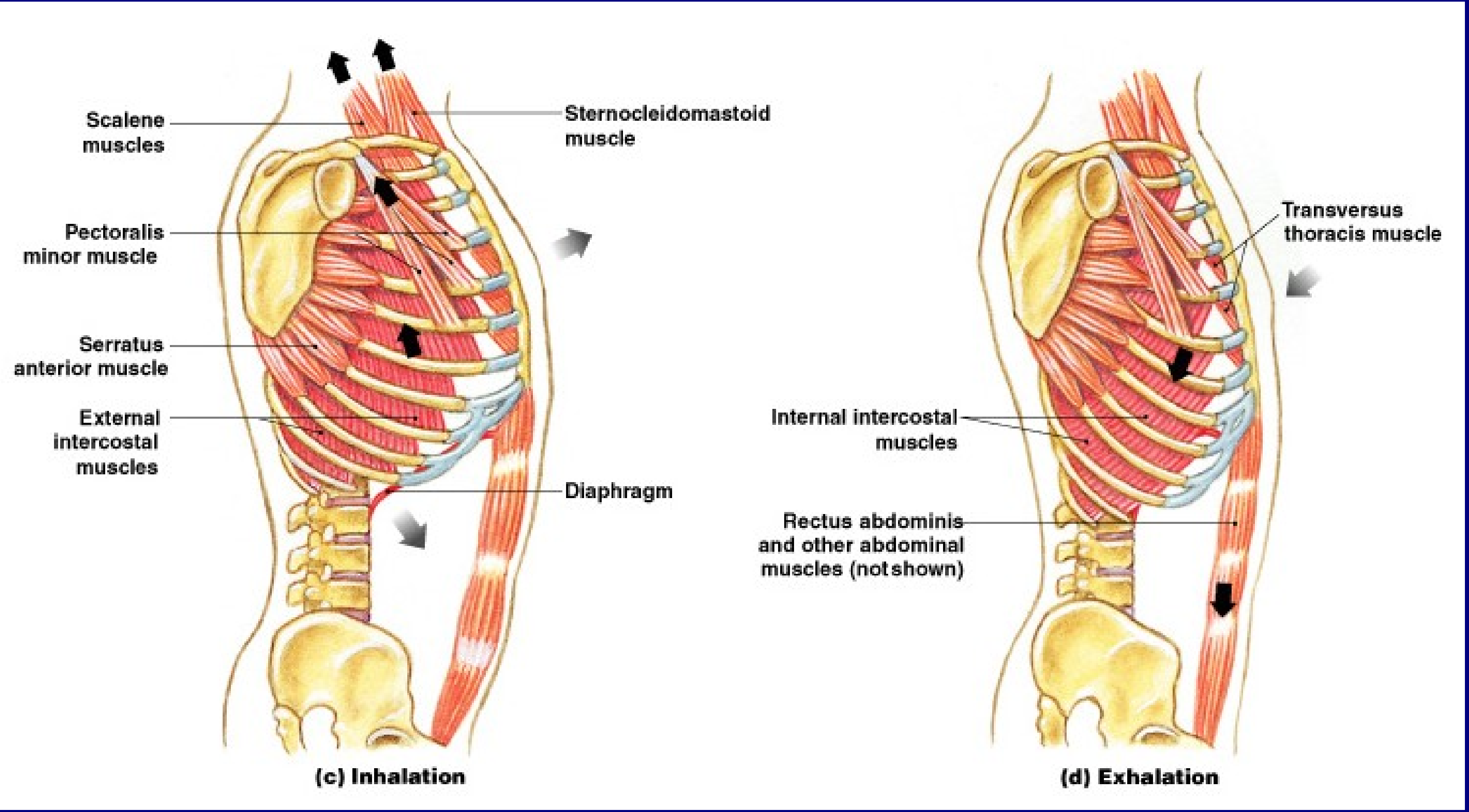


Figure 23-16c, d

Inspiration

Expiration

Quiet breathing

Predominantly Diaphragm

Active Breathing

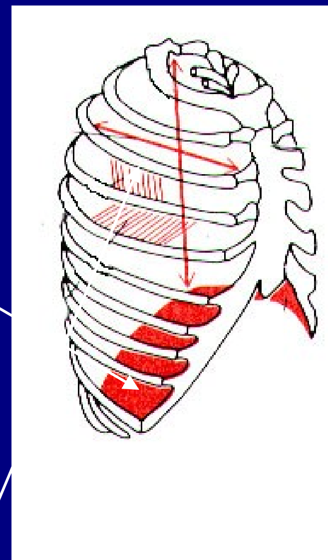
Diaphragm

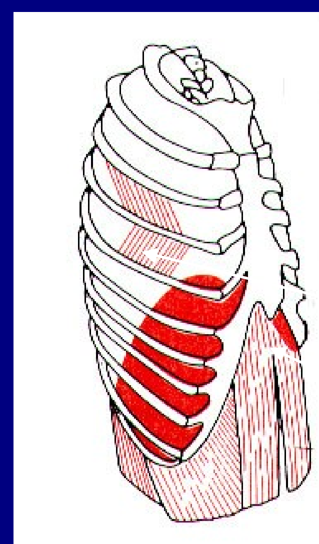
Elevation of ribs

→ external intercostals

→ Scalene muscles (1^{st} 2 ribs)

→ sternomastoids





Quiet breathing

Passive recoil of lungs

Active Breathing

Recoil of lungs

Contraction of abdominal muscles

Depression of ribs

→ internal intercostal

→ abdominal recti

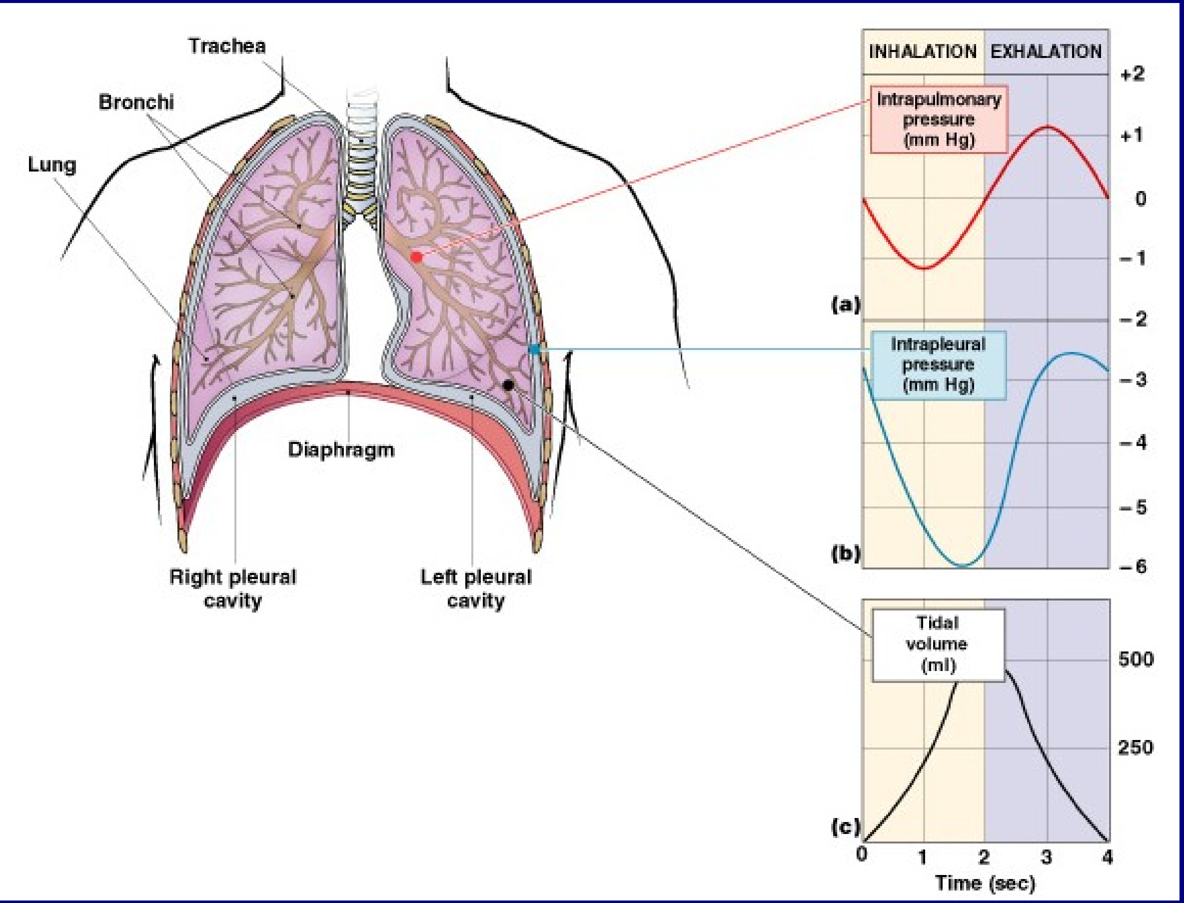
3 Muscle Groups of Inhalation

1. Diaphragm:
   - contraction draws air into lungs
   - 75% of normal air movement
2. External intracostal muscles:
   - assist inhalation
   - 25% of normal air movement
3. Accessory muscles assist in elevating ribs:
   - sternocleidomastoid
   - serratus anterior
   - pectoralis minor
   - scalene muscles

Muscles of Active Exhalation

1. Internal intercostal and transversus thoracis muscles:
   - depress the ribs
2. Abdominal muscles:
   - compress the abdomen
   - force diaphragm upward

Pressure and Volume Changes with Inhalation and Exhalation



- Can be measured inside or outside the lungs
- Normal atmospheric pressure:
  - 1 atm or Patm at sea level: 760 mm Hg

Figure 23-15

Compliance of the Lung

- An indicator of expandability
- Low compliance requires greater force
- High compliance requires less force

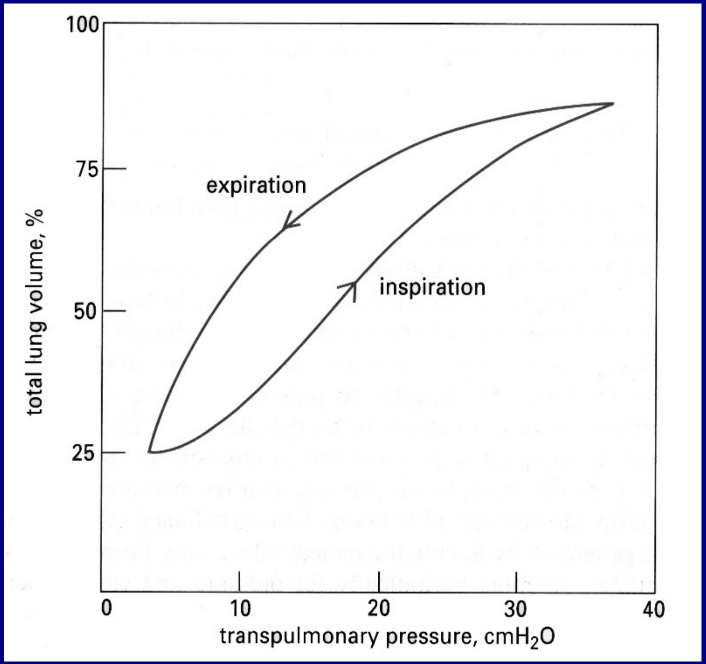
Factors That Affect Compliance

1. Connective-tissue structure of the lungs
2. Level of surfactant production
3. Mobility of the thoracic cage

Compliance

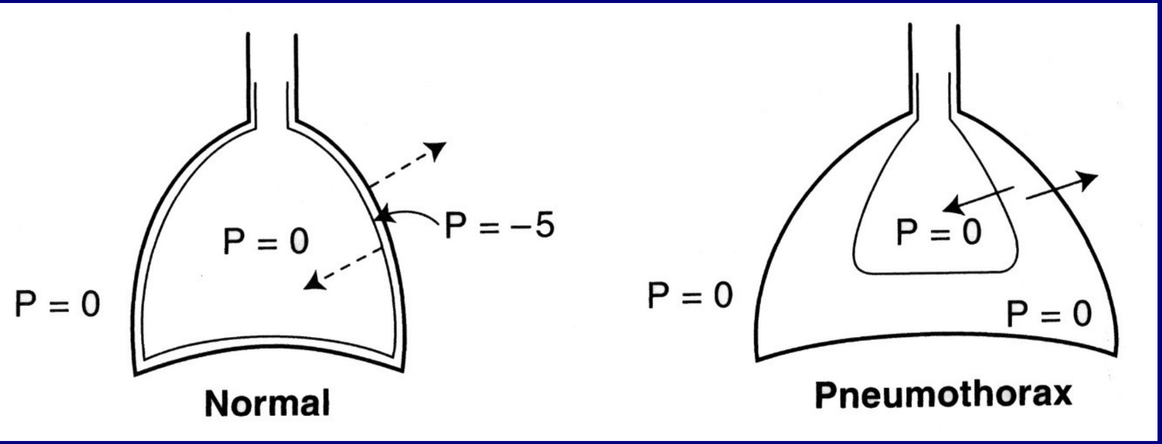
Lung compliance

$$= \frac{\text{change in lung volume}}{\text{change in TP pressure}}$$



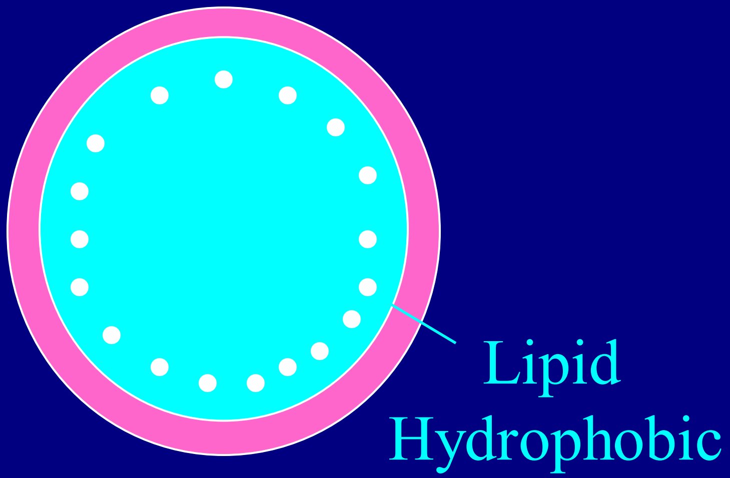
- Is the extent of lung expansion /unit ↑ in transpulmonary (TP) pressure.
- Determined by volume and distensibility
- Influenced by the elastic forces of the lung.

Elastic properties of the chest wall



- The thoracic cage has an outward elastic recoil.
- When the pressure in the pleural space = atmospheric the lung collapses but the chest wall bows out.

Surfactant
(Surface Acting Agent)



- Complex mix of phospholipids (85-90%), proteins and ions (10-15%).
- Decreases the surface tension in the alveoli
- Secreted by type II alveolar epithelial cells
- The cells are granular and comprise ~10% of the surface area of the alveoli

Lack of surfactant

- Not produced in fetal lung until after 4 months gestation, not fully functional until after 7 months. Premature birth results in unstable alveoli and Infant respiratory distress syndrome.

- Hypoxia may lead to a decrease in surfactant production and increase in destruction. Maybe a factor in adult respiratory distress syndrome.

- Pulmonary surfactant decreases the work of inspiration by decreasing surface tension and hence elastic recoil of the lung. Aids in the equalizing of pressure inside alveoli of different sizes.

Respiratory Rates and Volumes

- Respiratory system adapts to changing oxygen demands by varying:
  - the number of breaths per minute (respiratory rate)
  - the volume of air moved per breath (tidal volume)

Respiratory Volumes and Capacities

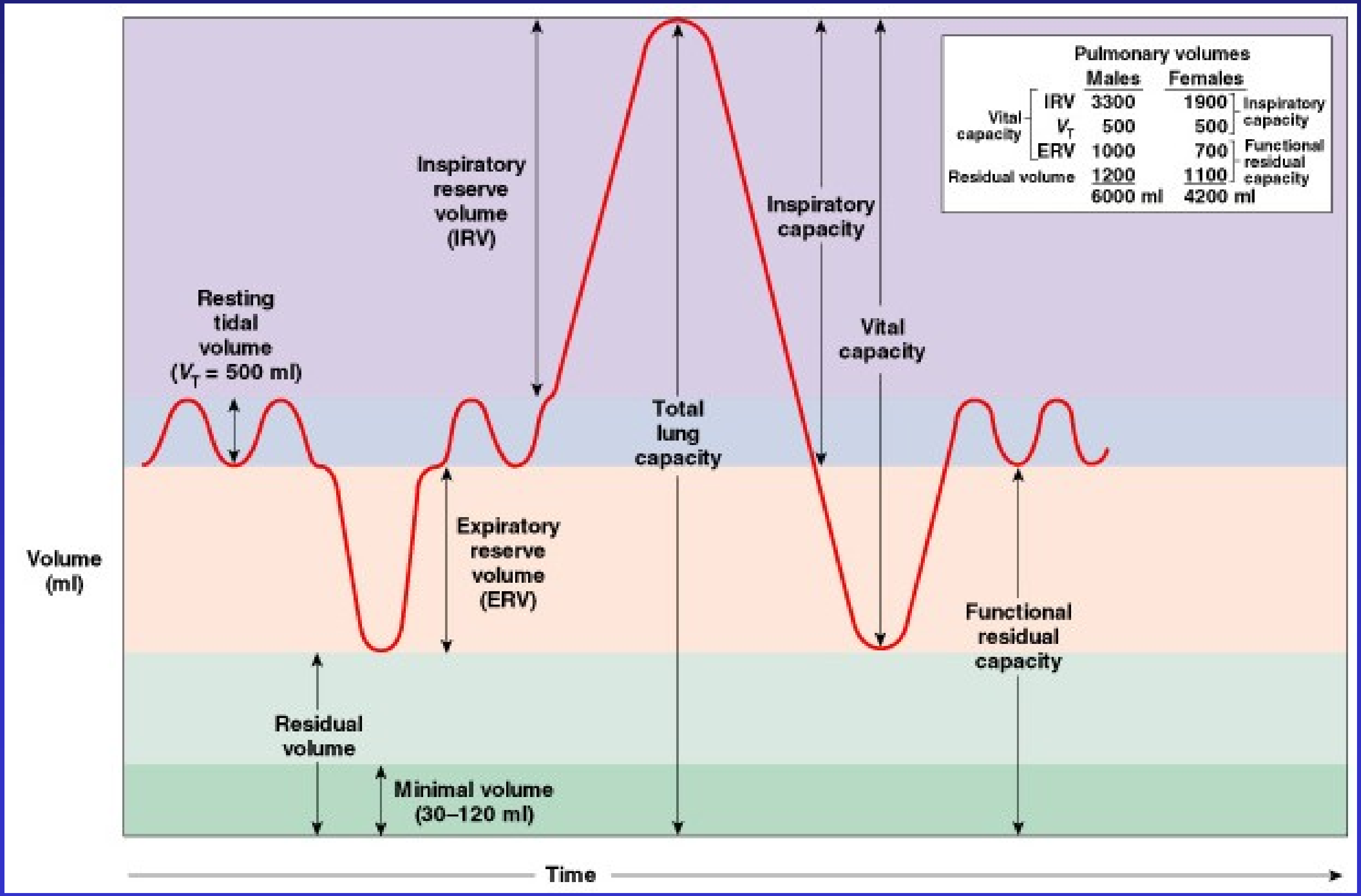


Figure 23-17

Lung Volume

- Total lung volume is divided into a series of volumes and capacities useful in diagnosis
- Pulmonary Function Tests
- Measure rates and volumes of air movements

4 Pulmonary Volumes

1. Resting tidal volume:
   – in a normal respiratory cycle
2. Expiratory reserve volume (ERV):
   – after a normal exhalation
3. Residual volume:
   – after maximal exhalation
   – minimal volume (in a collapsed lung)
4. Inspiratory reserve volume (IRV):
   – after a normal inspiration

4 Calculated Respiratory Capacities

1. Inspiratory capacity:

   tidal volume + inspiratory reserve volume

2. Functional residual capacity (FRC):

   expiratory reserve volume + residual volume

3. Vital capacity:

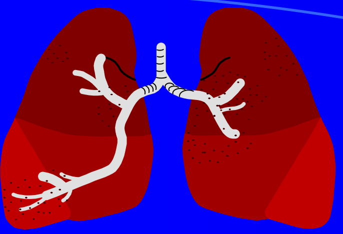
   expiratory reserve volume + tidal volume + inspiratory reserve volume

4. Total lung capacity:

   vital capacity + residual volume

Pulmonary Resistance

- Pulmonary resistance = Airway resistance (80%)+ pulmonary tissue resistance (20%)



Resistances

1) Elastic resistance (Static trait)

A) Lung: The tendency to collapse

B) Compliance: The change in volume (ΔV) accomplished by a change in pressure (ΔP)

$$C_L = \Delta V / \Delta P$$

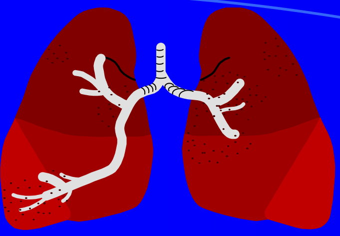
2) Flow resistance (Dynamic trait)

$$R = \frac{8 \text{ x vicosity x length}}{\pi \text{ x } (\text{radius})^4}$$

Overcoming airway resistance

Changes by airway caliber (bronchospasm, secretions)

The difference between atmospheric and alveolar pressure is driving pressure for flow

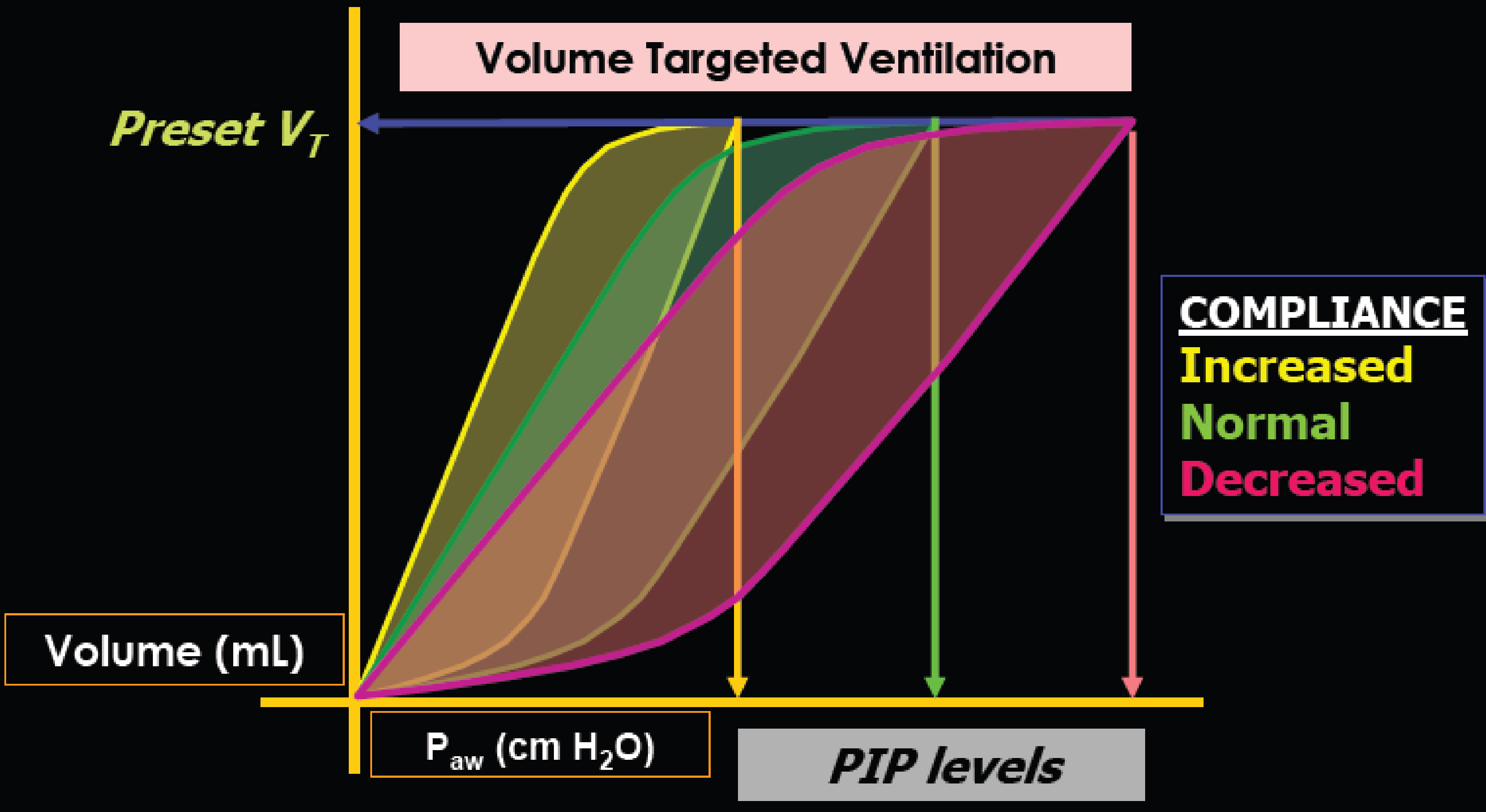


$$\text{Cdyn} = \text{Vt} / \text{Ppeak} - \text{PEEP}$$

$$\text{Cstat} = \text{Vt} / \text{Pplat} - \text{PEEP}$$

$$\text{Raw} = \text{PIP} - \text{Pplat} / \text{Flow}$$

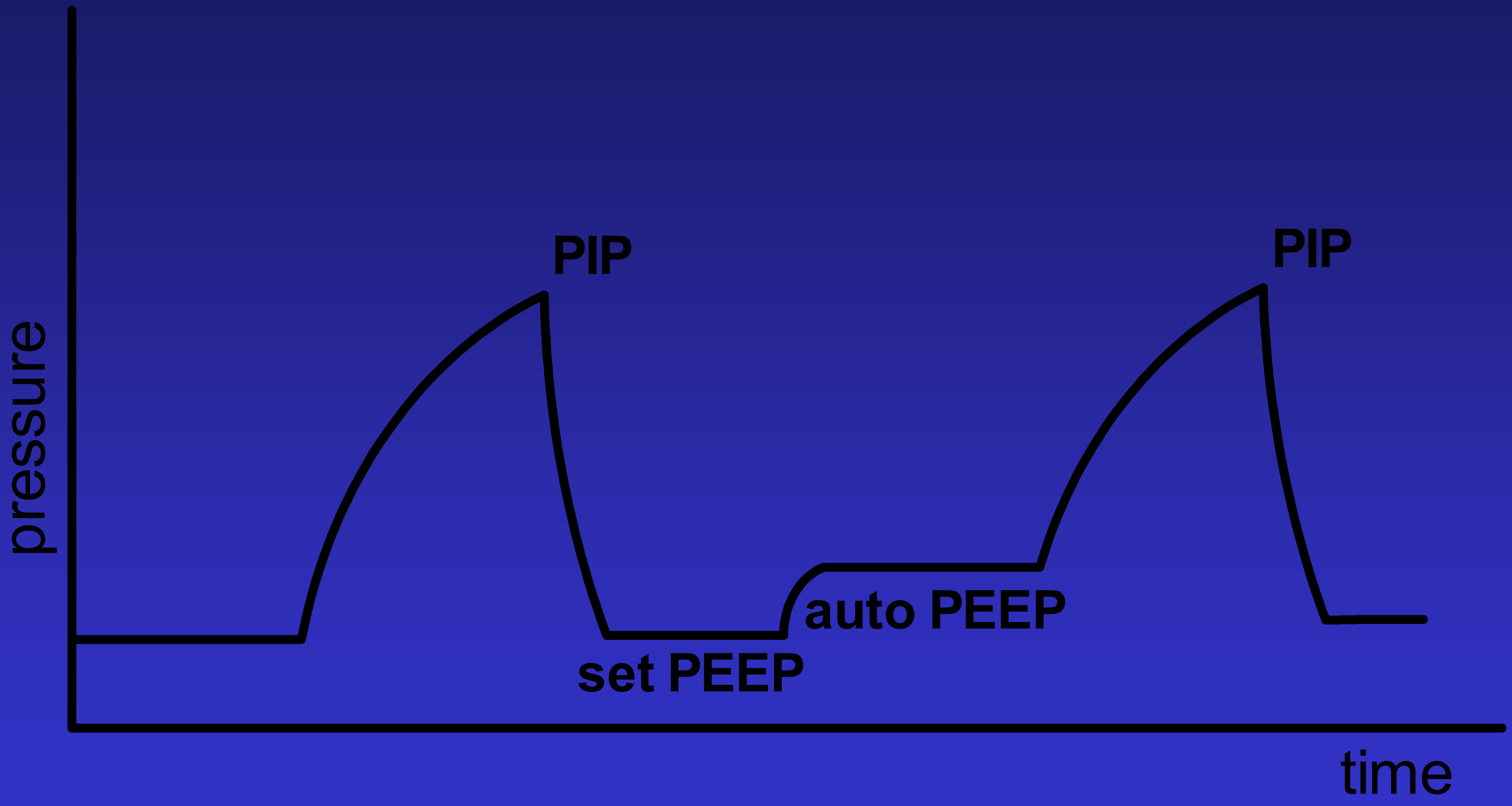
Lung Compliance Changes and the P-V Loop



Work of breathing

- Work to overcome the elastic forces of the lung
- Work to overcome the viscosity of the lung and the chest wall structures.
- Work to overcome airway resistance.
- Normal respiration uses 3-5% of total work energy
- Heavy exercise can require 50 x more energy

PEEP & Auto PEEP



Respiration

Oxygen delivery

Air to venous blood

Gas Exchange

Carbon Dioxide removal

Venous blood to air

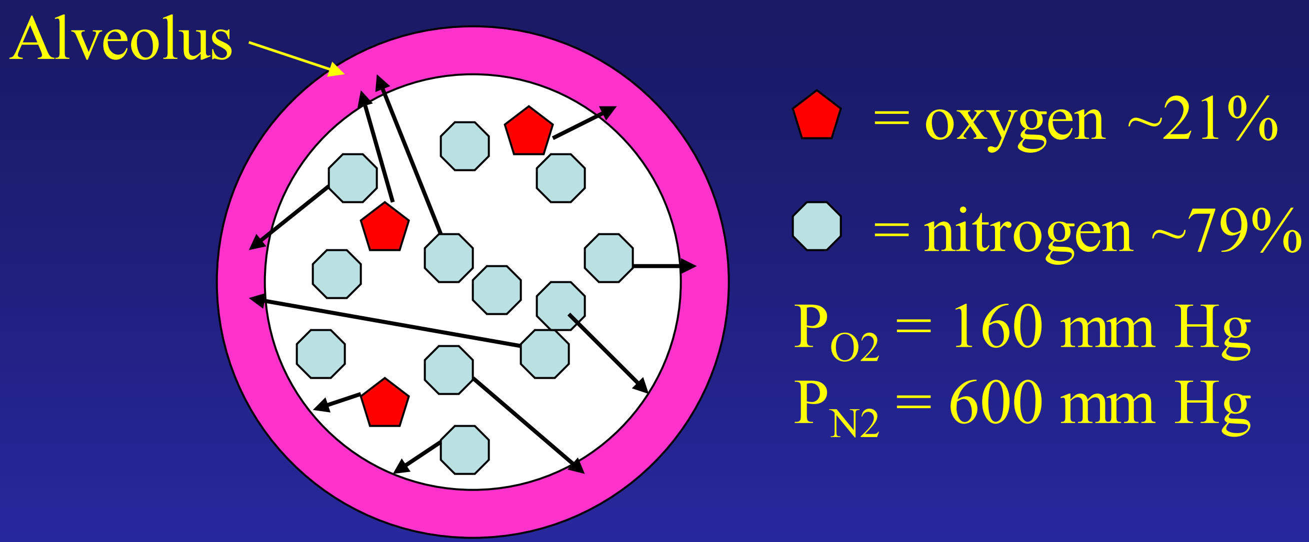
Composition of Air

- Nitrogen (N_2) about 78.6%
- Oxygen (O_2) about 20.9%
- Water vapor (H_2O) about 0.5%
- Carbon dioxide (CO_2) about 0.04%

“Air conditioning”

- Mucus keeps surface moist and entraps particles
- 200 cilia/ epithelial cell (nose to terminal bronchioles)
  - beat 10-20/s toward pharynx
- Nose
  - Extensive surfaces warm and humidify air
  - Filters through nose hair
  - Turbulent precipitation

Partial pressure



P_{O2} = 160 mm Hg
P_{N2} = 600 mm Hg

- Atmospheric pressure (760 mm Hg):
  - produced by air molecules bumping into each other
- The force of the molecules of a particular gas in the mix of gases produces partial pressure in proportion to its number of molecules (Dalton's law)
- Pressure of air is the sum of all the partial pressures of the gases.

Partial Pressure

- The pressure contributed by each gas in the atmosphere
- All partial pressures together add up to 760 mm Hg

TABLE 23–2 Partial Pressures (mm Hg) and Normal Gas Concentrations (%) in Air

SOURCE OF SAMPLE	Nitrogen (N_2)	Oxygen (O_2)	Carbon Dioxide (CO_2)	Water Vapor (H_2O)
Inhaled air (dry)	597 (78.6%)	159 (20.9%)	0.3 (0.04%)	3.7 (0.5%)
Alveolar air (saturated)	573 (75.4%)	100 (13.2%)	40 (5.2%)	47 (6.2%)
Exhaled air (saturated)	569 (74.8%)	116 (15.3%)	28 (3.7%)	47 (6.2%)

Diffusion

- Process by which alveolar air gases are exchanged between alveoli and pulmonary capillary and vice versa based on a concentration gradient (gas laws *e.g.,* Boyle's law) produced by work of breathing accomplished by respiratory muscles and the heart

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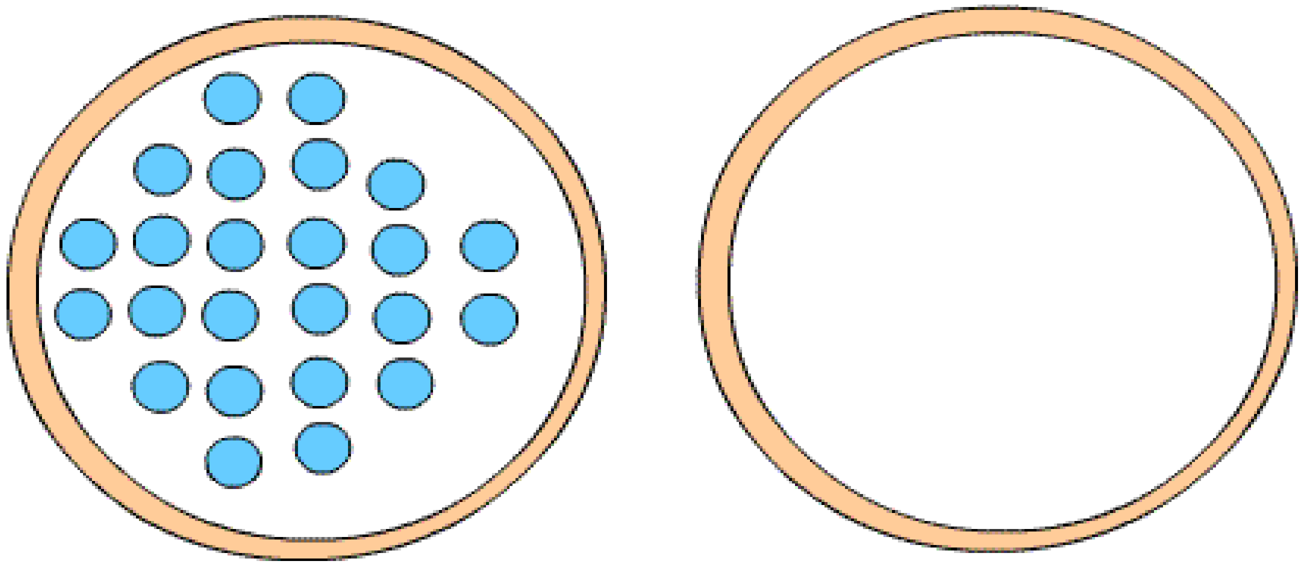
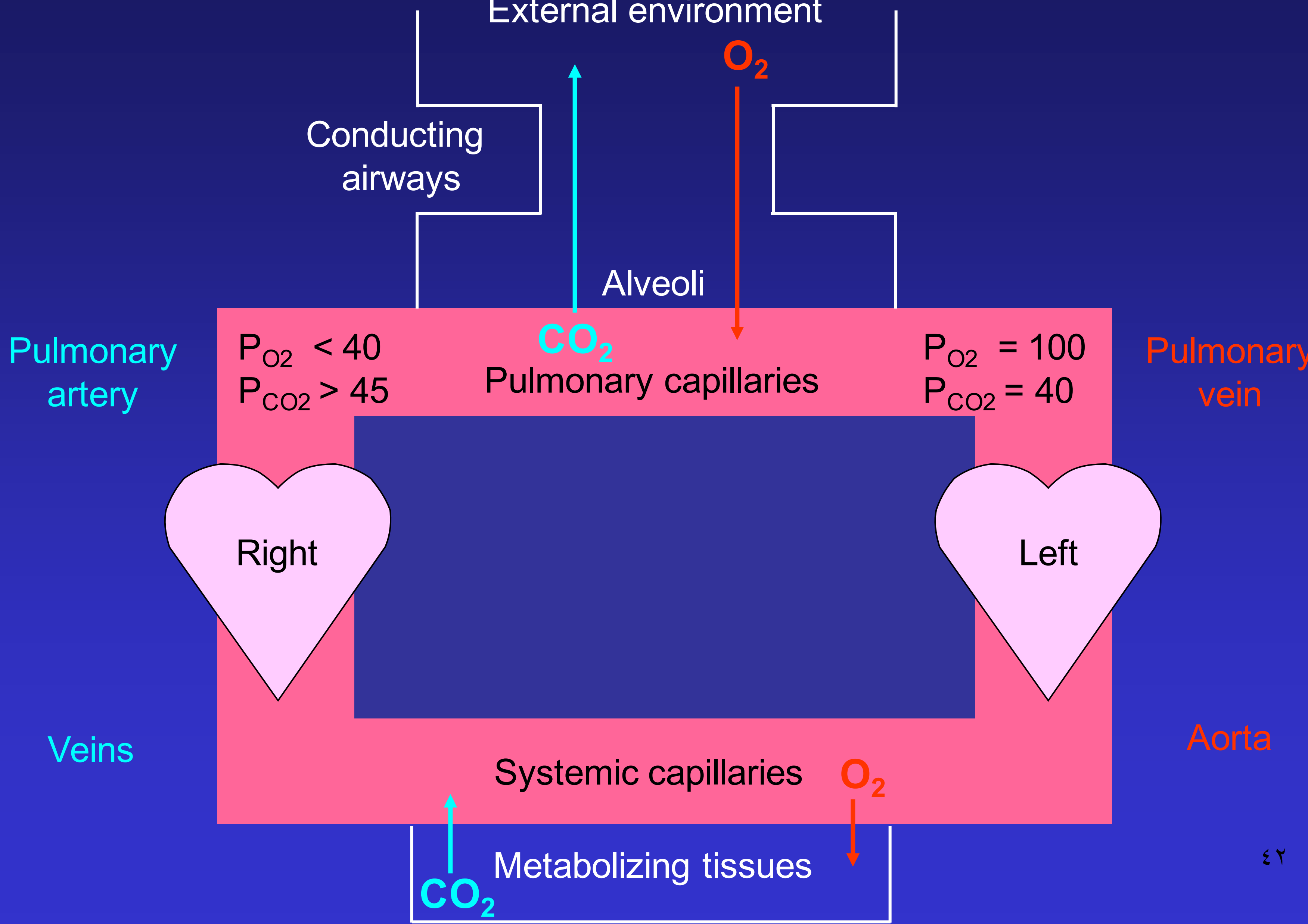
Diffusion

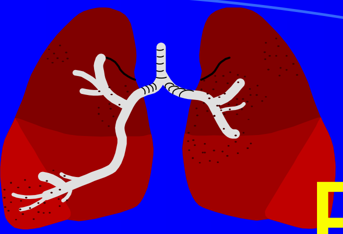


high concentration

low concentration

Gas exchange

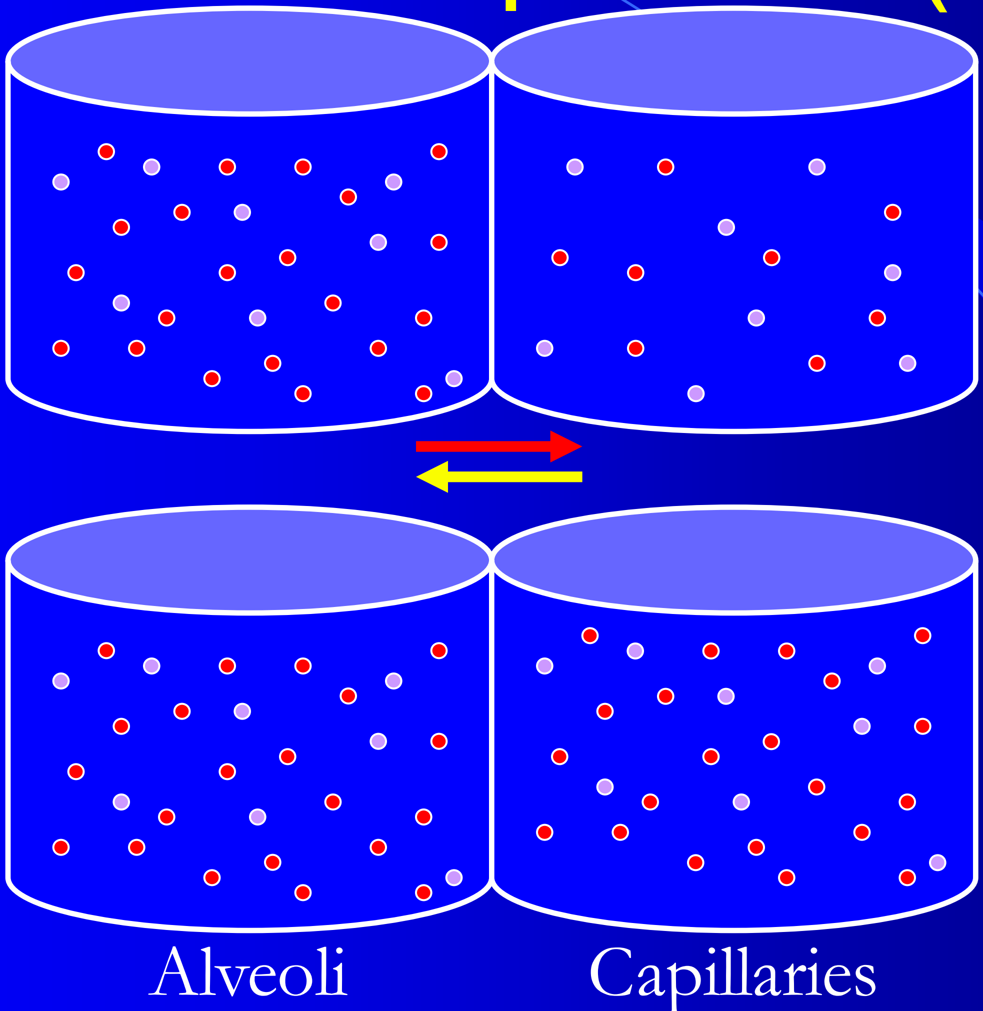




External respiration (in lungs)

- pO_2= 104 mm Hg
- pCO_2= 40 mm Hg

- pO_2= 40 mm Hg
- pCO_2= 45 mm Hg



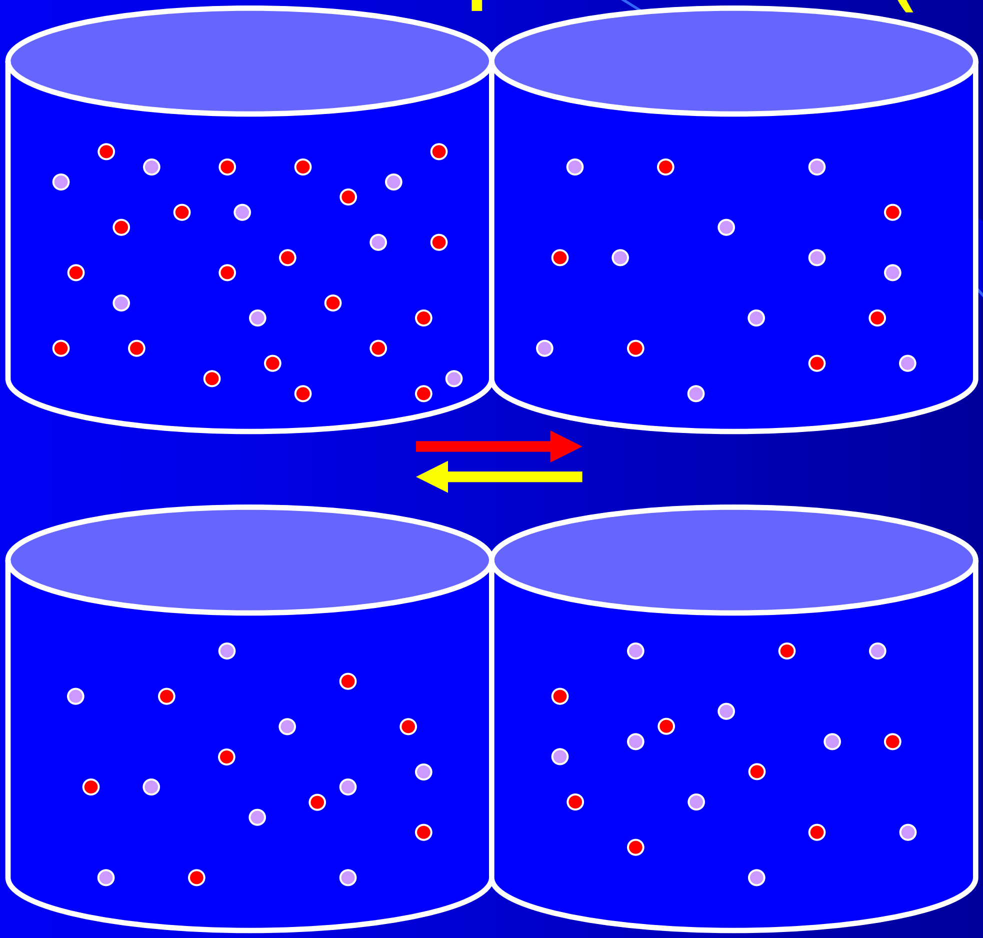
- pO_2= 104 mm Hg
- pCO_2= 40 mm Hg

- pO_2= 104 mm Hg
- pCO_2= 40 mm Hg

Internal respiration (in tissue)

- $pO_2 = 100$ mm Hg
- $pCO_2 = 40$ mm Hg

- $pO_2 < 40$ mm Hg
- $pCO_2 > 45$ mm Hg



- $pO_2 = 40$ mm Hg
- $pCO_2 = 45$ mm Hg

- $pO_2 = 40$ mm Hg
- $pCO_2 = 45$ mm Hg

Capillaries   Tissue

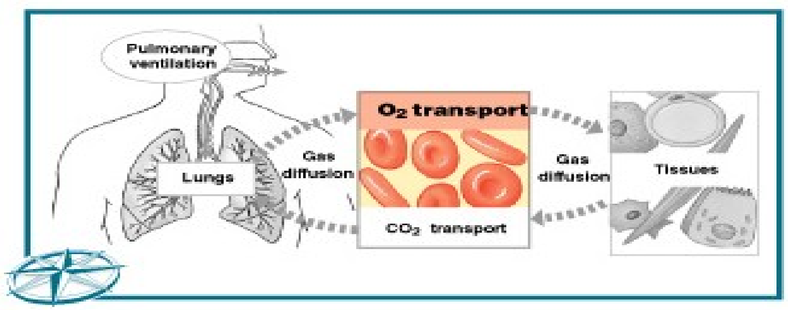
Transport of gases in the circulation: Oxygen

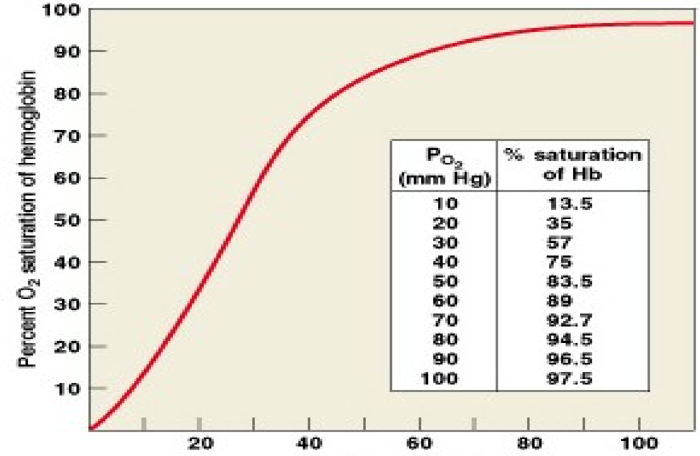
- Dissolved in plasma 3%
  - – amount is proportional to partial pressure
  - – O_2 is poorly soluble in plasma
    - average 0.3 ml O_2 / 100 ml blood
- Combined with hemoglobin 97%
  - – each hemoglobin molecule combines with 4 O_2
  - – average 20 ml O_2 / 100 ml blood

Cont.

Transport of gases in the circulation

Oxyhemoglobin Saturation Curve





- Oxygen-hemoglobin dissociation curve shows that hemoglobin is almost completely saturated when $P0_2$ is 80 mm Hg or above. At lower partial pressures, the hemoglobin releases oxygen.
- Is a graph relating the saturation of hemoglobin to partial pressure of oxygen:
  - higher P_{O_2} results in greater Hb saturation

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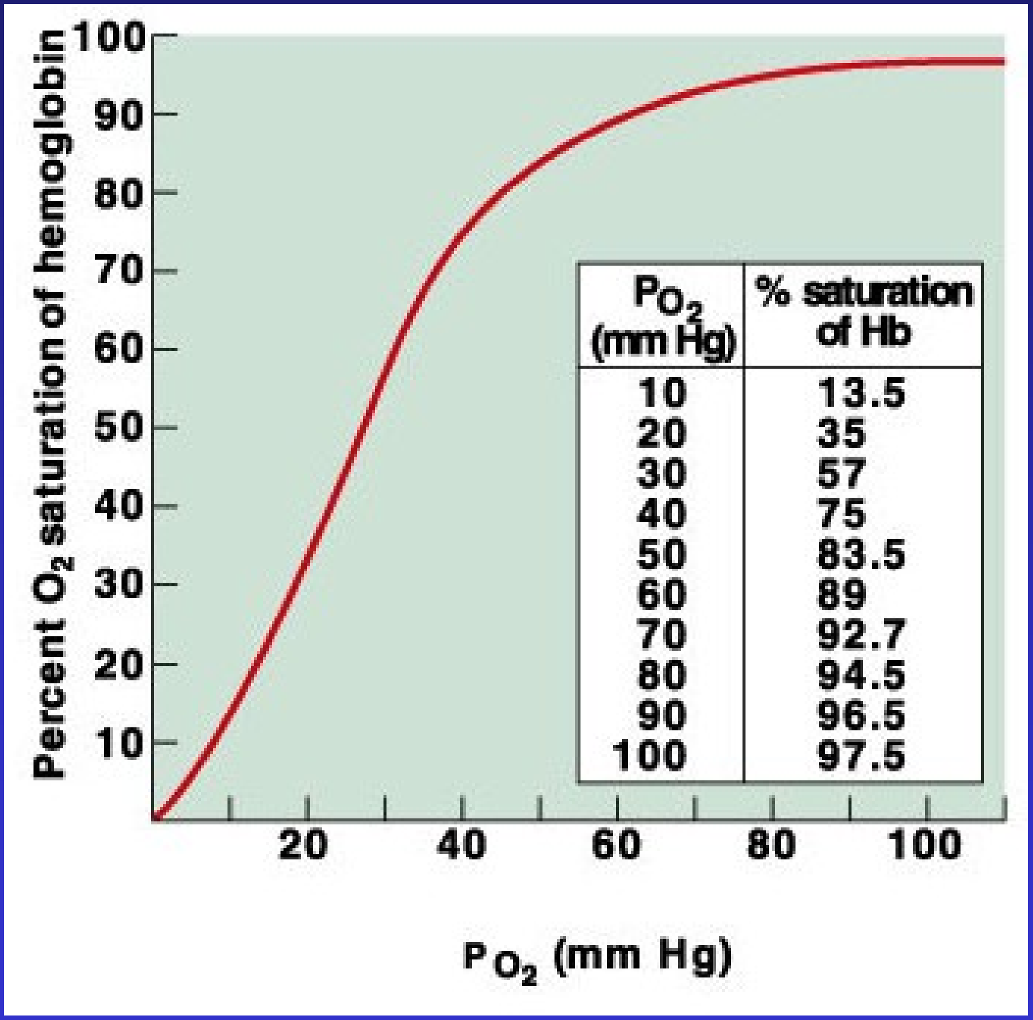
Oxygen-Hemoglobin Dissociation Curve at Rest



P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

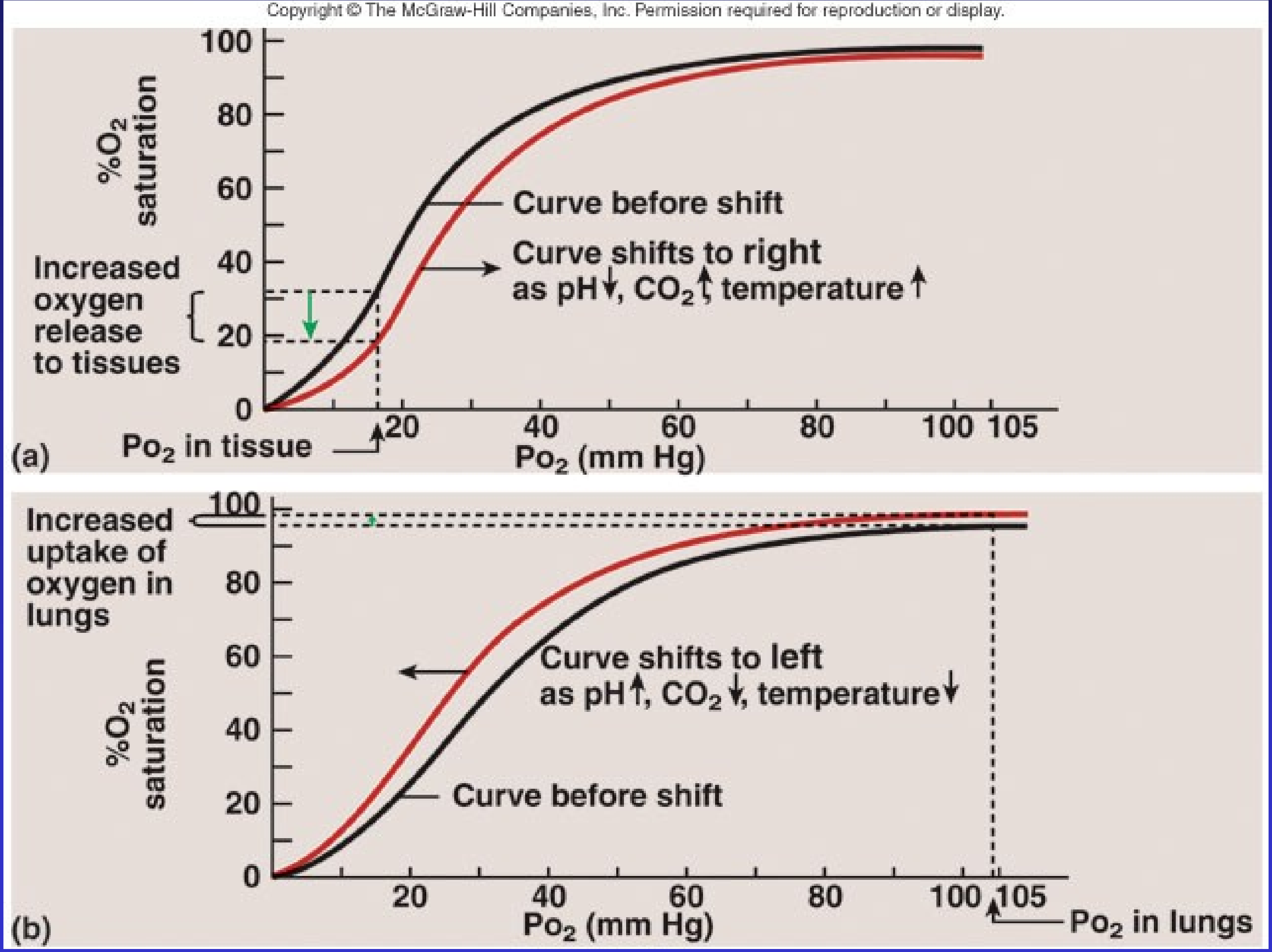
Oxyhemoglobin Saturation Curve

ارتباط بین فشار و محتوای O_2 خطی نیست پس..

۱. بخش عمده منحنی در قسمت مربوط به منطقه شریانی است یعنی حتی با نزول Po_2 اشباع Hb از اکسیژن همچنان بالا خواهد بود (مگر در افت شدید Po_2 به زیر ۶۰ mmHg). تمایل O_2 در اتصال به Hb با افزایش آن بیشتر می شود (در شریانها)

۲. بخش اندکی از منحنی به بخش وریدی اختصاص می یابد که امکان آزاد نمودن مقادیر بسیار قابل توجه اکسیژن در مجاورت بافت را فراهم می سازد.

Shifting the Curve



Hemoglobin and Oxygen Transport

- A shift of the curve to the left because of an increase in pH, a decrease in carbon dioxide, a decrease in temperature or 2,3-DPG and carbon monoxide poisoning results in an increase in the ability of hemoglobin to hold oxygen
- A shift of the curve to the right because of a decrease in pH, an increase in carbon dioxide, an increase in temperature or 2,3-DPG results in a decrease in the ability of hemoglobin to hold oxygen

Cont.
Transport of gases in the circulation

Carbon Dioxide Transport

- **Dissolved in plasma**
  - **CO_2 is 20 times more soluble than O_2**
  - **up to 10% of CO_2 is dissolved**
- **Combined with Hb as carbaminohemoglobin**
  - **Haldane effect: Hb's de-oxygenation enables bind CO_2**
  - **about 20 - 30% of CO_2**
- **Bicarbonate**
  - $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + (\text{Hb buffer}) + HCO_3^-$
  - **70% carried as bicarbonate**

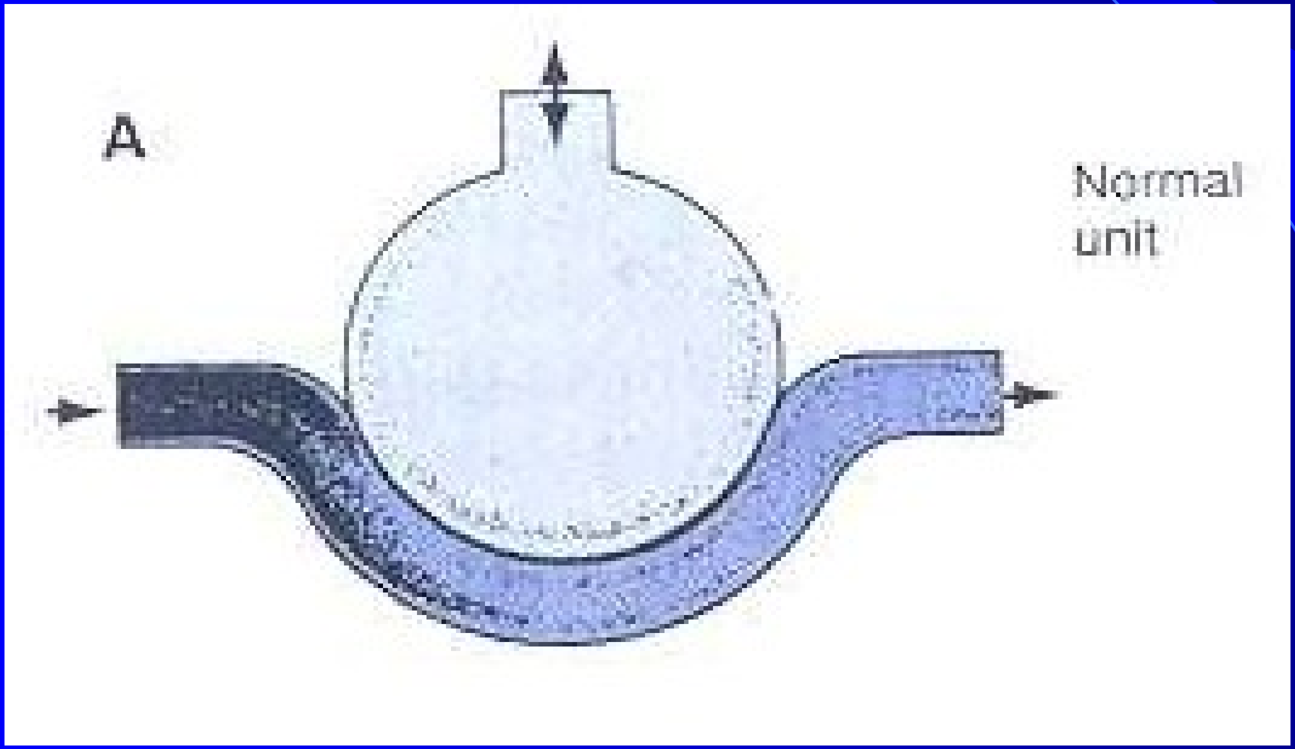
3 Effects of Aging on the Respiratory System

1. Elastic tissues deteriorate:
   – reducing lung compliance
   – lowering vital capacity
2. Arthritic changes:
   – restrict chest movements
   – limit respiratory minute volume
3. Emphysema:
   – affects individuals over age 50
   – depending on exposure to respiratory irritants (*e.g.,* cigarette smoke)

- هماهنگی تهویه (V) و جریان خون (Q) لازمه انجام تبادلات گازی است و در شرایط معمول این تعادل برقرار می باشد

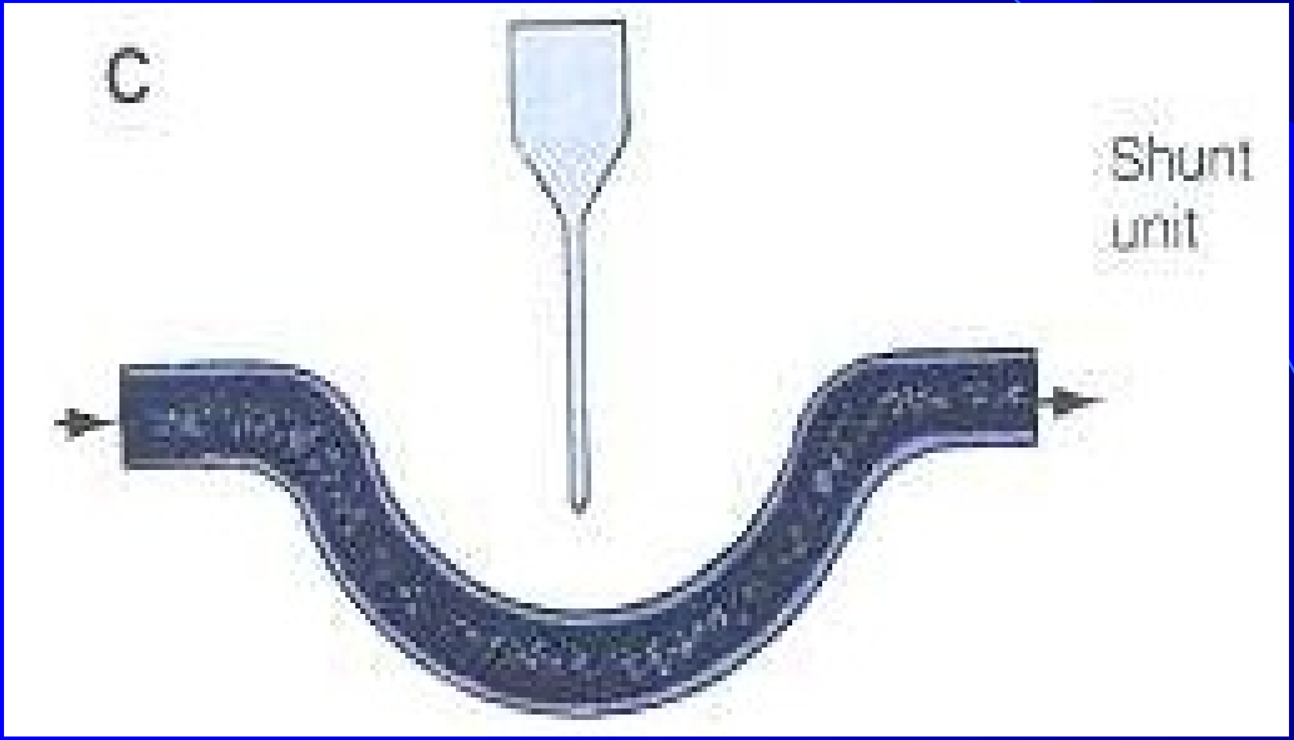
Ventilation/ Perfusion Mismatching: V/Q ratio

- Ideally V= Q means V/Q = 1 but usually
- 4:5 = 0.8 = normal V/Q



V/Q mismatch

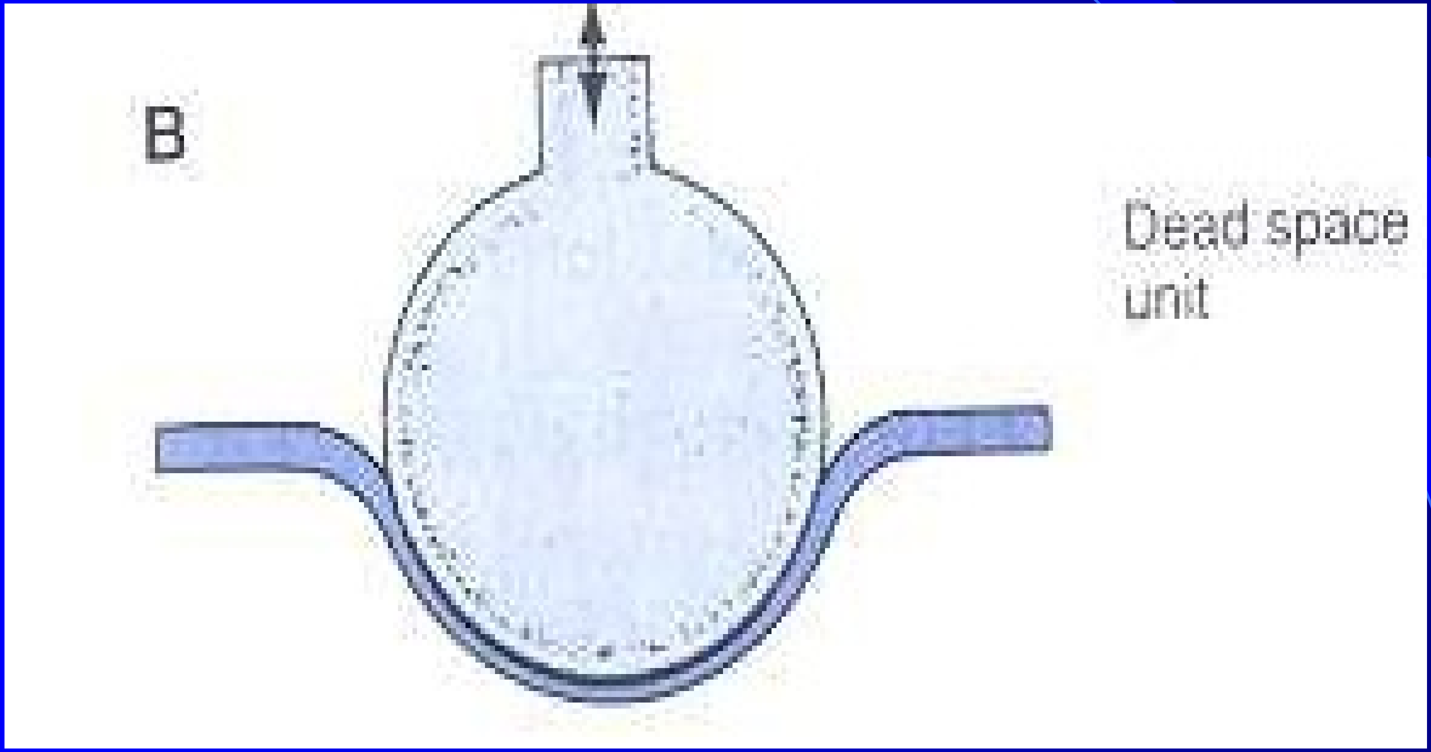
- V/Q < 0.8 Shunt unit similar to right - to- left shunt: atelectasis, pneumonia, pulmonary edema



V/Q mismatch

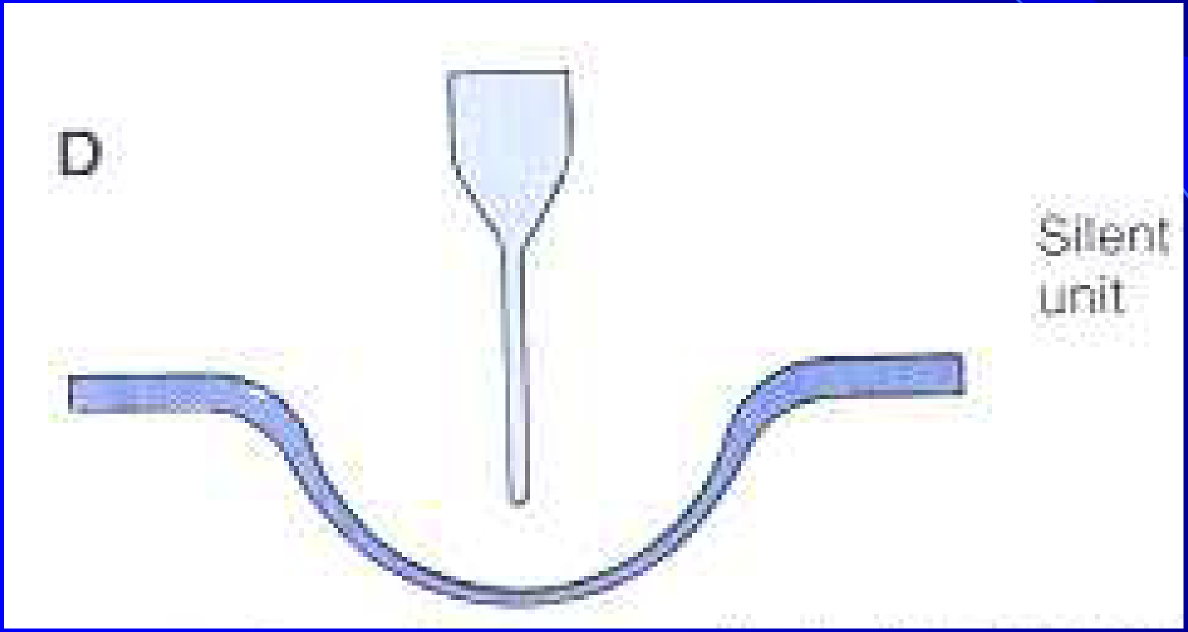
- V/Q > 0.8 Dead space unit or wasted ventilation

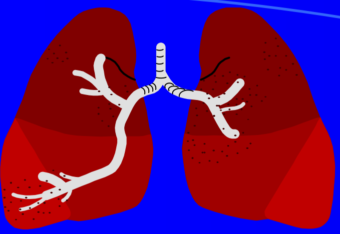
  Pulmonary emboli, cardiogenic shock



V/Q mismatch

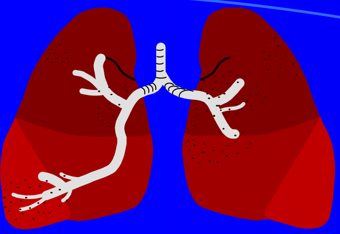
- Silent unit: No ventilation No perfusion





V/Q mismatch

- Hypoxemia due to V/Q mismatch can be corrected by oxygen therapy. If it does not happened what is the reason?
- A R-L shunt should be considered



Control of ventilation

Although it is rhythmic activity without conscious effort, it has controlling mechanism in CNS

A) Respiratory generator in medulla **(two groups of neurons)**

1) respiration initiator and its rate regulator

2) “switching off” controller which means expiration starts

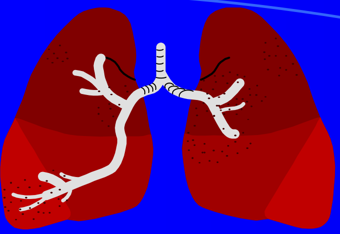
B) Other regions of CNS

1) Pons 2) Cerebral cortex

C) Chemoreceptors: feedback to blood gases imbalance

1) central chemoreceptors 2) peripheral receptors

D) Other receptors



Cont.

Control of ventilation

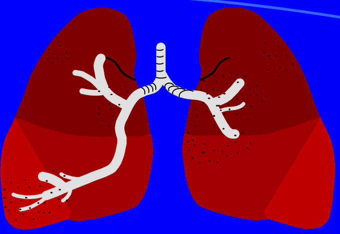
* Central chemoreceptors in medulla

Respond to Pco2 change but not directly (?)

$\uparrow P_aco_2 \rightarrow \uparrow Pco_2$ in brain ECF $\rightarrow \downarrow$brain ECF PH $\rightarrow \downarrow$PH at chemoreceptor $\rightarrow$Stimulation of central and then modularly respiratory center $\rightarrow \uparrow$ventilation $\rightarrow \downarrow PaCo_2 VO$

* Peripheral chemoreceptors in carotid and aortic bodies

Sensitive to Po2 changes in hypoxemia stimulating chemoreceptors, minor role in Pco2 changes



Cont.
Control of ventilation

- Stretch receptors (Hering –Breuer reflex)
- Irritant receptors in airways responding to noxious stimuli
- “J” (juxtacapillary) receptors in the alveolar interstitial space
  – Rapid shallow breathing, $\downarrow$PR, $\downarrow$BP due to high pulmonary capillary pressure such as heart failure
- Receptors in the chest wall (intercostal muscles) to tune and adjust the muscular work

Control of Respiration