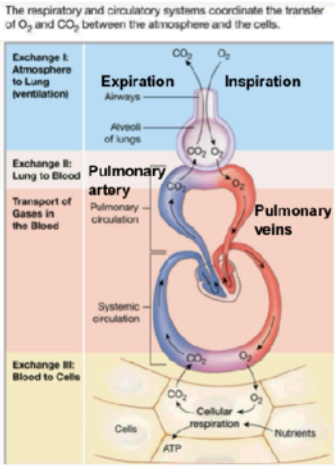
Lecture 2: Respiratory system

primary functions of the respiratory system

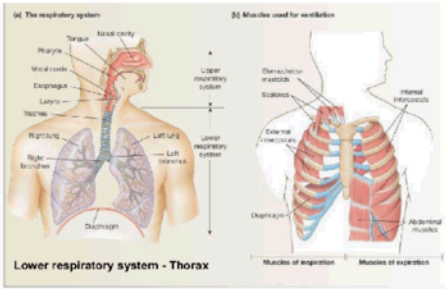
- exchange of gasses between the atmosphere and the blood: bring O2 and eliminate CO2
- homeostatic regulation of body pH: alter the body pH by selectively retaining or excreting CO2
- protection from inhaled pathogens and irritating substances: respiratory epithelium removes harmful substances before they enter the body
- vocalization: air moving across the vocal cords creates vibrations for speech/communication

Respiratory and Circulatory systems

- inspiration: the process of taking in O2
- expiration: the process of blowing out CO2
- pulmonary circulation: carries oxygen-depleted blood from the heart, to the lungs, and returns oxygenated blood to the heart, containing 500mL of blood.



Anatomy (structure) of the respiratory system



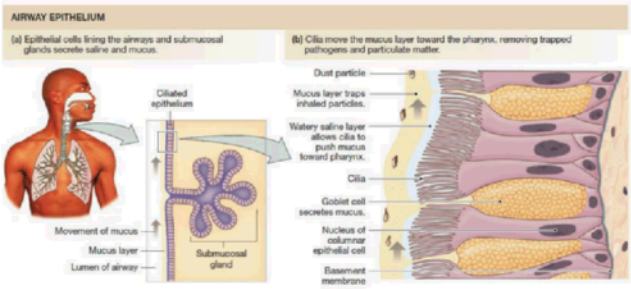
Lower respiratory system - Thorax

The **thorax (chest cavity)** is bounded by bones, spine, rib cage and the associated muscles

Role of airways

- warming air to body temperature, so that the body temperature does not change and alveoli are not damaged by cold air
- adding water vapor until the air reaches 100% humidity, so that the moist exchange epithelium does not dry out
- filtering out foreign material, so that viruses, bacterial, and inorganic particles do not reach the alveoli.

structure and function of airway epithelium



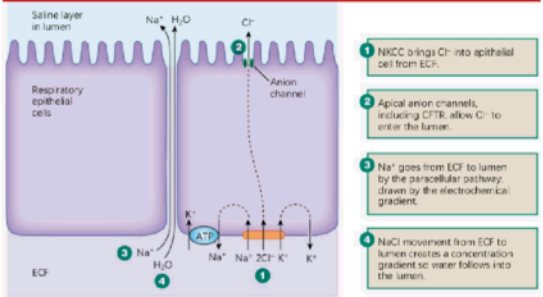
On the left

- mucus layer is secreted by goblet cells
- the underlying cilia create an upward motion toward the pharynx mucus, that reaches the pharynx, is swallowed

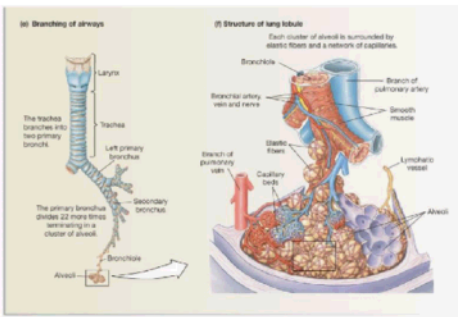
On the right

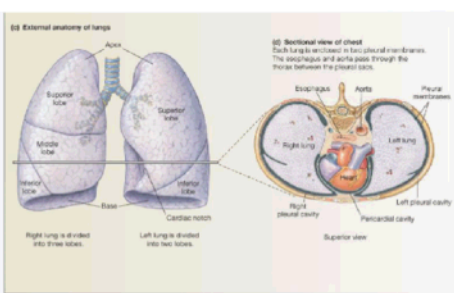
- mucus contains immunoglobulins (antibodies) that disable pathogens
- the fluid layer beneath the mucus does not allow the cilia to stick to the mucus

Model of saline secretion by airway epithelium



Lower respiratory system; bronchi, alveoli, and lungs enclosed by thorax (chest cavity)





The airflow velocity in the bronchi is determined by the pressure gradient and the resistance of the respiratory system: flow~P/R

Poiseuille's law: $R \propto L\eta/r^4$

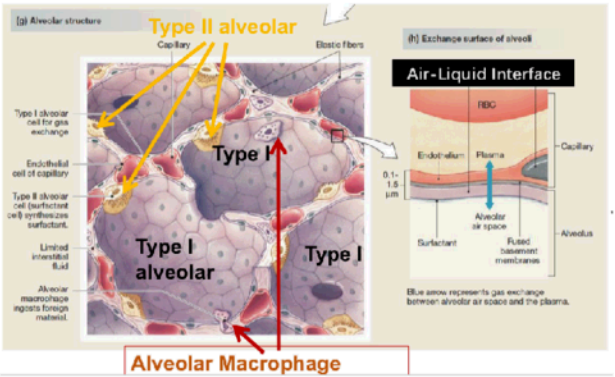
η - The viscosity of the air

L – length of a tube

r – cross-sectional radius

Types of alveoli cells

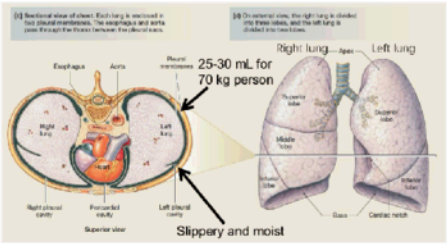
- Type I alveolar epithelium: a thin squamous cell, occupying 95% of the alveolar surface, dedicated to rapid gas exchange.
- Type II alveolar epithelium: produces pulmonary surfactant, which decreases the surface tension within the alveoli, helping the expansion of lungs during breathing
- Alveolar macrophage (dust cell): ingesting foreign material (bacteria)



What are between alveoli cells?

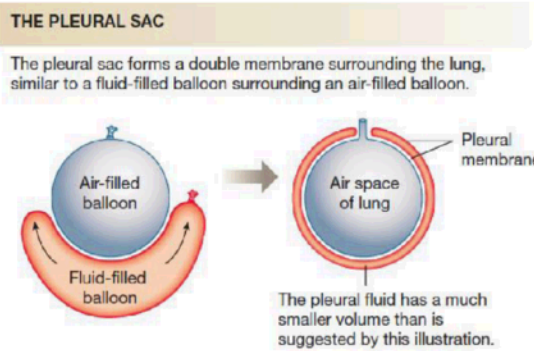
- in alveoli, there is no muscle, since muscle will block gas exchange
- connective tissues contain many elastin and collagen fibers —> elastic
- blood vessels fill 80-90% of the space between alveoli

Structure and image of lungs



Surface area in the lungs: For a 70 kg person, gas exchange area of 75 m^2

the pleural sac and pleural fluid



Functions of pleural fluid

- total volume is minimal (25-30 ml in a 70-kg man).
- It is similar to spreading 3 ml of water over the surface of a 3-liter bottle
- creating a moist, slippery surface so that the lungs can.Movee within the thorax
- holding the lungs tight against the thoracic wall.

Pressure and volume of gas

- Ideal gas: theoretical gas, do not interact with each other: PV=nRT
- In the human body, we can assume that the number of moles (n) and temperature (T) are constant
- When the volume of gas increases, the pressure decreases- inverse relationship

Boyle's Law- Pressure-volume relationships

- P1V1=P2V2
- As the volume of gas increases, the pressure decreases. Decreasing the volume increases collisions and increases pressure.
- In the respiratory system, when chest volume increases, alveolar pressure decreases and air flows into the lungs because the lung is an open system.

Dalton's Law

- The total pressure of a mixture of gasses is the sum of the pressures of the individual gasses.
- Total pressure= sum of all partial pressures
- The pressure of an individual gas in a mixture is known as the partial pressure of the gas (Pgas)
- The partial pressure of a gas (Pgas)= Patm * % of gas in the atmosphere (this should be in decimal form). This is Patm 760 mmHg
- Pgas in humid air = (Patm-PH2O) * % of gas

Pressure gradients law

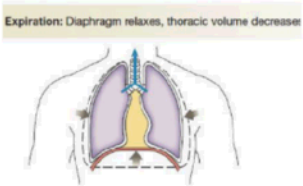
- gasses, singly or in a mixture, move from areas of higher pressure to areas of lower pressure. This law also applies to single gases: single gases (O2) move from areas of higher partial pressure (high Po2) to areas of lower partial pressure (low Po2) regardless of other gases' partial pressures.

Pulmonary ventilation

Pulmonary Ventilation is the bulk flow exchange of air between the atmosphere and the alveoli (= breathing)

During inspiration,

- Diaphragm contracts
- External intercostal muscles and scalene contract
- Thoracic cavity expands



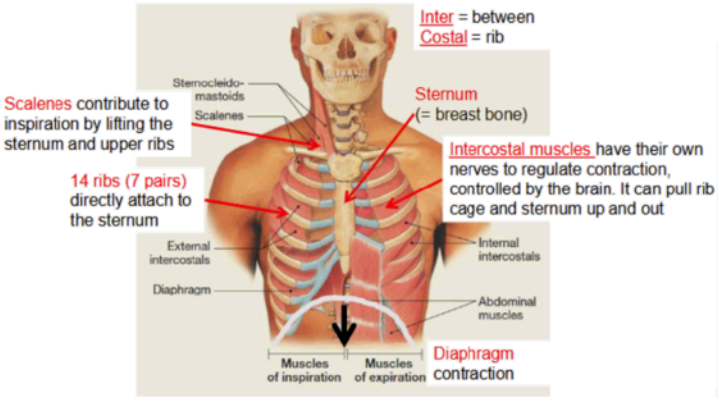
During expiration,

- Diaphragm relaxes
- Thoracic cavity reduces
- Forced: Internal intercostal and abdominal muscles contract

Breathing mechanism

- Changing volume makes a pressure difference. By Boyle's law, increasing the volume of a gas will cause the volume to decrease.
- Pressure difference makes air plow. By pressure gradient law, gases move from higher pressure to lower pressure.
- Changing volume makes airflow.

Muscle Involved in Pulmonary Ventilation



Quiet and forced breathing

Quiet breathing

- Breathing at rest: contraction of the diaphragm, external intercostal muscles, and scalene, but exhalation is a passive process

- The diaphragm contracts to move about 1.5 cm, which causes 60-70% of the inspiratory volume to change
- Movement of the rib cage creates the remaining 25-40% of the volume change

Forced breathing

- Exhalation involves the contraction of accessory muscles, such as the internal intercostal muscles and abdominal muscles.

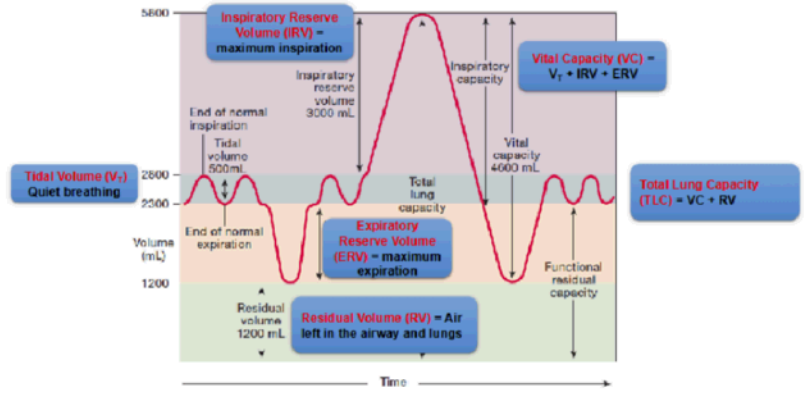
Diseases affecting ventilations

- A neuromuscular disease that weakens skeletal muscles or damages motor neurons can adversely affect ventilation.
- Examples of diseases that affect the motor control of ventilation include
  - Pyasthenia gravis: an illness in which acetylcholine receptors of the motor end plates of skeletal muscles are destroyed
  - Polio (poliomyelitis): a viral illness that paralyzes skeletal muscles by damaging the motor neurons in the spinal cord
  - With decreased ventilation, less fresh air enters the lungs. In addition, loss of the ability to cough increases the risk of pneumonia and other infections
  - We measure pulmonary function using a spirometer

Spirometer: a pulmonary function test

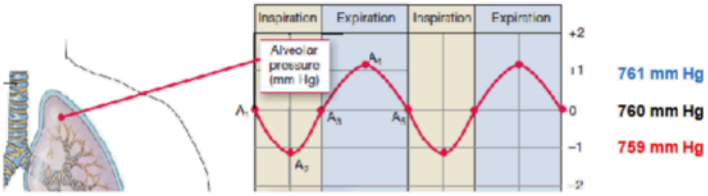
- The subjects's respiratory tract and the spirometer form a closed system
- When breathing, air moves from the spirometer into the lungs

Respiratory Volumes and Capacities



- Normal resting ventilation rates = 12-20 breaths/min
- Active exhalation rates = 30-40 breaths/min
- Tidal volume =~500 mL/breath
- Respiratory minute volume (RMV)= ~6 L/min (~500 mL/breath * 12 breaths/min)

Alveolar Pressure Changes during Quite Breathing



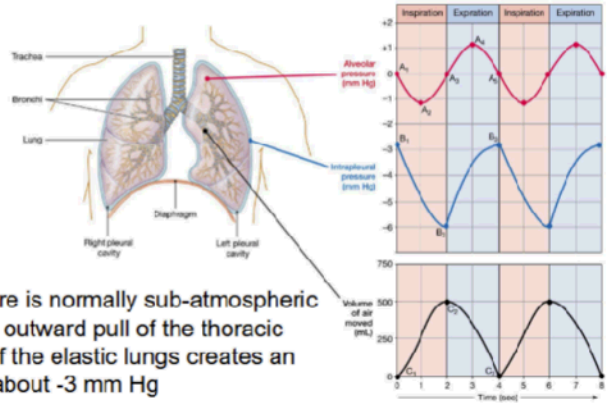
Inhaling (= inspiration)

1. Chest size increases
2. Volume ↑ A1→A2
3. Pressure ↓ A2 (759 mm Hg)
4. Air molecules move in A2→A3
5. Pressure ↑ (760 mm Hg) A3

Exhaling (= expiration)

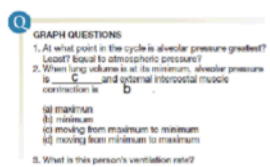
1. Chest size decreases
2. Volume ↓ A3→A4
3. Pressure ↑ A4 (761 mm Hg)
4. Air molecules move out A4→A5
5. Pressure ↓ (760 mm Hg) A5

Intrapleural Pressure and Removed Air

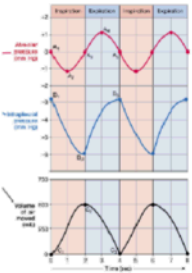


- The intrapleural pressure is normally sub-atmospheric
- The combination of the outward pull of the thoracic cage and inward recoil of the elastic lungs creates an intrapleural pressure of about -3 mm Hg

Intrapleural Pressure and Removed Air

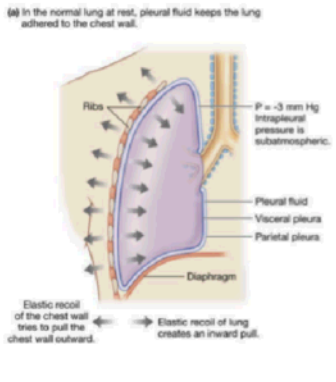


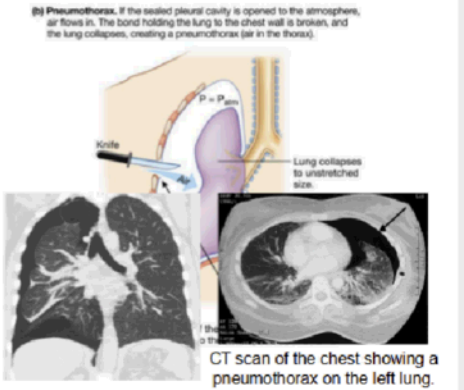
Minimum lung volume
↓
Air gases move out
↓
Alveolar pressure is decreasing
↓
External intercostal muscle contraction is minimum



What is the ventilation (respiration) rate of this person?
2 breaths / 8 sec = 15 breaths / min

Pleura Fluid Keeps Lung Adhered to the Chest Wall





CT scan of the chest showing a pneumothorax on the left lung.

Treatment of pneumothorax through tube thoracostomy

- Pneumothorax can be life-threatening
- The immediate treatment for pneumothorax is tube thoracostomy, or the insertion of a test tube: a long flexible tube is inserted through the ribs into the pleural solace, and the tube is attached to a suction device
- Tube thoracostomy allows the air to be evacuated from the pleural space, and allows the lungs to re-expand
- The chest tube is left in place until the lung seals on its own: this usually occurs within two to 5 days