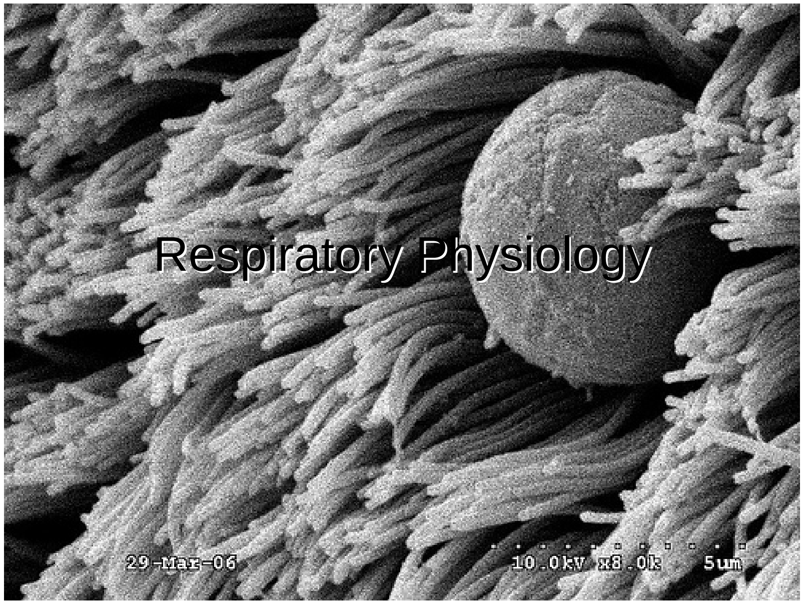
Respiratory Physiology



Lecture Outline

- Basics of the Respiratory System
  - Functions & functional anatomy
- Gas Laws
- Ventilation
- Diffusion & Solubility
- Gas Exchange
  - Lungs
  - Tissues
- Gas Transport in Blood
- Regulation of Ventilation & Impacts on
  - Gas levels, pH

Basics of the Respiratory System

General Functions

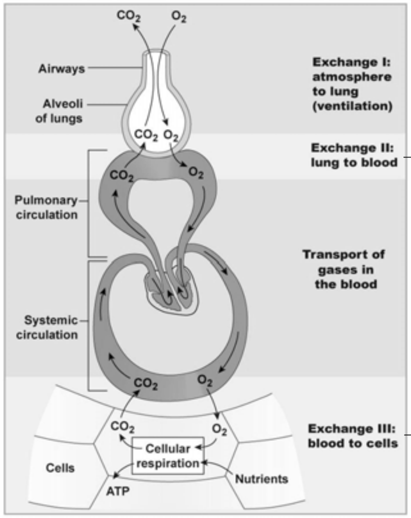
- Exchange of gases
    - Directionality depends on gradients!
  - Atmosphere to blood
  - Blood to tissues
- Regulation of pH
  - Dependent on rate of CO_2 release
- Protection
- Vocalization
- Synthesis

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



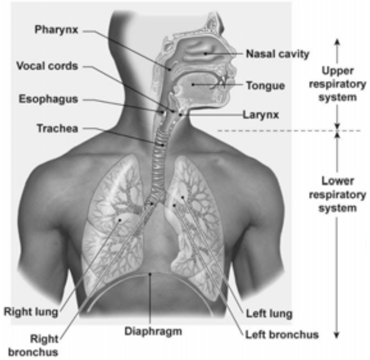
External Respiration

Internal Respiration

Basics of the Respiratory System

Functional Anatomy

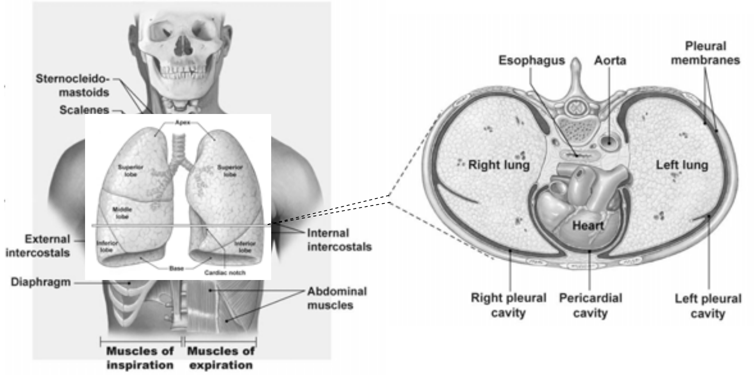
- What structural aspects must be considered in the process of respiration?
  - The conduction portion
  - The exchange portion
  - The structures involved with ventilation
    - Skeletal & musculature
    - Pleural membranes
    - Neural pathways
- All divided into
  - Upper respiratory tract
    - Entrance to larynx
  - Lower respiratory tract
    - Larynx to alveoli (trachea to lungs)



Basics of the Respiratory System

Functional Anatomy

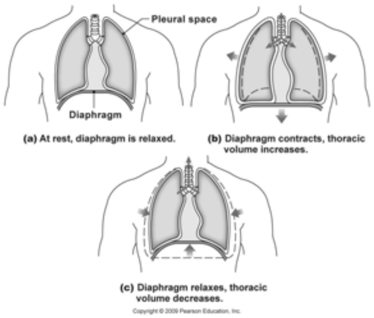
- Bones, Muscles & Membranes



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 = <u>collapsed lung or pneumothorax</u>

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

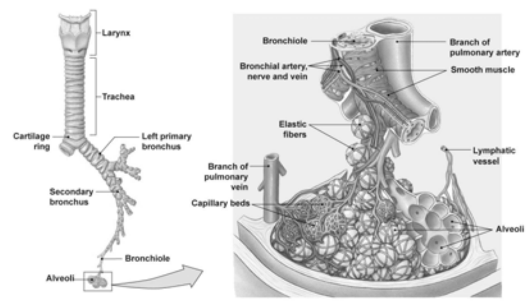
Basics of the Respiratory System
Functional Anatomy

- 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

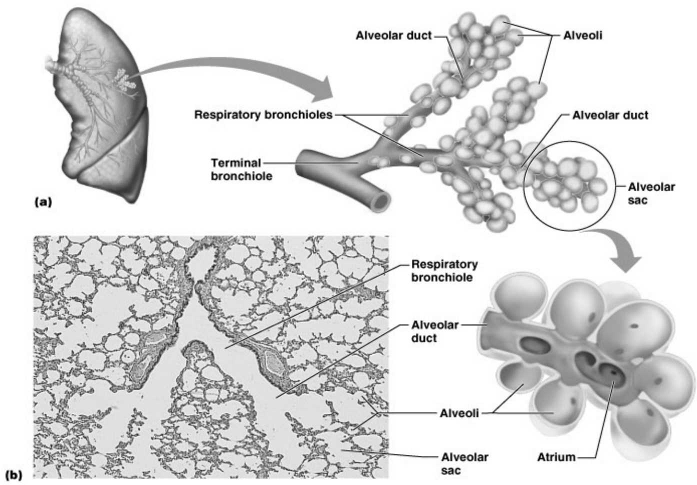
    conductive portion

    - 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	$3\text{-}6 \times 10^8$	$>1 \times 10^6$



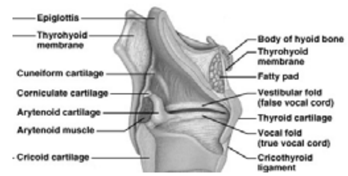
Basics of the Respiratory System

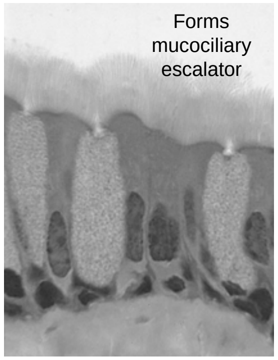
Functional Anatomy

- 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"

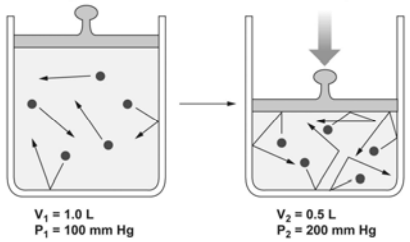
      Or
    - The total pressure of a mixture of gases is equal to the sum of the individual gas pressures.
  - What does this mean in practical application?
    - If we know the total atmospheric pressure (760 mm Hg) and the relative abundances of gases (% of gases)
      - We can calculate individual gas effects!
      - P_{atm} x % of gas in atmosphere = Partial pressure of any atmospheric gas
        - » P_{O2} = 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!

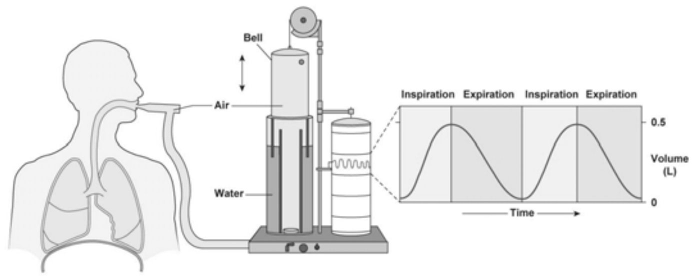
Respiratory Physiology
Gas Laws

- 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



Respiratory Physiology
Gas Laws

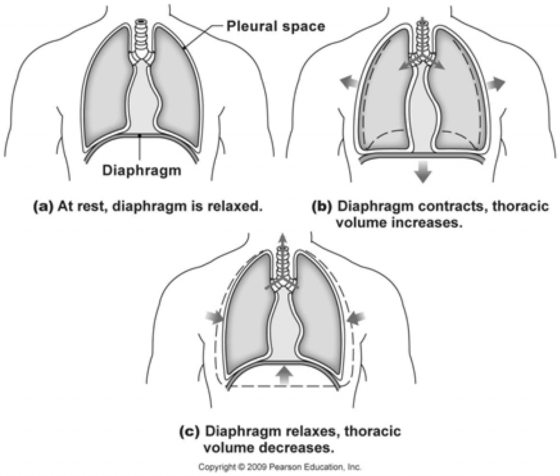
- Ideal Gas law
  - The pressure and volume of a container of gas is directly related to the temperature of the gas and the number of molecules in the container
  - $PV = nRT$
    - n = moles of gas
    - T = absolute temp
    - R = universal gas constant @ 8.3145 J/mol K
  - Do we care?

Ventilation

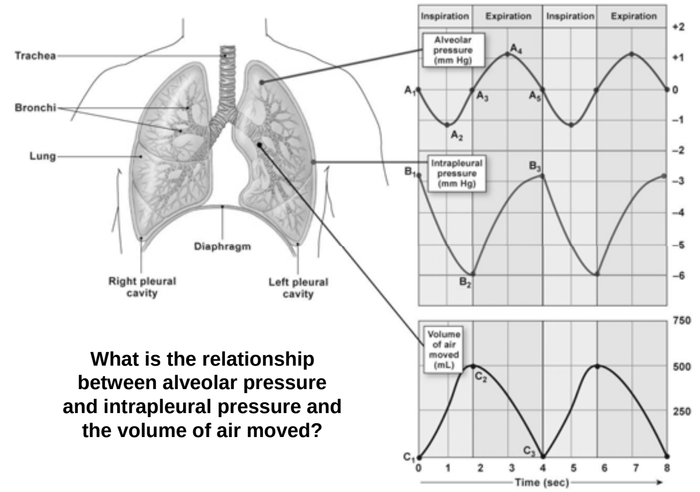
- Terminology
  - Inspiration = the movement of air into the respiratory tracts (upper & lower)
  - Expiration = movement of air out of the respiratory tracts
  - Respiratory cycle is one inspiration followed by an expiration
- Cause of Inspiration?
  - Biological answer
    - Contraction of the inspiratory 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?



Ventilation

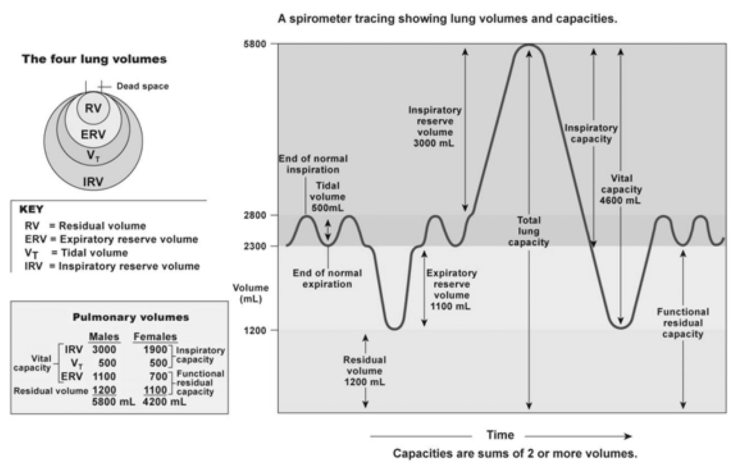


What is the relationship between alveolar pressure and intrapleural pressure and the volume of air moved?

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

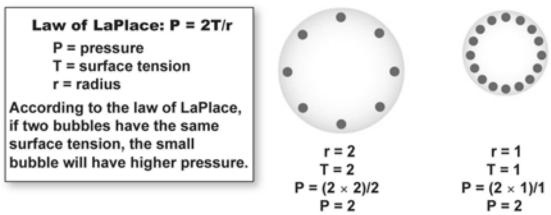
- Both inspiration and expiration can be modified
  - Forced or active inspiration
  - Forced or active expiration
  - The larger and quicker the expansion of the thoracic cavity, the larger the gradient and
    - The faster air moves down its pressure gradient

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



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

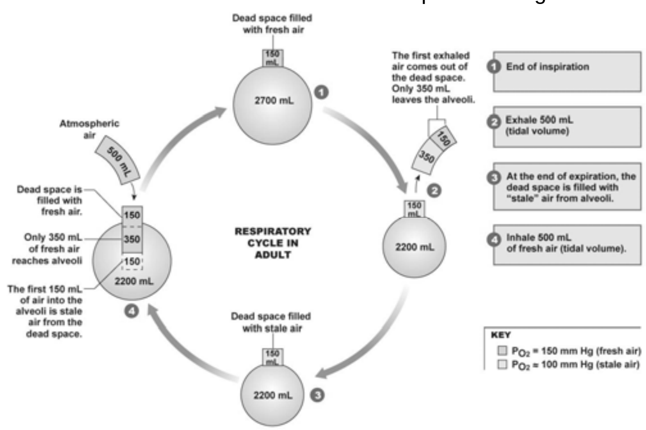
Ventilation

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



Next Time…

- Diffusion and Solubility
  - Gas composition in the alveoli
- Gas exchange
- Gas transport in blood
- Regulation of pulmonary function