Respiratory Physiology

Lecture Outline

- Basics of the Respiratory System
  - Functions & functional anatomy
- Gas Laws
- Ventilation
- Diffusion & Solubility
- Gas Exchange
  - Lungs
  - Tissues

Basics of the Respiratory System

General Functions

- Exchange of gases
    - Directionality depends on gradients!
  - Atmosphere to blood
  - Blood to tissues
- Regulation of pH
  - Dependent on rate of CO_2 release
- Protection
- Vocalization
- Synthesis

Basics of the Respiratory System

Respiration

- What is respiration?

  - **Respiration** = the series of exchanges that leads to the uptake of oxygen by the cells, and the release of carbon dioxide to the lungs

    Step 1 = ventilation
    - Inspiration & expiration

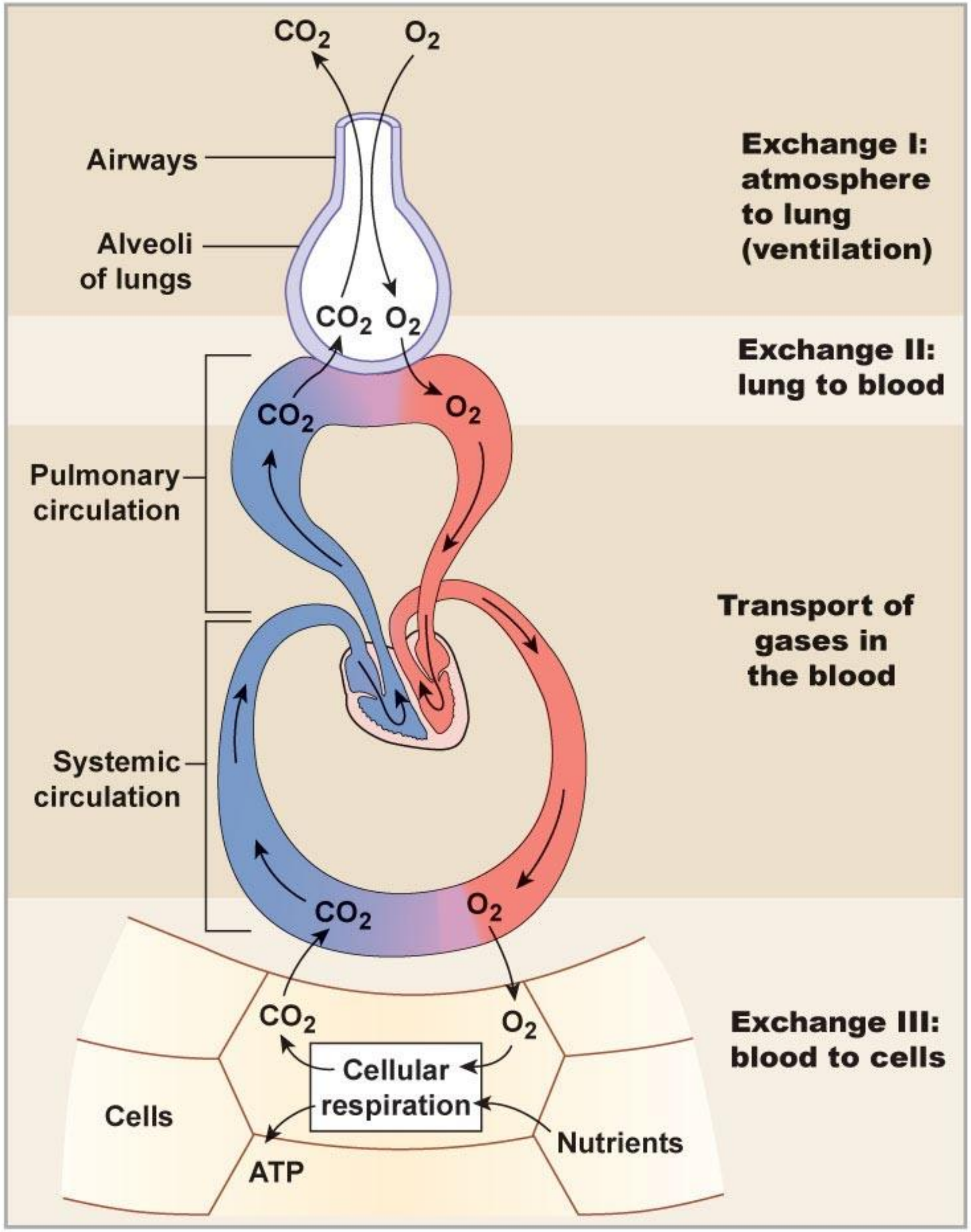
    Step 2 = exchange between alveoli (lungs) and pulmonary capillaries (blood)
    - Referred to as *External Respiration*

    Step 3 = transport of gases in blood

    Step 4 = exchange between blood and cells
    - Referred to as *Internal Respiration*

  - **Cellular respiration** = use of oxygen in ATP synthesis

Schematic View of Respiration



→ **External Respiration**

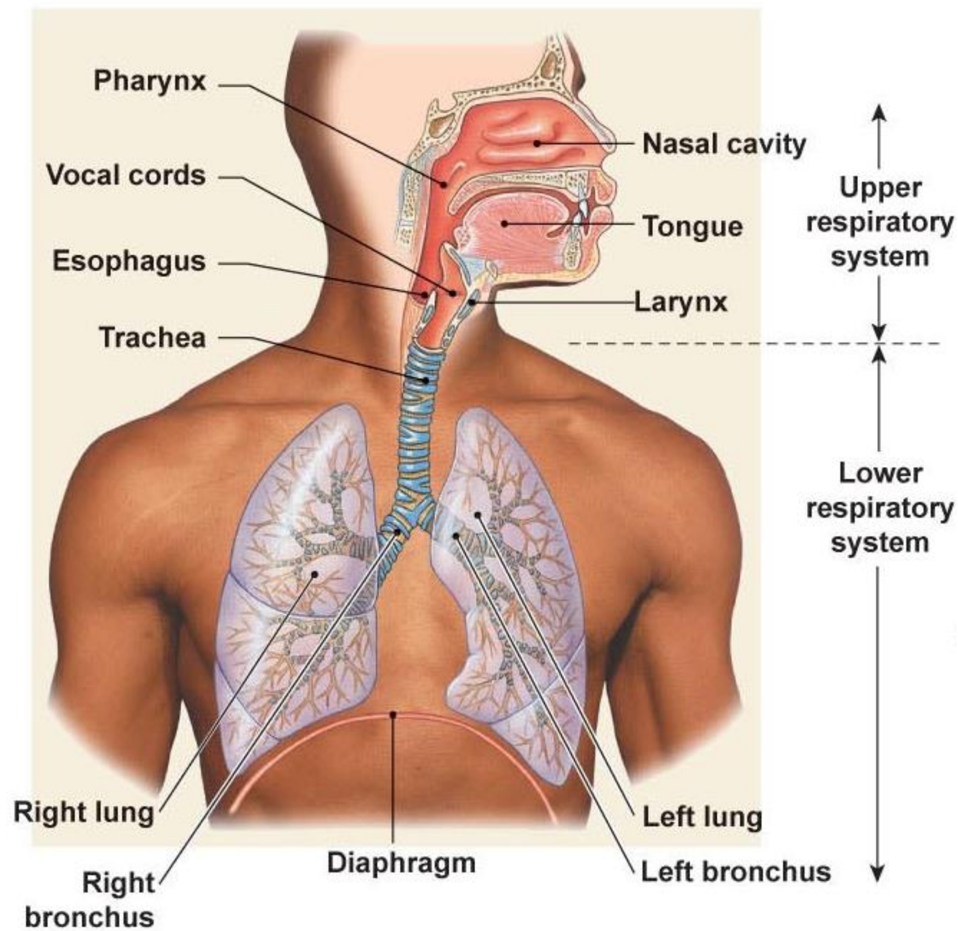
→ **Internal Respiration**

Basics of the Respiratory System

Functional Anatomy

- What structural aspects must be considered in the process of respiration?
  - The conduction portion
  - The exchange portion
  - The structures involved with ventilation
    - Skeletal & musculature
    - Pleural membranes
    - Neural pathways

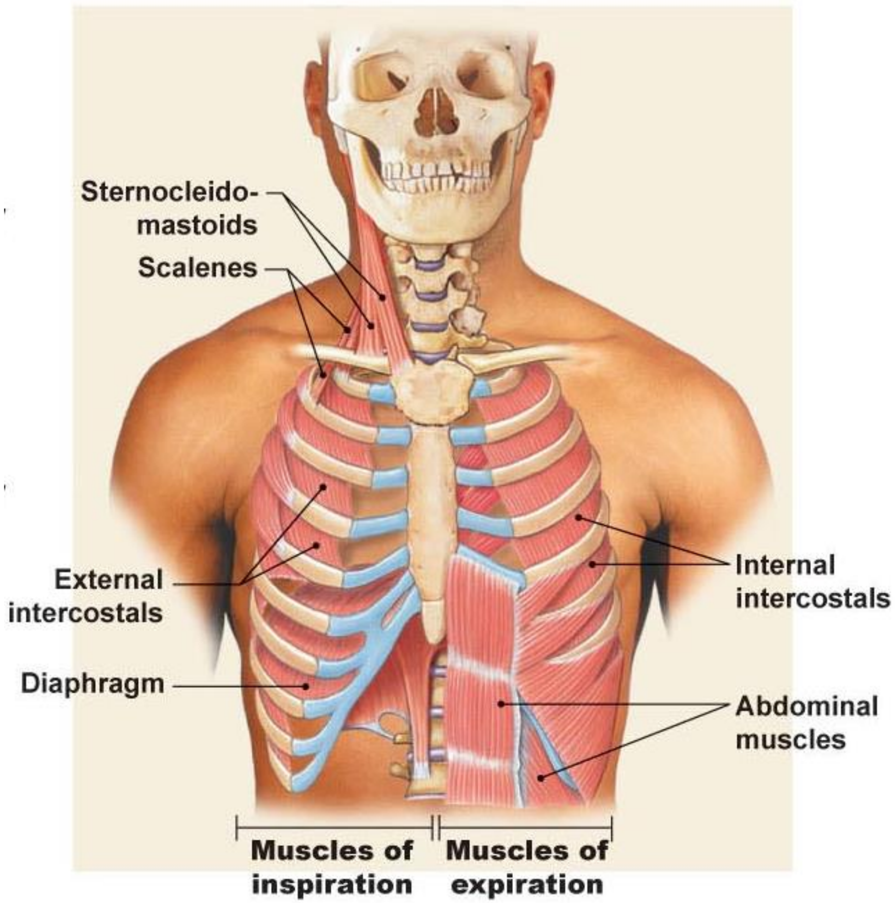
- All divided into
  - Upper respiratory tract
    - Entrance to larynx
  - Lower respiratory tract
    - Larynx to alveoli (trachea to lungs)

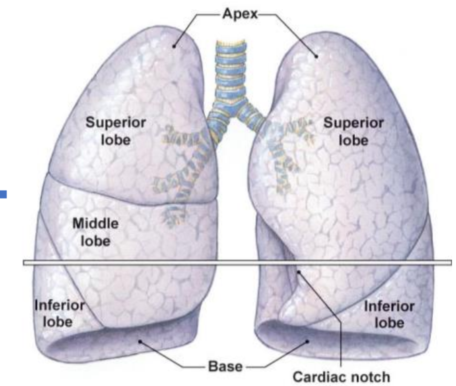


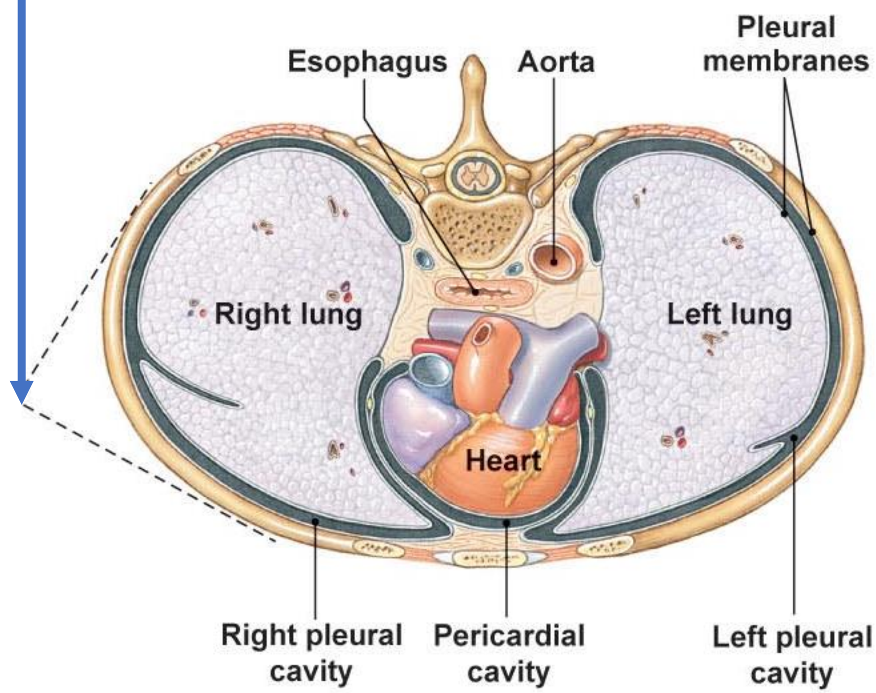
Basics of the Respiratory System

Functional Anatomy

- Bones, Muscles & Membranes

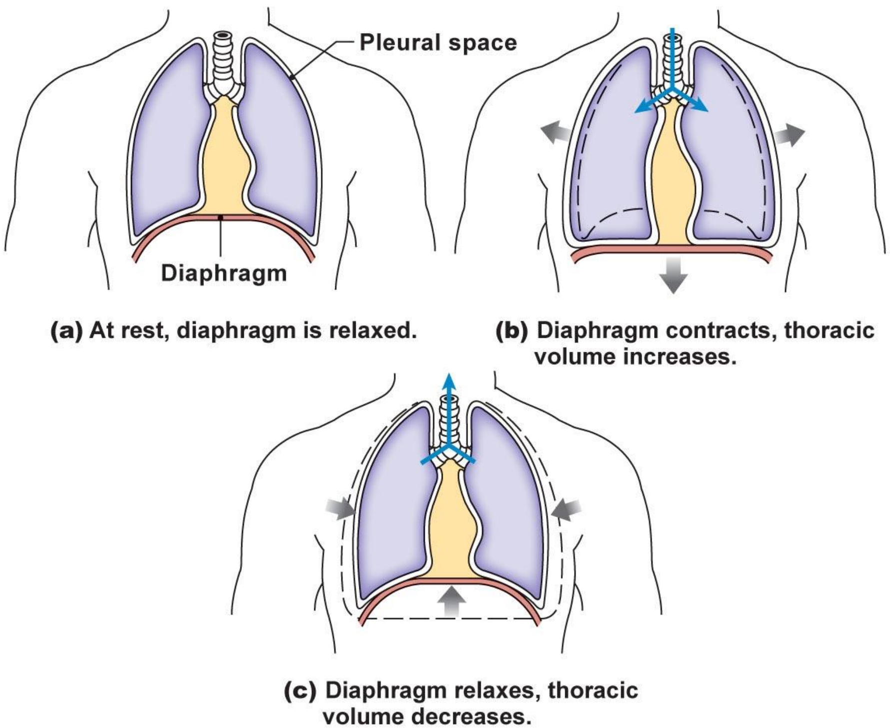






Basics of the Respiratory System
Functional Anatomy

- Function of these Bones, Muscles & Membranes
  - Create and transmit a pressure gradient
    - Relying on
      - the attachments of the muscles to the ribs (and overlying tissues)
      - The attachment of the diaphragm to the base of the lungs and associated pleural membranes
      - The cohesion of the parietal pleural membrane to the visceral pleural membrane
      - Expansion & recoil of the lung and therefore alveoli with the movement of the overlying structures



Basics of the Respiratory System

Functional Anatomy

- Pleural Membrane Detail
  - Cohesion between parietal and visceral layers is due to serous fluid in the pleural cavity
    - Fluid (30 ml of fluid) creates an attraction between the two sheets of membrane
    - As the parietal membrane expands due to expansion of the thoracic cavity it “pulls” the visceral membrane with it
      - And then pulls the underlying structures which expand as well
    - Disruption of the integrity of the pleural membrane will result in a rapid equalization of pressure and loss of ventilation function = collapsed lung or pneumothorax

Basics of the Respiratory System

Functional Anatomy

- The Respiratory Tree
  - connecting the external environment to the exchange portion of the lungs
  - similar to the vascular component
  - larger airway = higher flow & velocity
    - small cross-sectional area
  - smaller airway = lower flow & velocity
    - large cross-sectional area

Basics of the Respiratory System

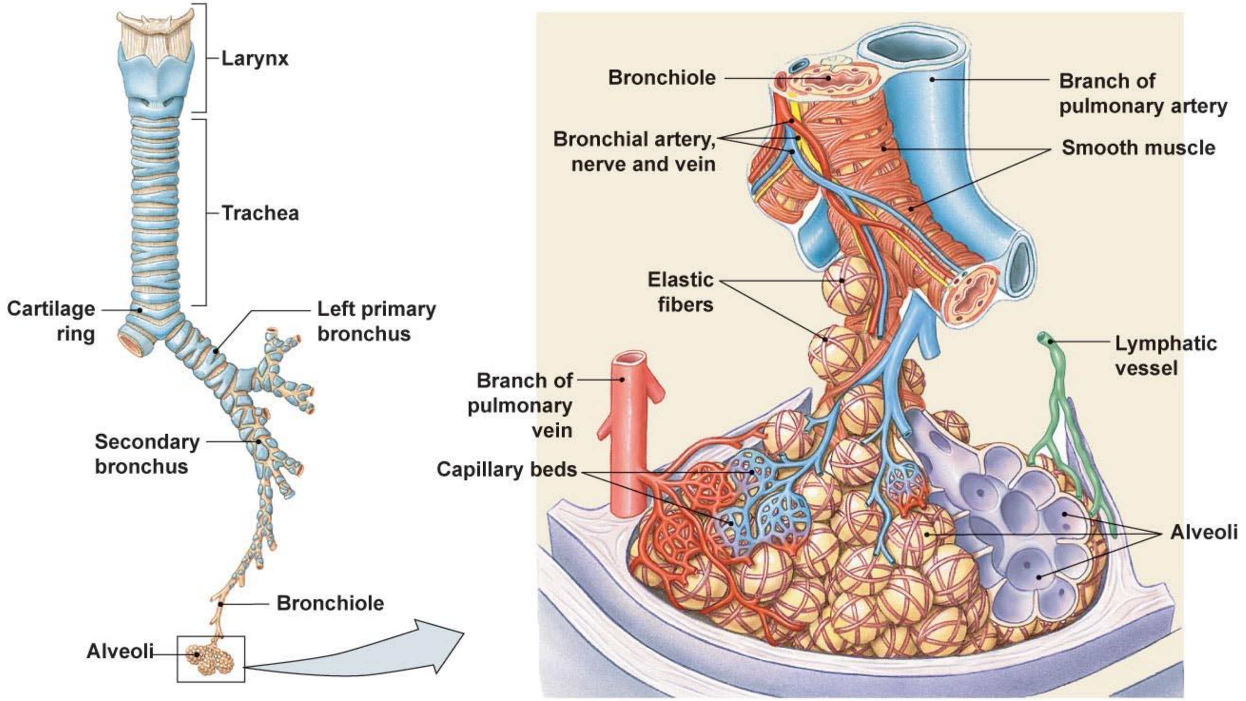
Functional Anatomy

- The Respiratory Tree
  - Upper respiratory tract is for all intensive purposes a single large conductive tube
  - The lower respiratory tract starts after the larynx and divides again and again…and again to eventually get to the smallest regions which form the exchange membranes
    - Trachea
    - Primary bronchi
    - Secondary bronchi
    - Tertiary bronchi
    - Bronchioles
    - Terminal bronchioles

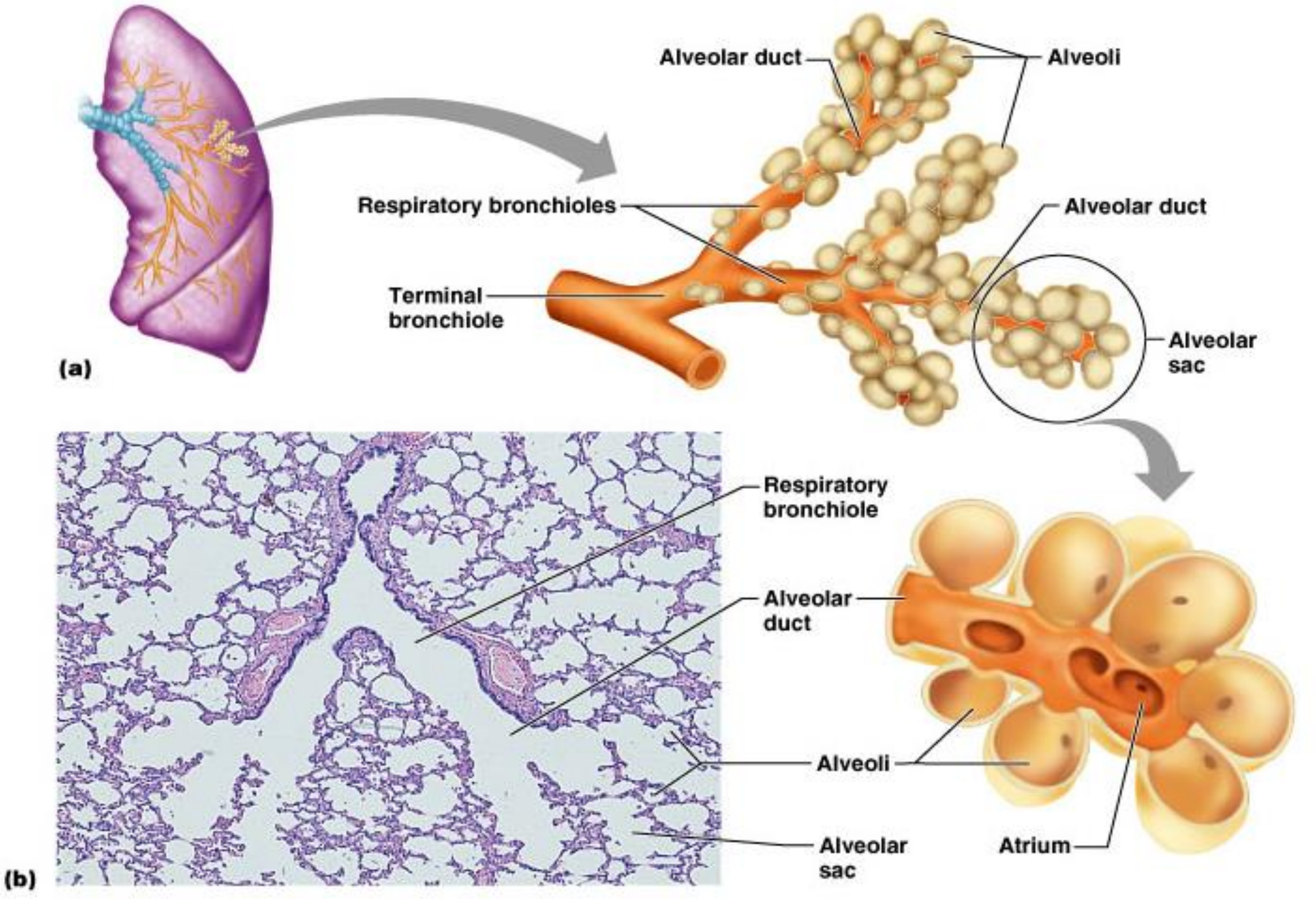
    } **conductive portion**

    - Respiratory bronchioles with start of alveoli outpouches
    - Alveolar ducts with outpouchings of alveoli

    } **exchange portion**



	Name	Division	Diameter (mm)	How many?	Cross-sectional area (cm^2)
Conducting system	Trachea	0	15-22	1	2.5
	Primary bronchi	1	10-15	2	↓
	Smaller bronchi ↓	2	1-10	4 ↓	
		3			
		4			
		5			
		6-11		1×10^4	
	Bronchioles	12-23	0.5-1	2×10^4 ↓ 8×10^7	100 ↓ 5×10^3
Exchange surface	Alveoli	24	0.3	$3\text{-}6 \times 10^8$	$>1 \times 10^6$

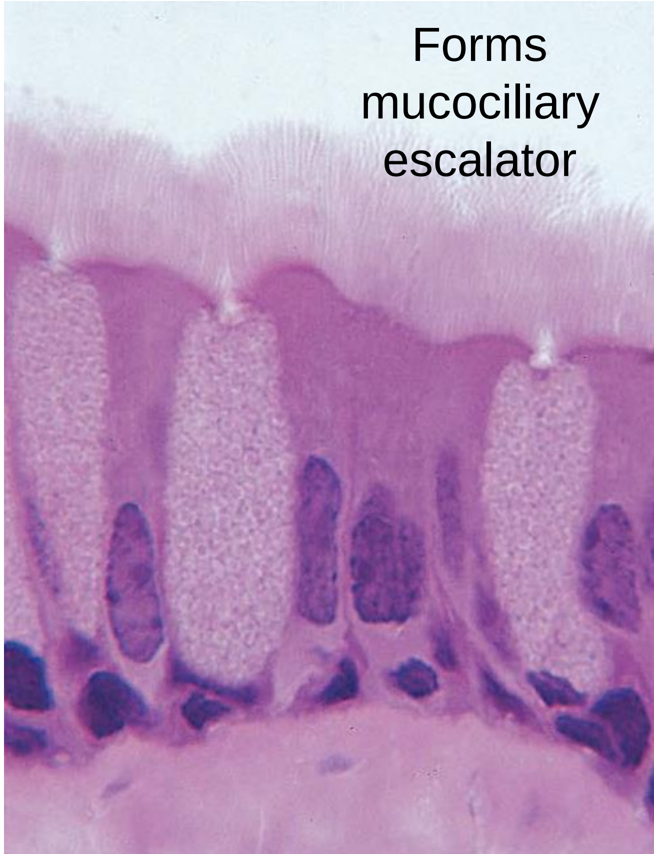

Alveolar duct
Alveoli
Respiratory bronchioles
Alveolar duct
Terminal bronchiole
Alveolar sac
(a)
Respiratory bronchiole
Alveolar duct
Alveoli
Alveolar sac
Atrium
(b)

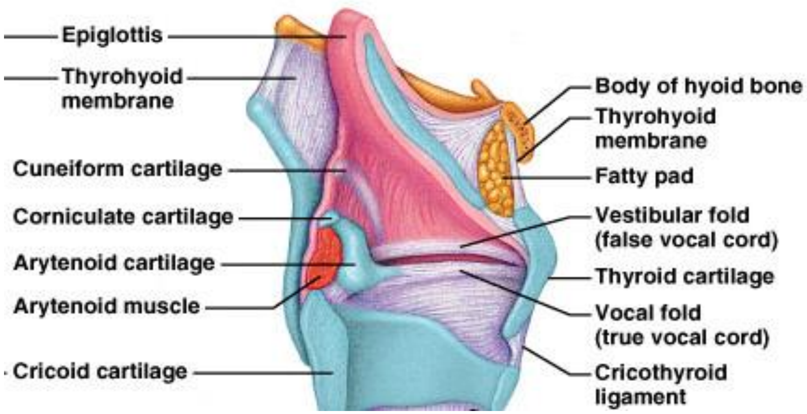
Basics of the Respiratory System
Functional Anatomy

- What is the function of the upper respiratory tract?
  - Warm
  - Humidify
  - Filter
  - Vocalize

Raises incoming air to 37 Celsius

Raises incoming air to 100% humidity





Basics of the Respiratory System
Functional Anatomy

- What is the function of the lower respiratory tract?
  - Exchange of gases …. Due to
    - Huge surface area = $1x10^5$ m^2 of type I alveolar cells (simple squamous epithelium)
    - Associated network of pulmonary capillaries
      - 80-90% of the space between alveoli is filled with blood in pulmonary capillary networks
    - Exchange distance is approx 1 um from alveoli to blood!
  - Protection
    - Free alveolar macrophages (dust cells)
    - Surfactant produced by type II alveolar cells (septal cells)

Basics of the Respiratory System
Functional Anatomy

- Characteristics of exchange membrane
  - High volume of blood through huge capillary network results in
    - Fast circulation through lungs
      - Pulmonary circulation = 5L/min through lungs….
      - Systemic circulation = 5L/min through entire body!
    - Blood pressure is low…
      - Means
        - Filtration is not a main theme here, we do not want a net loss of fluid into the lungs as rapidly as the systemic tissues
        - Any excess fluid is still returned via lymphatic system

Basics of the Respiratory System

Functional Anatomy

- Sum-up of functional anatomy
  - Ventilation?
  - Exchange?
  - Vocalization?
  - Protection?

Respiratory Physiology

Gas Laws

- Basic Atmospheric conditions
  - Pressure is typically measured in mm Hg
  - Atmospheric pressure is 760 mm Hg
  - Atmospheric components
    - Nitrogen = 78% of our atmosphere
    - Oxygen = 21% of our atmosphere
    - Carbon Dioxide = .033% of our atmosphere
    - Water vapor, krypton, argon, …. Make up the rest
- A few laws to remember
  - Dalton's law
  - Fick's Laws of Diffusion
  - Boyle's Law
  - Ideal Gas Law

Respiratory Physiology

Gas Laws

- Dalton's Law
  - Law of Partial Pressures
    - "each gas in a mixture of gases will exert a pressure independent of other gases present"

      Or
    - The total pressure of a mixture of gases is equal to the sum of the individual gas pressures.
  - What does this mean in practical application?
    - If we know the total atmospheric pressure (760 mm Hg) and the relative abundances of gases (% of gases)
      - We can calculate individual gas effects!
      - P_{atm} x % of gas in atmosphere = Partial pressure of any atmospheric gas
        - P_{O_2} = 760mmHg x 21% (.21) = **160 mm Hg**
    - Now that we know the partial pressures we know the gradients that will drive diffusion!

Respiratory Physiology

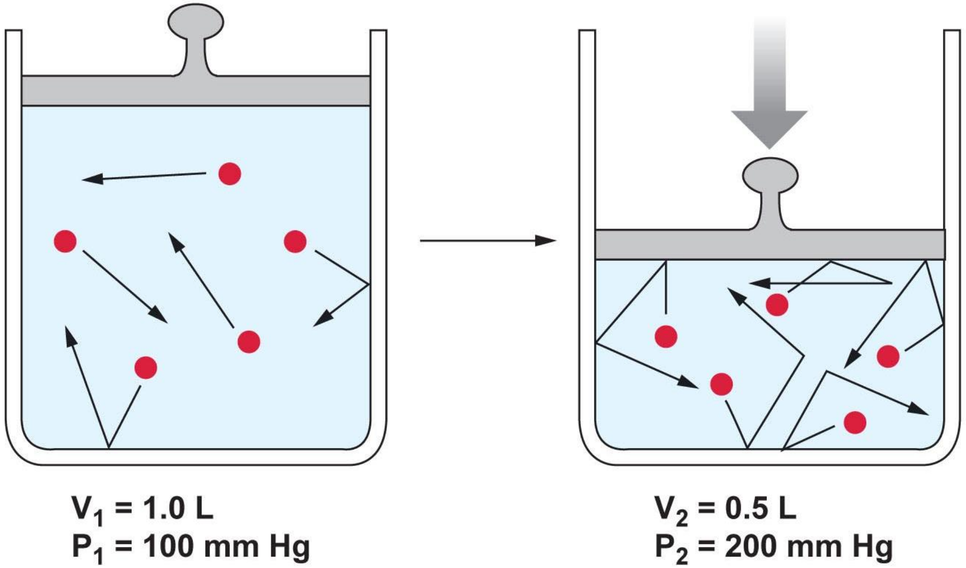
Gas Laws

- Fick's Laws of Diffusion
  - Things that affect rates of diffusion
    - Distance to diffuse
    - Gradient sizes ✓
    - Diffusing molecule sizes ✓
    - Temperature ✓
  - What is constant & therefore out of our realm of concern?
    - So it all comes down to partial pressure gradients of gases… determined by Dalton's Law!

Respiratory Physiology

Gas Laws

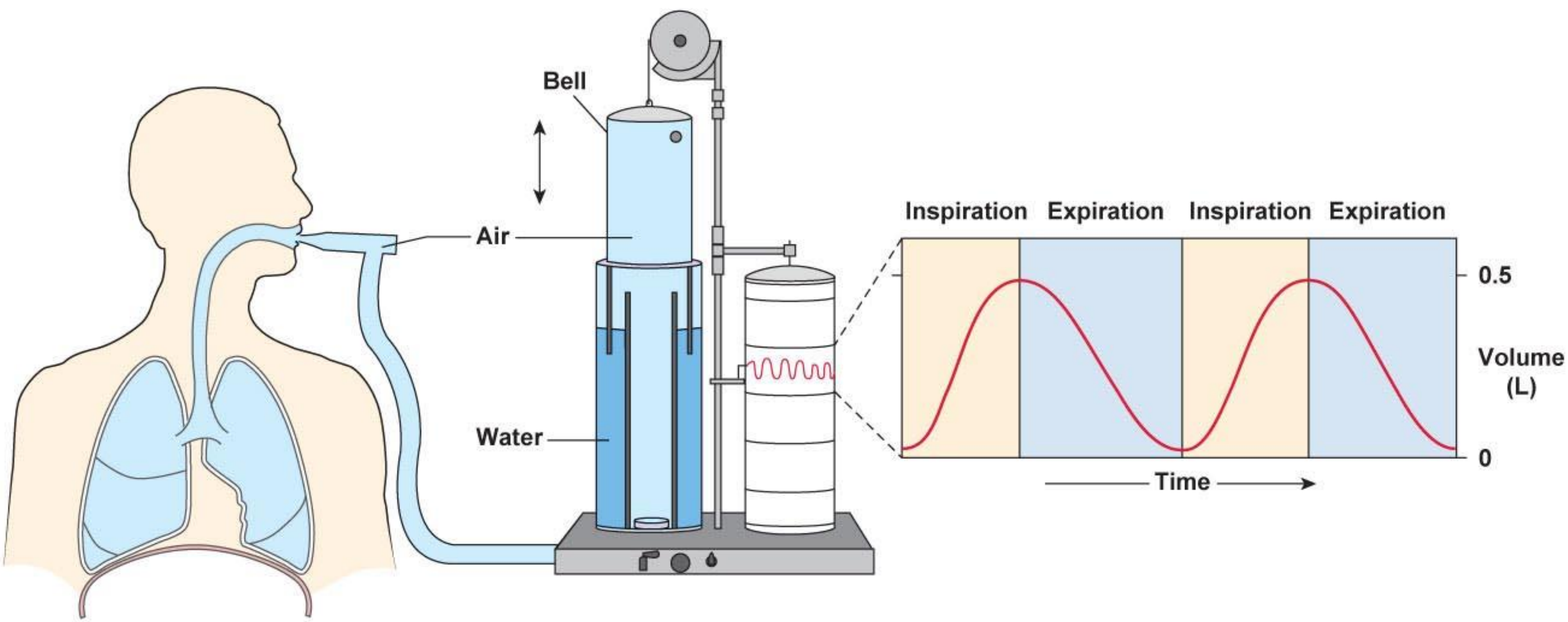
- Boyle's Law
  - Describes the relationship between pressure and volume
    - "the pressure and volume of a gas in a system are inversely related"
    - $P_1V_1 = P_2V_2$



Respiratory Physiology

Gas Laws

- How does Boyle's Law work in us?
  - As the thoracic cavity (container) expands the volume must up and pressure goes down
    - If it goes below 760 mm Hg what happens?
  - As the thoracic cavity shrinks the volume must go down and pressure goes up
    - If it goes above 760 mm Hg what happens

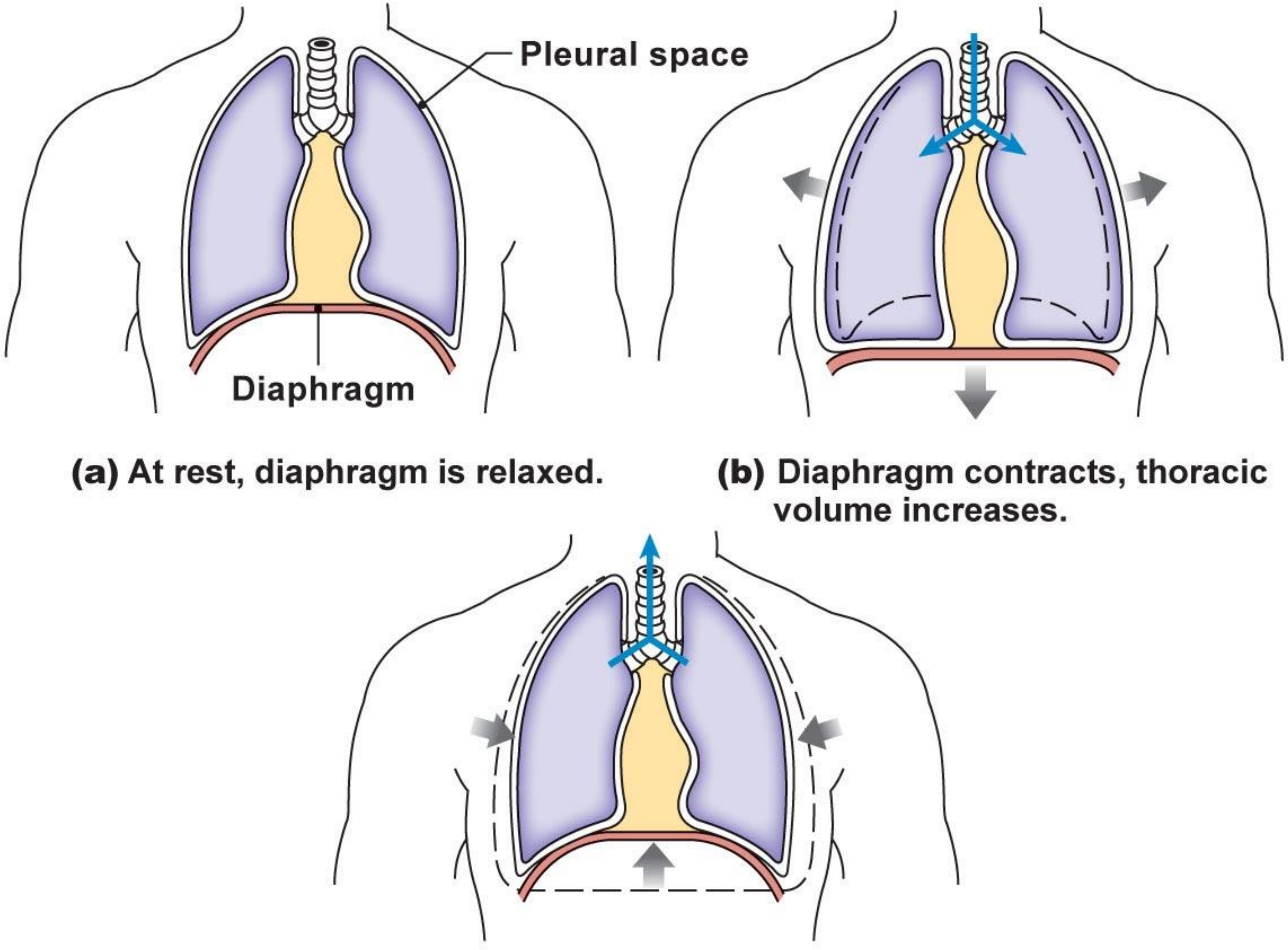


Ventilation

- Terminology
  - Inspiration = the movement of air into the respiratory tracts (upper & lower)
  - Expiration = movement of air out of the respiratory tracts
  - Respiratory cycle is one inspiration followed by an expiration
- Cause of Inspiration?
  - Biological answer
    - Contraction of the inspiratory muscles causes an increase in the thoracic cavity size, thus allowing air to enter the respiratory tract
  - Physics answer
    - As the volume in the thoracic cavity increases (due to inspiratory muscle action) the pressure within the respiratory tract drops below atmospheric pressure, creating a pressure gradient which causes molecular movement to favor moving into the respiratory tract
  - Cause of Expiration?

Ventilation

Besides the diaphragm (only creates about 60-75% of the volume change) what are the muscles of inspiration & expiration?

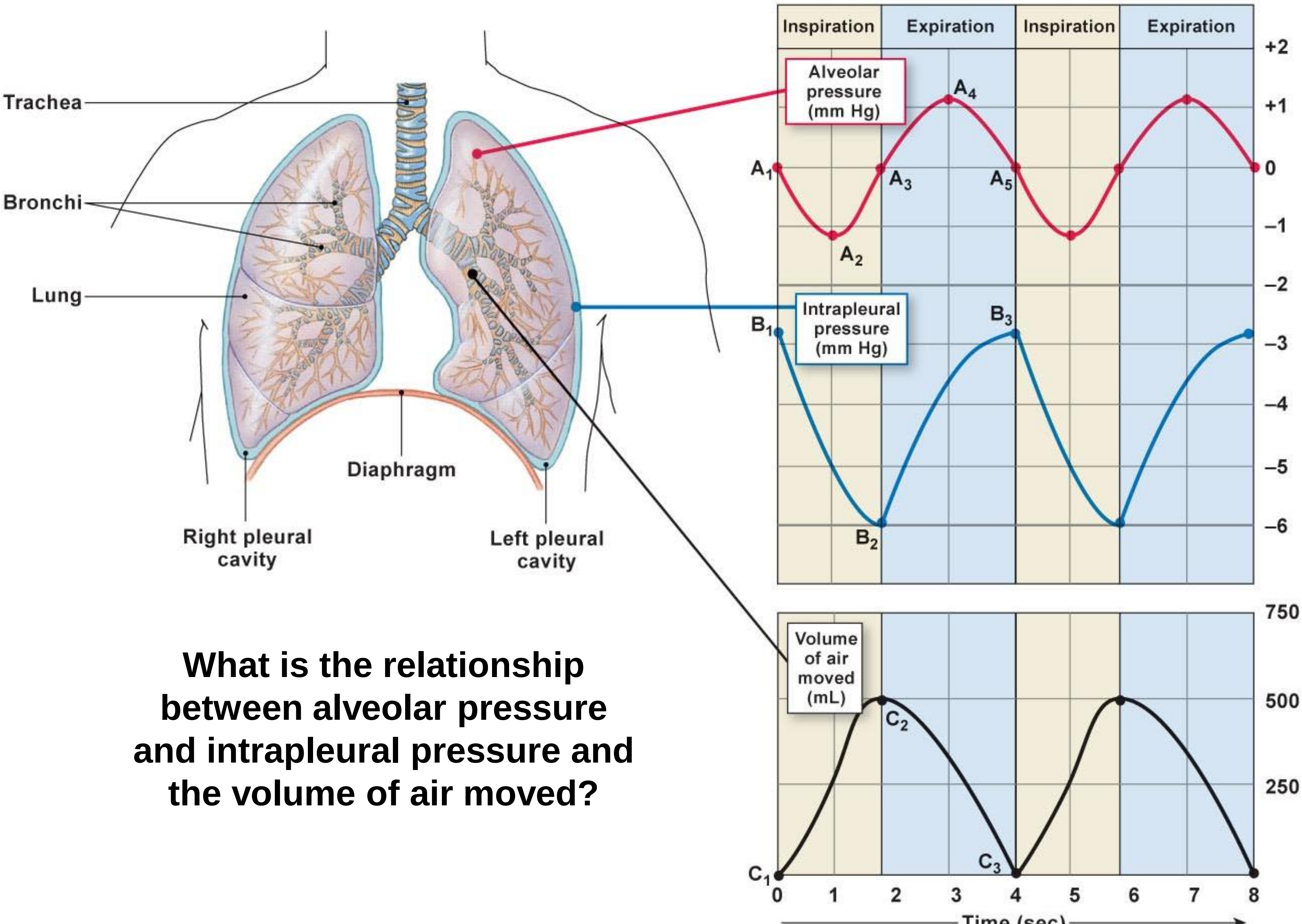


(a) At rest, diaphragm is relaxed.

(b) Diaphragm contracts, thoracic volume increases.

(c) Diaphragm relaxes, thoracic volume decreases.

Ventilation

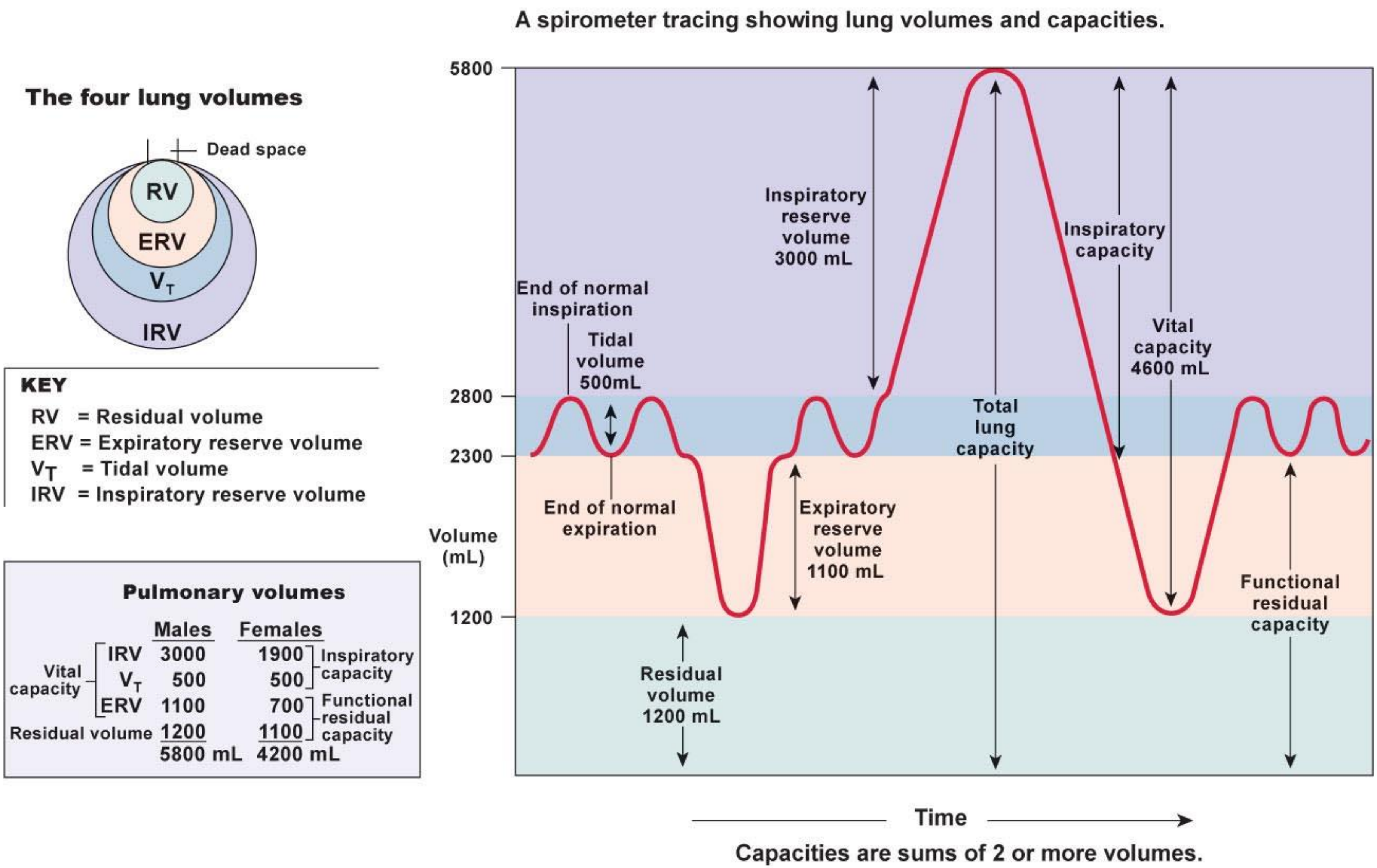


What is the relationship between alveolar pressure and intrapleural pressure and the volume of air moved?

Ventilation

- What are the different respiratory patterns?
  - Quiet breathing (relaxed)
  - Forced inspirations & expirations
- Respiratory volumes follow these respiratory patterns…

Ventilation



Ventilation

- Inspiration
  - Occurs as alveolar pressure drops below atmospheric pressure
    - For convenience atmospheric pressure = 0 mm Hg
      - A (-) value then indicates pressure below atmospheric P
      - A (+) value indicates pressure above atmospheric P
    - At the start of inspiration (time = 0),
      - atmospheric pressure = alveolar pressure
        - No net movement of gases!
    - At time 0 to 2 seconds
      - Expansion of thoracic cage and corresponding pleural membranes and lung tissue causes alveolar pressure to drop to -1 mm Hg
      - Air enters the lungs down the partial pressure gradient

Ventilation

- Expiration
  - Occurs as alveolar pressure elevates above atmospheric pressure due to a shrinking thoracic cage
    - At time 2-4 seconds
      - Inspiratory muscles relax, elastic tissue of corresponding structures initiates a recoil back to resting state
      - This decreases volume and correspondingly increases alveolar pressure to 1 mm Hg
        - This is above atmospheric pressure, causing…?
    - At time 4 seconds
      - Atmospheric pressure once again equals alveolar pressure and there is no net movement

Ventilation

- Both inspiration and expiration can be modified
  - Forced or active inspiration
  - Forced or active expiration

  - The larger and quicker the expansion of the thoracic cavity, the larger the gradient and
    - The faster air moves down its pressure gradient

Ventilation

- Things to consider
  - surfactant effect
  - airway diameter
  - Minute volume respiration (ventilation rate times tidal volume) & anatomical dead space
    - Leading to a more accurate idea of alveolar ventilation rates
  - Changes in ventilation patterns

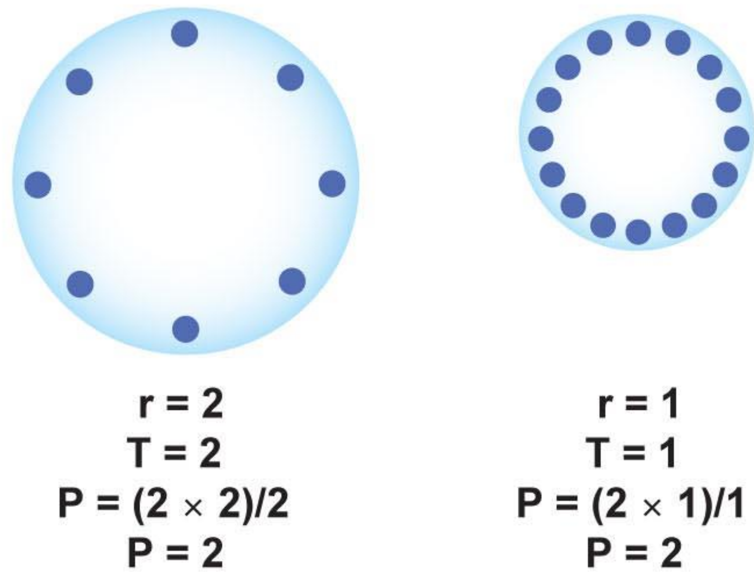
Ventilation

- Surfactant is produced by the septal cells
  - Disrupts the surface tension & cohesion of water molecules
  - Impact?
    - prevents alveoli from sticking together during expiration

Law of LaPlace: P = 2T/r

P = pressure
T = surface tension
r = radius

According to the law of LaPlace, if two bubbles have the same surface tension, the small bubble will have higher pressure.



(b) Surfactant reduces surface tension (T). Pressure is equalized in the large and small bubbles.

Ventilation

Airway diameter & other factors that affect airway resistance?

FACTOR	AFFECTED BY	MEDIATED BY
Length of the system	Constant; not a factor	
Viscosity of air	Usually constant; humidity and altitude may alter slightly	
Diameter of airways		
Upper airways	Physical obstruction	Mucus and other factors
Bronchioles	Bronchoconstriction	Parasympathetic neurons (muscarinic receptors), histamine, leukotrienes
	Bronchodilation	Carbon dioxide, epinephrine (β_2-receptors)

Ventilation

The relationship between minute volume (total pulmonary ventilation) and alveolar ventilation & the subsequent "mixing" of air