Respiratory Physiology

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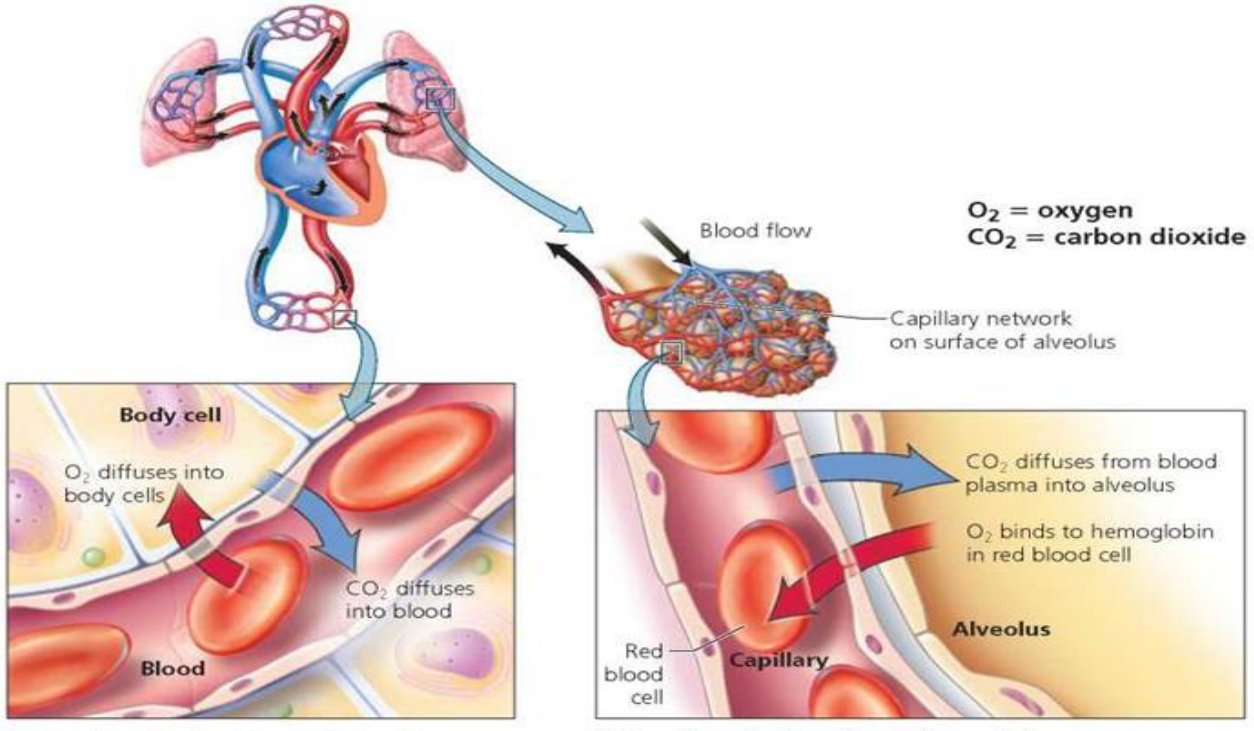
Introduction

- Exchanges of Gases Between the Atmosphere, the Blood, and the Tissues
  - Pulmonary Ventilation (External Respiration)
    - Movement of air between the atmosphere and the alveoli
    - △ Pressure
  - Diffusion Across the Alveolar Membrane
    - Movement of gases between the alveoli and the bloodstream
    - △ Concentration
  - Diffusion of Gases in the Blood
    - Movement of blood through the vessels
    - △ Pressure
  - Diffusion Across the Capillaries
    - Movement of gases between the capillaries and the tissues
    - △ Concentration
  - Cellular Respiration (Internal Respiration)
    - Oxidation of food for energy
- Oxygen Consumption by the Body
  - At rest – 200 ml of O_2/minute
  - During strenuous exercise – 4,000 ml. of O_2/minute

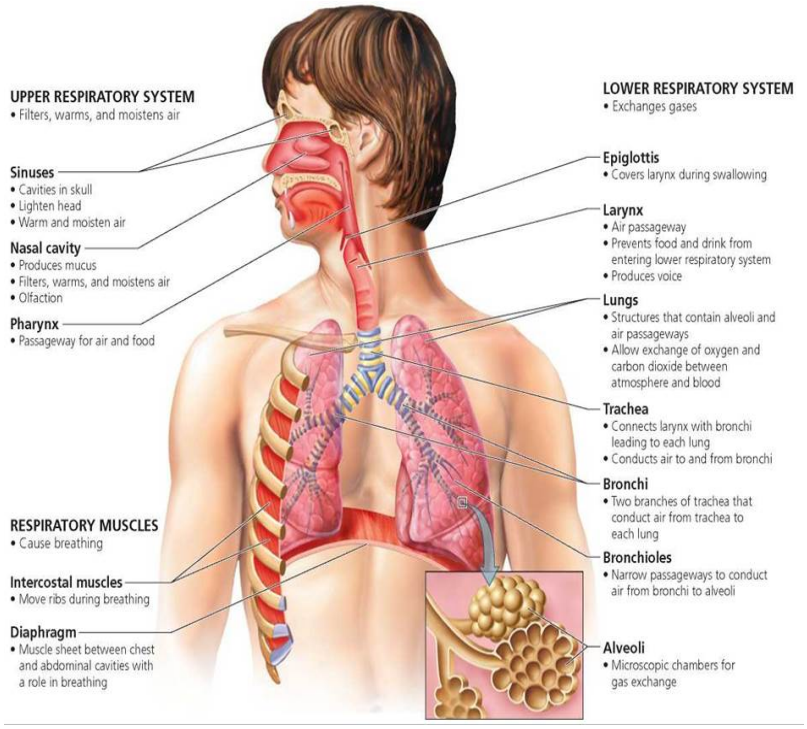


Internal respiration: Gas exchange in capillary beds throughout body tissues

External respiration: Gas exchange in lungs

Pneumocytes - Alveolar Cells

- Pneumocytes (or alveolar cells) are the cells that line the alveoli and comprise of the majority of the inner surface of the lungs
- There are two types of alveolar cells – type I pneumocytes and type II pneumocytes

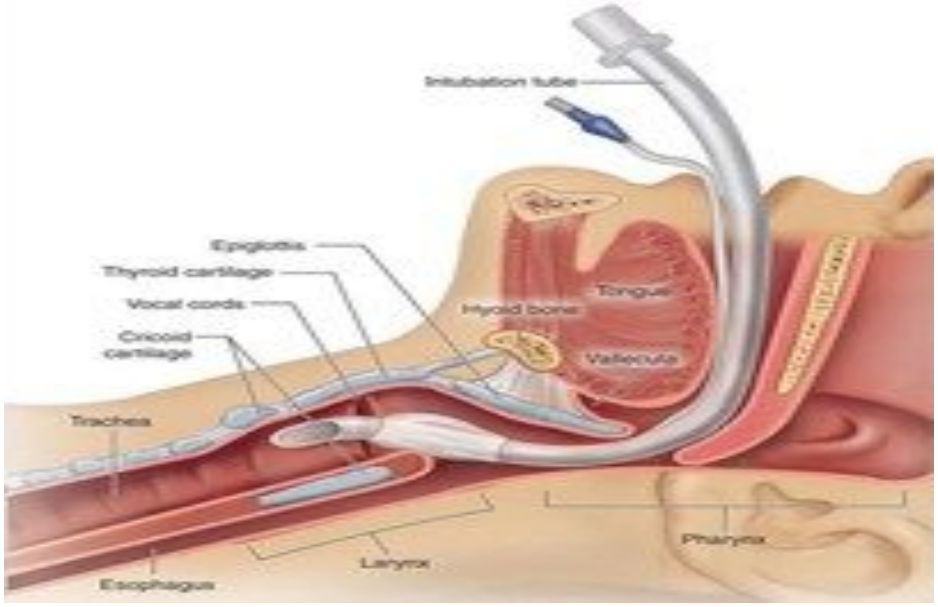


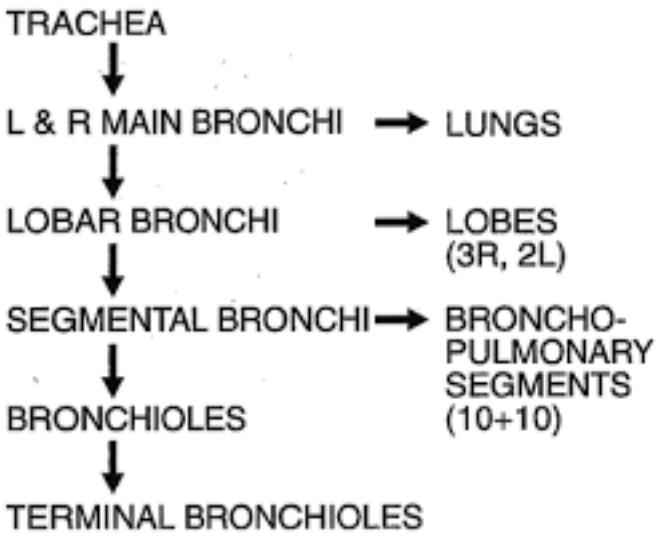
The Upper Respiratory Track

- Everything <u>outside</u> the chest cavity
- The Nasal Cavity & Paranasal Sinuses
    - Lined with psuedostratified ciliated columnar epithelium with goblet cells
    - Acts to warm and humidify the inhaled air
    - Rhinitis
- The Pharynx (throat)
    - Serves as a common passage for both food and air
    - Pharyngitis – sore throat
- The Larynx (Voice Box, Adam's Apple)
    - Laryngeal aperture
        - Opening between the pharynx and the larynx
    - The glottis
        - The narrow opening between the vocal cords
    - Laryngitis
    - Laryngospasm
        - Spasmodic contraction of the laryngeal muscles

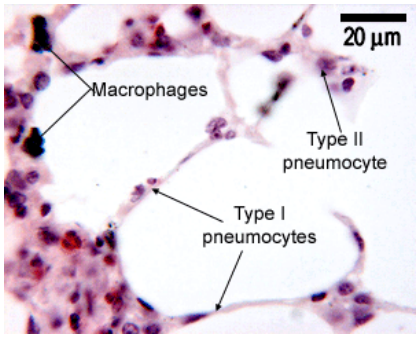
The Lower Respiratory Tract

- Everything <u>inside</u> the chest cavity
- Lined by ciliated mucous membranes
- The Trachea – Windpipe_
    - The trachea is 4 ½ inches long extending from C6 down to T5
    - Located anterior to the esophagus
    - It is C-shaped cartilaginous rings (which prevents the collapse of the airway when breathing)
- The Bronchial Tree
- With each subdivision, there is progressively:
    - Less cartilage in the walls
    - More visceral muscle and elastic connective tissue in the walls





Alveoli (air sacs)



- Alveoli are delicate hollow sacs (composed of simple squamous epithelium) surrounded by pulmonary capillaries
- There are about 300 million alveoli in each lung, providing a total surface area (for the exchange of gases) equal to 760 sq. ft.
    - This surface area is 40X the surface area of the entire body
- Microanatomy of the Alveolar (Respiratory) Membrane
    - "Air-Blood Barrier"
    - Type II Alveolar (Septal) Cells
        - Secretes pulmonary surfactant into the thin film of tissue fluid surrounding the alveoli
        - Macrophage Cells
            - Engulfs dust and foreign matter
- The alveoli starts to develop in the embryo during the 6th fetal month and continues throughout childhood.

Type I Alveolar Cells

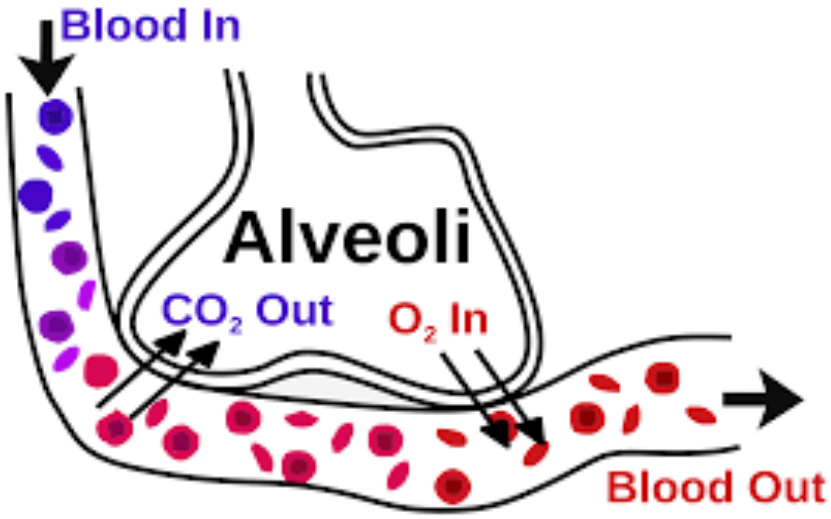
- 95% of alveolar cells with simple squamous epithelium
- 80% - 85% of alveoli come in direct contact with capillaries
- Very fast transfer of gas
- Type I pneumocytes are involved in the process of gas exchange between the alveoli and the capillaries
- They are squamous (flattened) in shape and extremely thin (~ 0.15µm) – less diffusion distance for respiratory gases
- Type I pneumocytes are connected by occluding junctions, which prevents the leakage of tissue fluid into the alveolar air space
- Type I pneumocytes are amitotic and unable to replicate, however type II cells can differentiate into type I cells if required

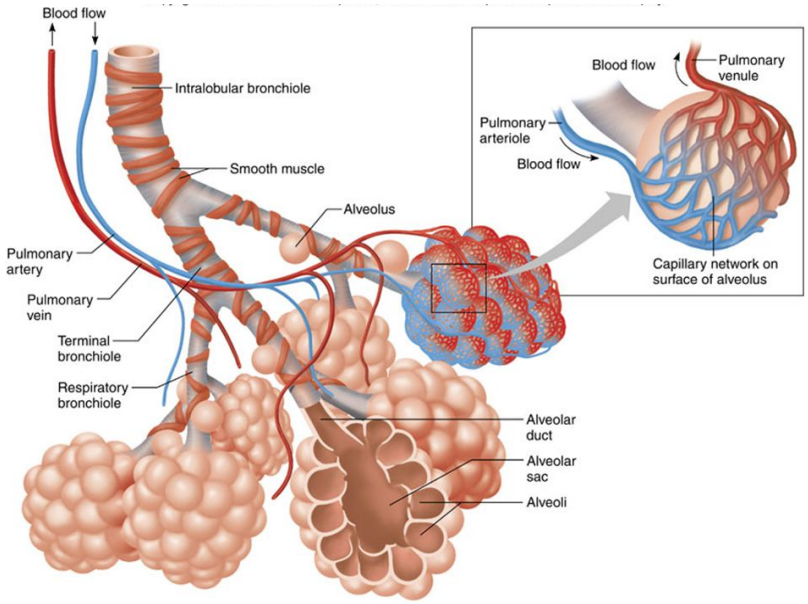
Type II Alveolar Cells

- Produces surfactant which reduces surface tension
- Sucks solutes, debris, ions, etc. out of the alveoli which keeps the alveoli clean.
- What happens to water in the alveoli when this happens?
- Type II pneumocytes are responsible for the secretion of pulmonary surfactant, which reduces surface tension in the alveoli
- They are cuboidal in shape and possess many granules (for storing surfactant components)
- Type II pneumocytes only comprise a fraction of the alveolar surface (~5%) but are relatively numerous (~60% of total cells)
- As an alveoli expands with gas intake, the surfactant becomes more spread out across the moist alveolar lining.
- This increases surface tension and slows the rate of expansion, ensuring all alveoli inflate at roughly the same rate.

Microanatomy of the Alveolar (Respiratory) Membrane
"Air-Blood Barrier" or "Blood-Air Barrier"

- Type II Alveolar (Septal) Cells
    - Secretes pulmonary surfactant into the thin film of tissue fluid surrounding the alveoli
        - Macrophage Cells - Engulfs dust and foreign matter
    - The alveoli starts to develop in the embryo during the 6th fetal month and continues throughout childhood.
- The **blood–air barrier** (alveolar–capillary **barrier** or membrane) exists in the gas exchanging region of the lungs.
- It exists to prevent **air** bubbles from forming in the **blood**, and from **blood** entering the alveoli.



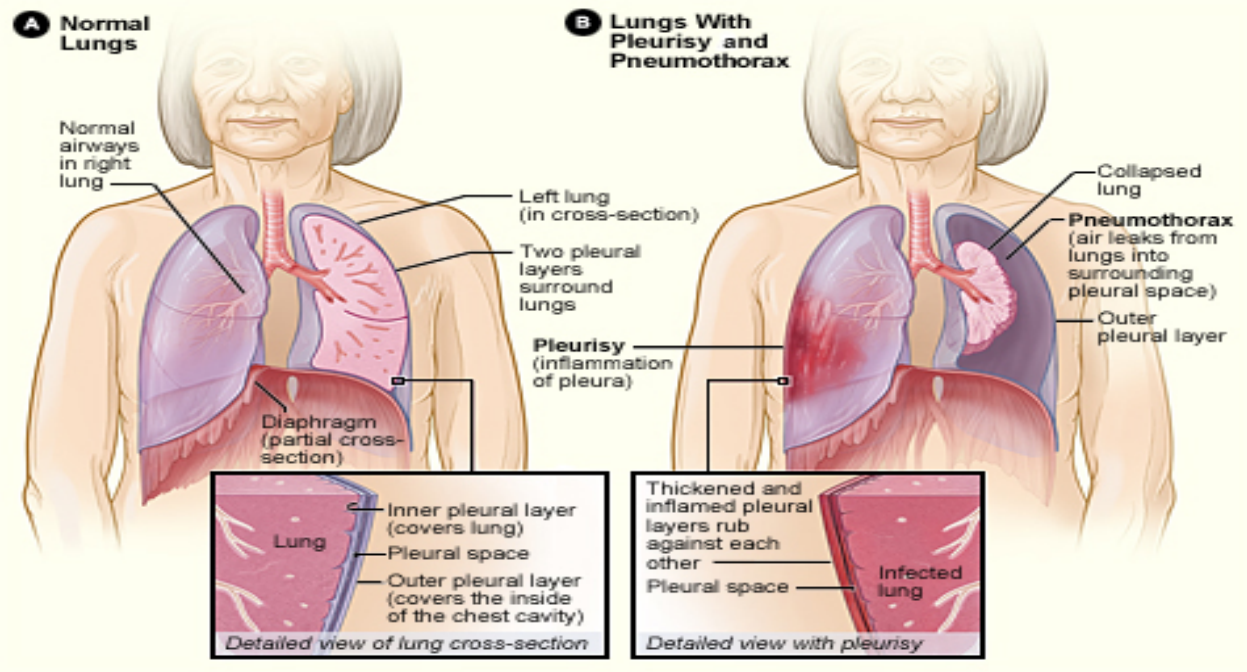


The Pleural Membranes of the Lungs

- The pleural membranes secrete slippery serous fluid
    - Visceral pleural membrane – covers the surface of each lung
    - Parietal pleural membrane- lines the inner wall of the chest
- Intrapleural cavity
    - Fluid-filled space between the pleural membranes
    - Intrapleural (Intrathoracic) Pressure
        - Tendency of the balloon-like lungs to collapse and pull-away from the chest wall normally creates a subatmospheric (“negative”) Intra-pleural Pressure
        - However, during any forceful exhalation (Valsalva Manuever) the chest walls is compressed down upon the lungs, creating a greater than atmospheric (“positive”) Intrapleural Presuure
        - Forceful exhalation, coughing, sneezing, vomiting, defecation, pushing during labor.

Clinical Considerations

- Pleurisy (Pleuritis)
    - Inflammation of the pleural membranes
- Pneumothorax / Hemothorax
    - Entry of air / blood into the intra-pleural cavity caused partial or complete collapse of the lung >>>> deceased TLC (Total Lung Capacity)
        - Example – fractured ribs



Breathing

- Breathing, or pulmonary ventilation, consists of two phases
    - Inspiration – air flows into the lungs
    - Expiration – gases exit the lungs

Pressure Relationships in the Thoracic Cavity

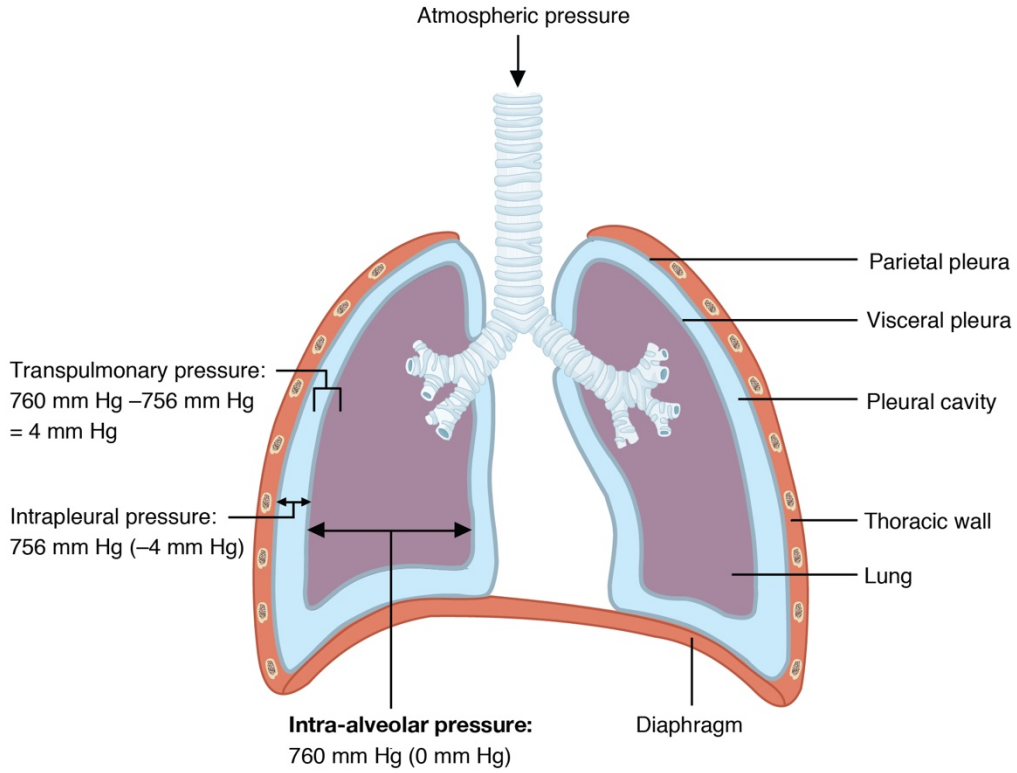
- Respiratory pressure is always described relative to atmospheric pressure
- Atmospheric pressure
    - Pressure exerted by the air surrounding the body
- Intrapulmonary pressure – pressure within the alveoli
- Intrapleural pressure – pressure within the pleural cavity
- Two forces act to pull the lungs away from the thoracic wall, promoting lung collapse
    - Elasticity of lungs causes them to assume smallest possible size
    - Surface tension of alveolar fluid draws alveoli to their smallest possible size
- Opposing force – elasticity of the chest wall pulls the thorax outward to enlarge the lungs

Mechanics of Pulmonary Ventilation

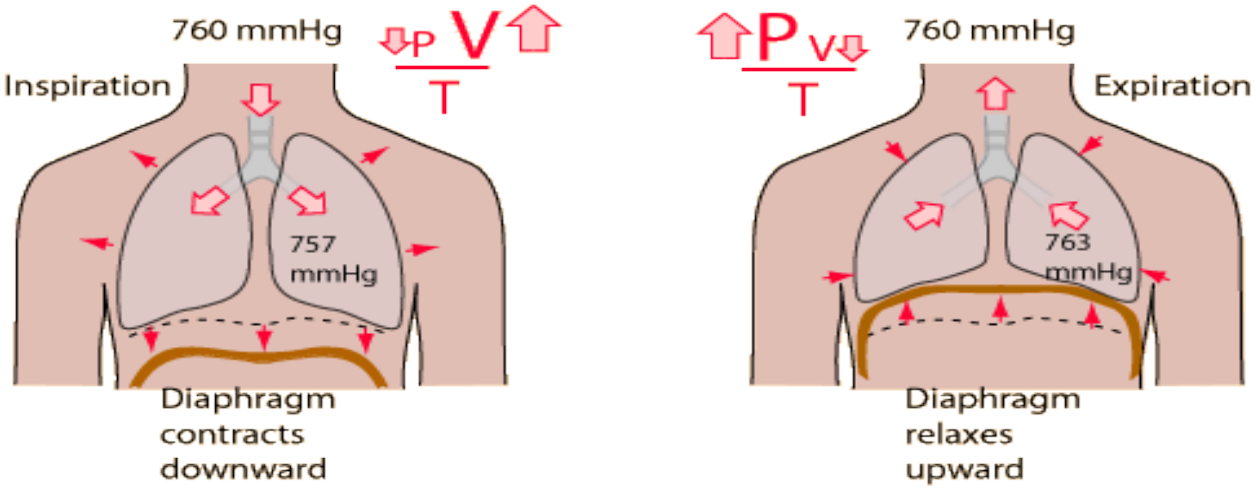
- Definitions:
    - Atmospheric Pressure
        - Since the atmospheric pressure is constant, it is essentially assumed to be zero.
    - Intrapleural (Intrathoracic) Pressure
        - The pressure recorded in the intrapleural cavity
        - This pressure reflects what the chest wall is doing
    - Alveolar (Intrapulmonary) Pressure
        - The pressure recorded within the lungs
        - This pressure reflects what the lungs are doing
- **Air Flow In & Out of the Lungs**
    - Air flow in or out of the lungs is due to changes in the Alveolar (Intrapulmonary) Pressure

      Air Flow = Atmospheric Pressure – Alveolar Pressure / Airway Resistance

    - These changes in the Alveolar (Intrapulmonary) Pressure are produced by the contraction or relaxation of the Diaphragm and other respiratory muscles
        - As the Alveolar Pressure becomes <u>less</u> than atmospheric, air flows <u>into</u> the lungs
        - As the Alveolar Pressure becomes <u>more</u> than atmospheric, air flows <u>out</u> of the lungs



- **Air Flow In & Out of the Lungs**
  - Changes in Airway Resistance (A.R.)



Review from blood flow: Remember that in blood flow, if there was an increased TPR (Total Peripheral Resistance), there was a decrease in blood flow after the resistance. It is the same in respiration. If there is a Bronchoconstriction, there will be an increase of AR (Airway Resistance), which will decrease air flow. Vessels and bronchioles are the very similar. This is exactly what happens in asthma.

Parasympathetic motor neurons ➡ Bronchoconstriction ➡ ⬆️ A.R. ➡ ⬇️ Air Flow

Histamine & Nicotine

What can cause the bronchi to constrict? Parasympathetic stimulation which will release histamines. What does histamine do to blood vessels? It dilates them.

Histamine dilates blood vessels causing decreased peripheral resistance causing increased blood flow AND histamine constricts bronchi which increases resistance which decreases air flow.

Sympathetic motor neurons ➡ Bronchodilation ➡ ⬇️ A.R. ➡ ⬆️ Air Flow

Epinephrine

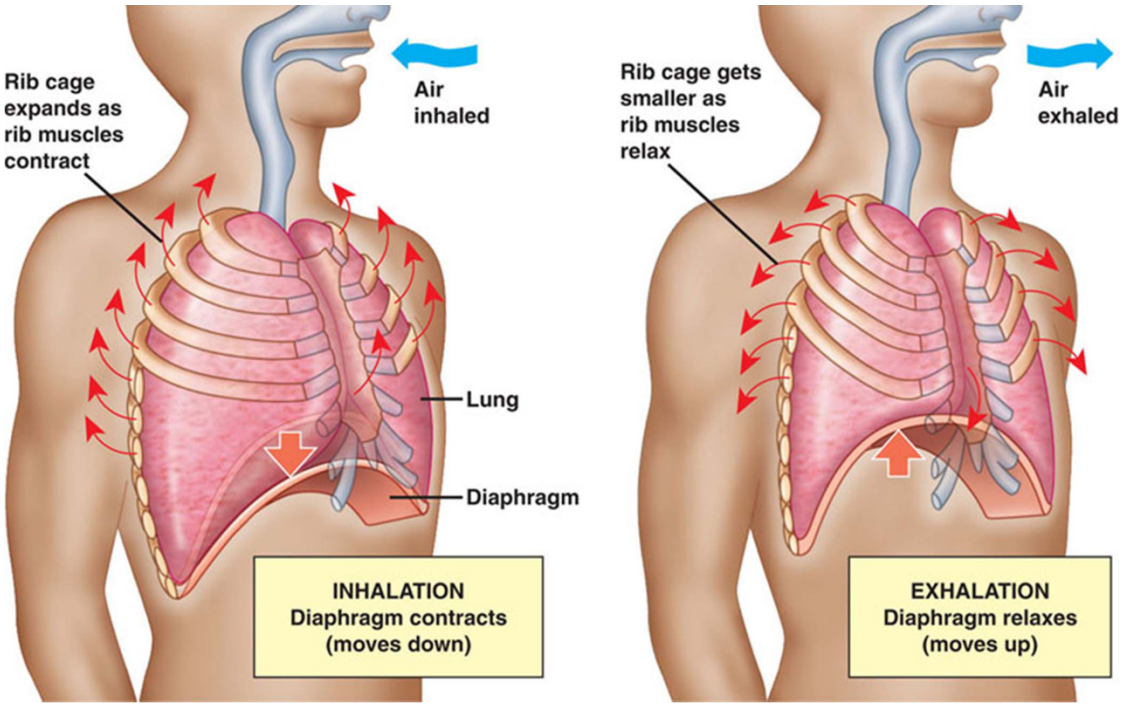
What can cause the bronchi to dilate? Sympathetic stimulation which will release Epinephrine. What does epinephrine do to blood vessels? It constricts them.

Epinephrine constricts blood vessels causing decreased peripheral resistance causing decreased blood flow AND epinephrine dilates bronchi which decreases resistance which increases air flow.

Mechanics of Pulmonary Ventilation

- Air Flow In & Out of the Lungs
  - Velocity of Air Flow
    - Air flows fastest through the larger bronchi and slowest in the small bronchioles (due to the total cross-sectional area)
    - Identical to the blood vessels

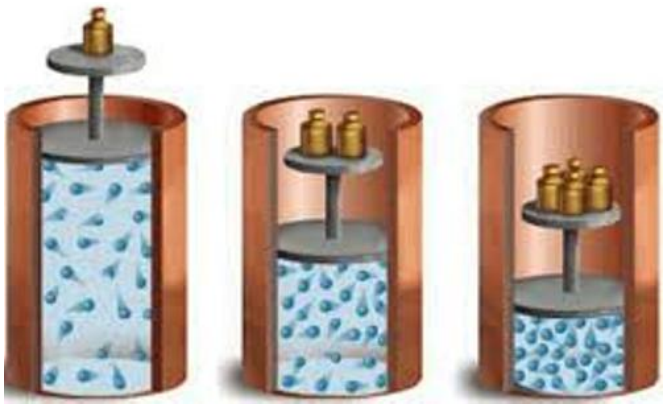
- Normal Pulmonary Ventilation
  - Contraction of the diaphragm enlarges the volume of the chest from top-to-bottom
  - Contraction of the other respiratory muscles enlarges the volume of the chest from front-to-back as the ribs are elevated
    - When you enlarge the chest cavity, it creates a pressure less than atmospheric pressure. This sub-atmospheric pressure creates a vacuum or “sucking effect” that will continue until the atmospheric pressure is zero.



Mechanics of Pulmonary Ventilation

- Boyle's Law states that in a closed space, pressure and volume are inversely related.
- As volume decreases, pressure increases and vice versa.
- During Inhalation, <u>air is sucked into</u> the lungs:

Boyle's Law



Respiratory muscles contract ➡ ⬆ Chest Volume ➡ ⬇ Alveolar Pressure as the lungs are stretched bigger ➡ Air flows INTO the lungs until the pressure in the lungs becomes atmospheric

- The more the Chest Volume increases, the more air that is drawn into the lungs
- Since inhalation of air involves a negative (sub-atmospheric) pressure being produced within the lungs, normal Pulmonary Ventilation is called “negative pressure breathing”

- During Exhalation, <u>air is forced out</u> of the lungs:

Respiratory muscles relax ➡ ⬇ Chest Volume ➡ ⬆ Alveolar Pressure as the lungs become compressed ➡ Air flows OUT OF the lungs until the pressure in the lungs becomes atmospheric

Artificial Ventilation

- The Drinker Iron Lung
  - Simulates the pressure changes that occur during normal pulmonary ventilation
  - Inhalation

⬇ Atmospheric pressure surrounding the chest ➡ ⬆ Chest Volume ➡ ⬇ Alveolar pressure as the lungs are stretched bigger ➡ Air flows into the lungs until the pressure in the lungs becomes atmospheric

- Exhalation

⬆ Atmospheric pressure surrounding the chest ➡ ⬇ Chest Volume ➡ ⬆ Alveolar pressure as the lungs becomes compressed ➡ Air flows into the lungs until the pressure in the lungs becomes atmospheric

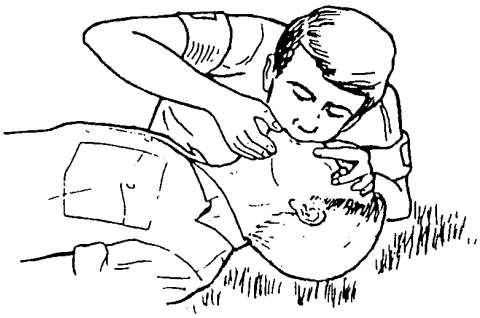
Intermittent Positive Pressure Breathing Resuscitators

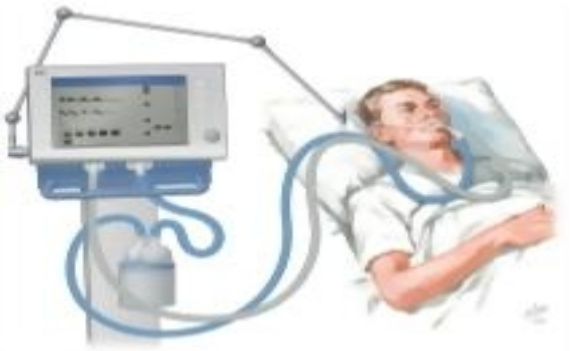
- Called IPPBD – Intermittent Positive Pressure Breathing Devices
- Air is intermittently forced into the lungs (rather than being sucked-in) at a positive (greater than atmospheric) pressure
- Examples
    - Mechanical Ventilators
    - Mouth-to Mouth Resuscitation
- Inhalation

Resuscitator "blasts" air into the lungs at a positive pressure ➡ ⬆️ Alveolar Pressure ➡ ⬆️ Chest Volume

- Exhalation

Resuscitator "shuts off" ➡ air flows out of the lungs until the pressure in the lungs becomes atmospheric ➡ ⬇ Alveolar pressure ➡ ⬇ Chest Volume





Pulmonary Function Tests – The Measurement of Lung Ventilatory Volumes

- **Spirometers**
    - Are used to measure the volume of air that is inhaled or exhaled
    - Normal lung volumes vary with a person's age and size
    - Spirometry readings are used to differentially diagnose different types of lung disease

Respiratory Volumes

- Tidal volume
  - Air that moves into and out of the lungs with each breath
  - Normal - 500 ml at rest (1/2 liter)
- Inspiratory reserve volume
  - Air that can be inspired forcibly beyond the tidal volume
  - Normal - 2100–3200 ml (2-3 liters)
- Forced expiratory reserve volume
  - Air that can be evacuated from the lungs after a tidal expiration
  - Normal - 1000–1200 ml (1 liter)
  - This reflects the maximum rate of exhalation in 1 second
    - Normally a person should be able to expel 80% of the vital capacity in 1 second
    - This % is greatly decreased in COPD, PE, myasthenia gravis and pregnancy
- Residual volume
  - Air left in the lungs after strenuous expiration
  - Approximately 1200 ml (1 liter)

Respiratory Capacities

- Inspiratory capacity
  - Total amount of air that can be inspired after a tidal expiration
- Functional residual capacity
  - Amount of air remaining in the lungs after a tidal expiration
  - FRC = ERV + RV
- Forced vital capacity
  - The total amount of air that can be forcefully exhaled (after a maximal inhalation)
  - Vital Capacity = TLC – RV
  - Normal – 4 liters
- Total lung capacity
  - The total volume of air in the lungs after a maximal inhalation
  - Sum of all lung volumes
  - Approximately 6 liters
  - The TLC is decreased in patients with restrictive lung diseases or pneumothorax

Qualifying Pulmonary Ventilation

- **Minute Ventilation – $\dot{V}$**
  - The volume of air inhaled or exhaled in 1 minute
    - Minute ventilation ⬇ in hypoventilation
    - Minute ventilation ⬆ in hyperventilation

$$\dot{V} = F \times V_T$$

Minute Ventilation = Frequency x Tidal Volume (inhaled with each breath)

= 15 breaths / minute x 500 mL / breath = 7,500 mL / min

= 7,500 mL / min = 7.5 L / min

- **Dead Space - V_D**
  - The volume of air that does NOT reach the alveoli (ie., the air in the conducting division of the respiratory system)
  - V_D = 150 ml
  - With any inhalation, the last 150 ml of air does not reach the alveoli
  - **Bronchodilation ➡ ⬆ V_D**

- **Alveolar Minute Ventilation**
  - The functional volume of air that actually moves in or out of the alveoli in 1 minute

$$V_A = F \times (V_T - V_D)$$

Minute Alveolar Ventilation = Frequency x (Tidal Volume – Dead Space)

= 15 breaths / minute x (500 mL / breath – 150 mL)

= 15 breaths / minute x 350 mL / breath

= 5,250 mL / min = 5.25 L / min

Why does 5.25 L / minute sound familiar

CO = HR x SV is 5.25 L / min !!!

$\dot{V}_A = F \times (V_T - V_D)$ is 5.35 L / min !!!

The Work of Breathing

- There are three principle factors that affect the work of breathing:
  - **Airway Resistance – A.R.**
  - **Lung Compliance**
  - **Alveolar Surface Tension**

- **Alveolar Resistance (A.R.)**
  - The hindrance of the flow of air
  - A.R. is affected by the degree of bronchoconstriction

Sympathetic stimulation➡Bronchodilation ➡⬇️A.R.➡ ⬇️Work of Breathing
Epinephrine

Parasympathetic stimulation➡Bronchoconstriction➡⬆️A.R.➡⬆️Work of Breathing
Histamine & Nicotine

Why aren't the bronchioles kept fully dilated all the time?

The airways become compressed during each exhalation
Visualize – a sponge with pores, being stretched and then compressed

The Work of Breathing

- **Lung Compliance**
  - The elasticity ("stretchability") of the lungs
  - The lungs are normally 100% more compliant than a balloon is
  - Pulmonary fibrosis (scar-tissue formation) causes a decrease in lung compliance

- **Alveolar Surface Tension**
  - The thin film of fluid that surrounds the alveoli tends to cause the delicate, microscopic alveoli to collapse
  - This results from high electrical attraction ("surface tension") between the water molecules in this thin film of fluid
  - Type II Alveolar (Septal) Cells in the lungs normally secrete a phospholipidprotein called Pulmonary Surfactant that reduces this tendency of the alveoli to collapse
  - Pulmonary Surfactant, which is similar to a detergent, lower the surface tension of water by interfering with the electrical attraction between the water molecules

Clinical Considerations – Restrictive Lung Diseases

- All restrictive lung diseases are associated with ⬇ TLC (total lung capacity)

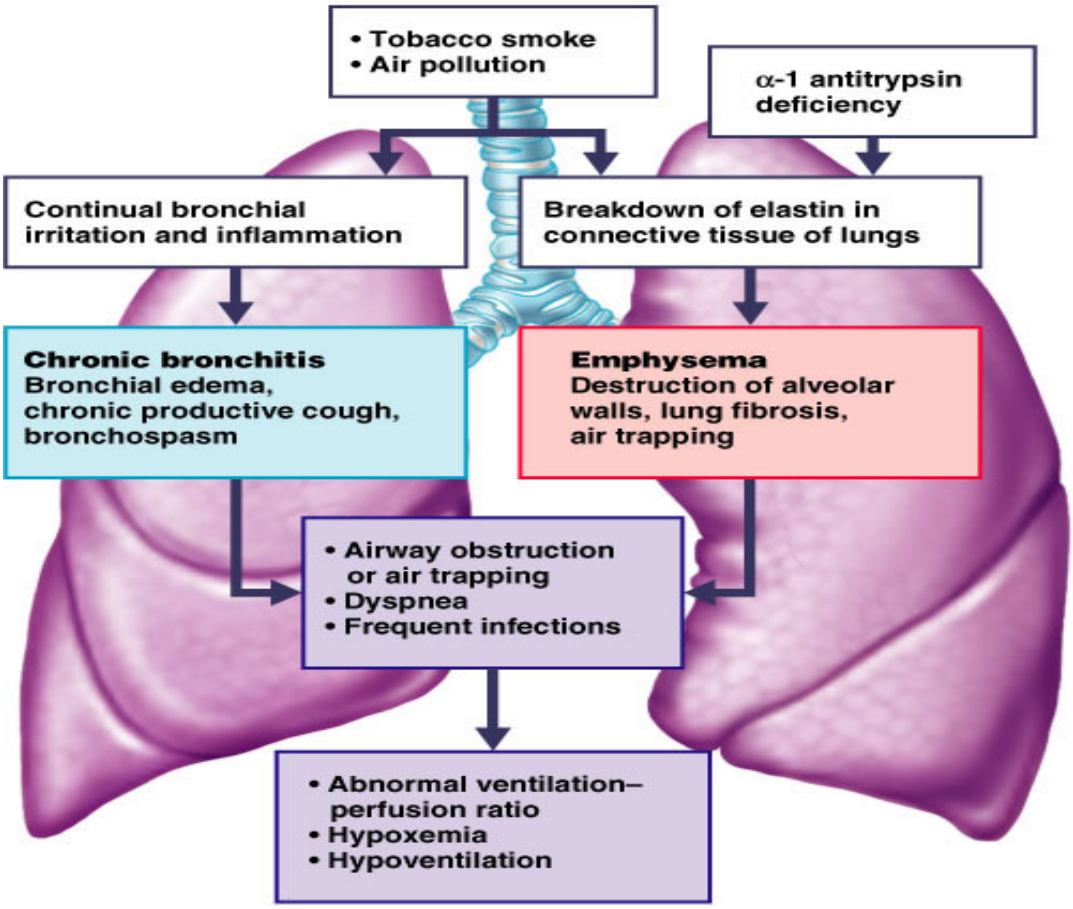
- **Atelectasis**
  - Collapsing of the alveoli ➡⬆ Work of Breathing: ⬇ TLC
  - Normal sighs and yawns act to re-inflate the alveoli that tend to collapse especially during quiet, shallow breathing (think of dozing off)

- **Respiratory Distress Syndrome (RDS) of the Newborn**
  - Called Hyaline Membrane Disease
  - Seen most commonly in premature births
  - ⬆ Work of Breathing associated with
    - ⬇ compliancy of the lungs
    - deficiency of Pulmonary Surfactant ➡ atelectasis

- **Tuberculosis – TB**
  - Fibrotic nodules (tubercles) of scar tissue forms around pockets of infected lung tissue to prevent further spread of the bacteria
    - *Mycobacterium tuberculi*
    - Fibrosis ➡ ⬇ compliancy of the lungs➡⬆ Work of Breathing: ⬇ TLC

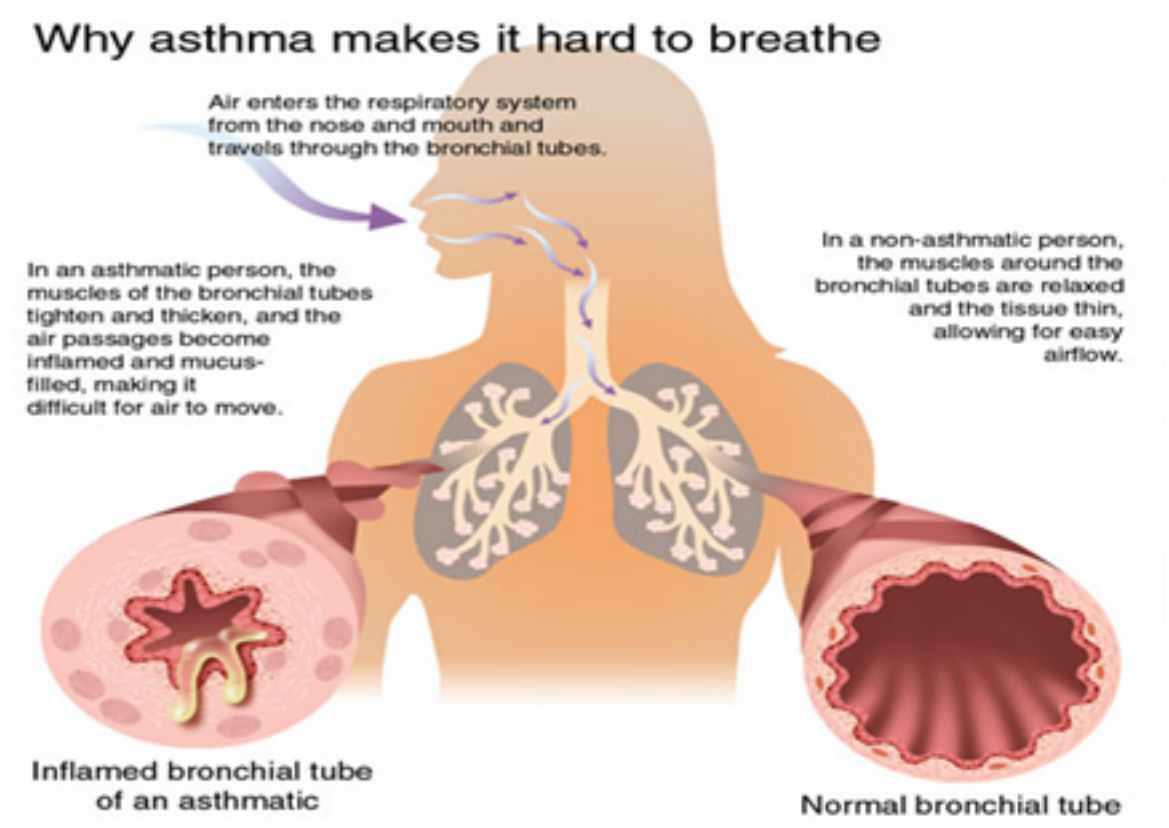
- **Emphysema**
  - "filled with air"
  - A general inflammation of the lungs resulting in an irreversible and progressive degeneration of the lungs
  - Correlated with smoking and chronic bronchitis
  - Characterized by:
    - Atelectasis ➡⬆ Work of Breathing: ⬇ TLC
    - Collapsing of airways during exhalation ➡ state of hyperinflation
    - Fibrous (scar tissue) of lung tissue ➡ ⬇compliance of lungs➡⬆ Work of Breathing: ⬇ TLC

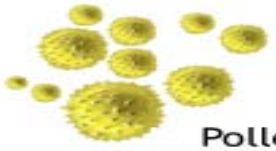
- **Obstructive Airway Disease**
  - **Bronchitis**
    - Caused by a viral or bacterial infection
    - Characterized by the production of yellow phlegm
    - Phlegm and mucus in airways ➡⬆ Airway Resistance ➡⬆ Work of Breathing: ⬇ TLC



Clinical Considerations – Restrictive Lung Diseases

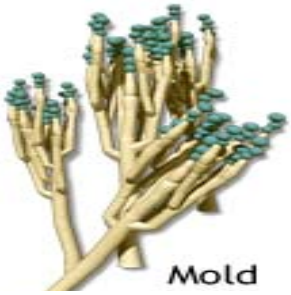
- **Bronchial Asthma**
  - Appears to be associated with bronchial hyper-reactivity to allergens, pollutants, cold air, etc.
  - Bronchial mast cells release histamine and other chemical mediators of inflammation leading to
    - Bronchospasm ➡⬆ Airway Resistance ➡⬆ Work of Breathing
    - Bronchiolar edema➡⬆ Airway Resistance ➡⬆ Work of Breathing
    - Increased mucus production➡⬆ Airway Resistance ➡⬆ Work of Breathing
  - Characterized by dyspnea, wheezing and phlegm
  - Treated with sympathetics - epinephrine





Pollen

Dust mites



Mold

Pet dander