Lecture 19, Mar 30, 2023

Respiratory System – Ventilation and Respiration

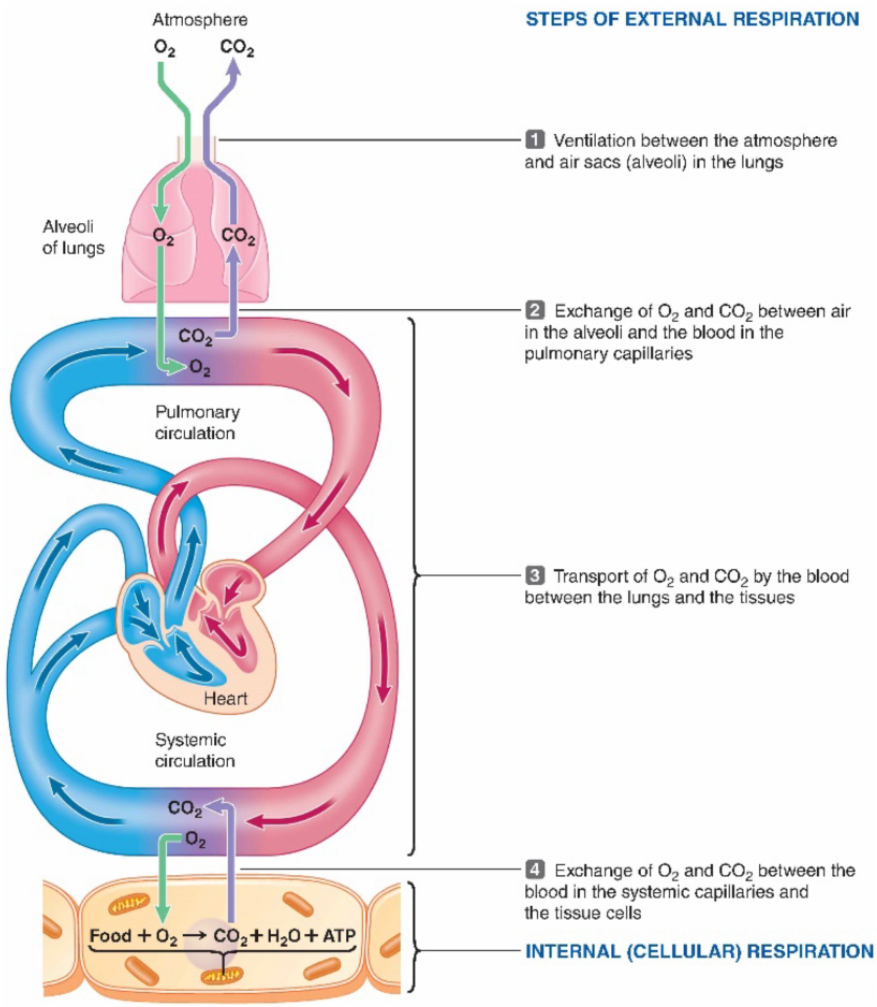

Figure 1: Overall structure of the respiratory system

- *Ventilation* is the movement of air in and out of the lungs, exchanging oxygen and CO2 with the blood
  - Ventilation is only external
- *Respiration* can be both internal (within the cell, at the mitochondrial level) and external (transfer from lungs to capillaries)
- Supply of oxygen to body cells is usually rate limited by the circulatory system (e.g. stroke volume, heart rate) instead of how much oxygen is breathed in

Lung Structure

- When the diaphragm muscle contracts, the entire muscle is pulled down, drawing air into the lungs
- Bronchioles are the branches in the lung; smooth muscles warp around this
- Alveolar sacs are made from alveoli (alveolus); venules and arterioles surround the alveolar sacs with capillaries, which lets oxygen transport happen
- There are 2 types of alveolar cells: type I and type II
  - Type I cells are very flat, which gives them surface area for oxygen diffusion
    * They are only 1 micron thick

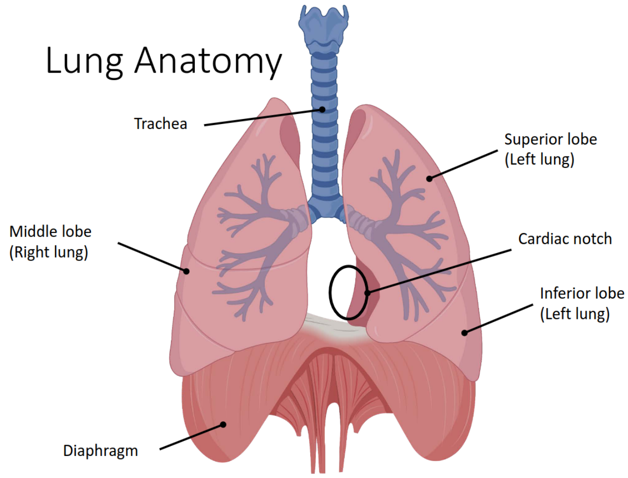

Figure 2: High-level structure of the lung

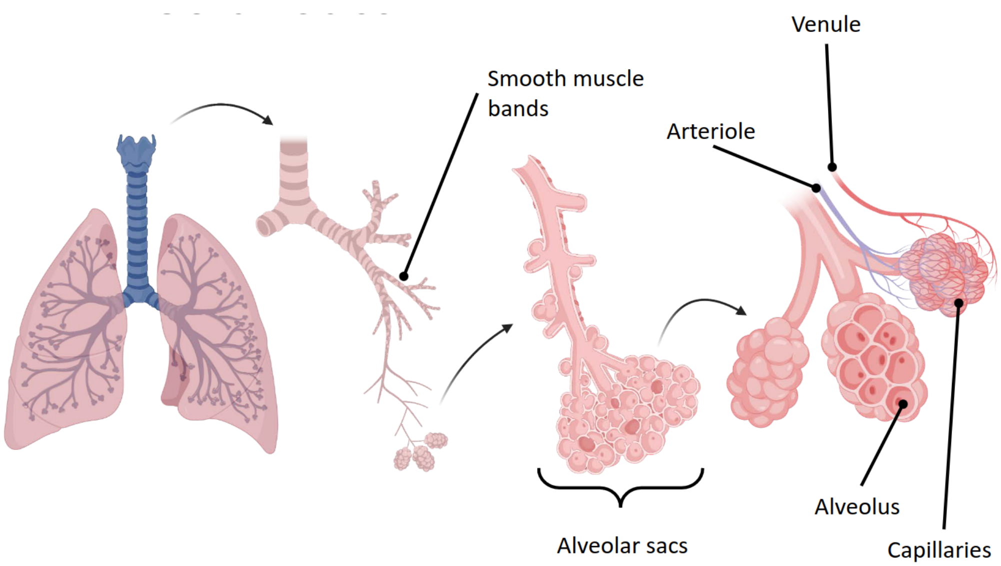

Figure 3: Low-level structure of the lung

    * Oxygen transfer happens through these cells
  - Type II alveolar cells are bigger than type I cells, and they excrete a mucus
    * The fluid layer is about 2 microns thick
    * Their thicker size makes it so that oxygen doesn't really transport through them much
  - Type I cells take up 95% of the area, but only 1/3 of the number of cells
- Capillaries surrounding the alveolar sacs have their own cells, which form a tube that carries fluid and red blood cells
  - The distance between the capillaries and the sacs is about 0.5 microns
- Every fluid, cell membrane, and cytosol between the red blood cell and the inside of the alveolar sacs forms a barrier to diffusion
- Alveoli are connected via pores of Kohn, which equalize their pressure
- Law of Laplace: $P = \frac{2T}{r}$ where T is the surface tension and P is the internal pressure of a fluid bubble
  - The surface tension of the fluid coating means the sacs want to contract back when they are expanded (recoil)
  - With just a normal fluid layer, a bigger sac would have a lower pressure, so the smaller sacs would get smaller and the larger sac gets larger – this leads to alveolar collapse
  - The Type II cells also secrete a surfactant; now as the sac gets smaller, the surfactant concentration per area increases, which decreases the surface tension, avoiding alveolar collapse

Muscles Responsible for Ventilation

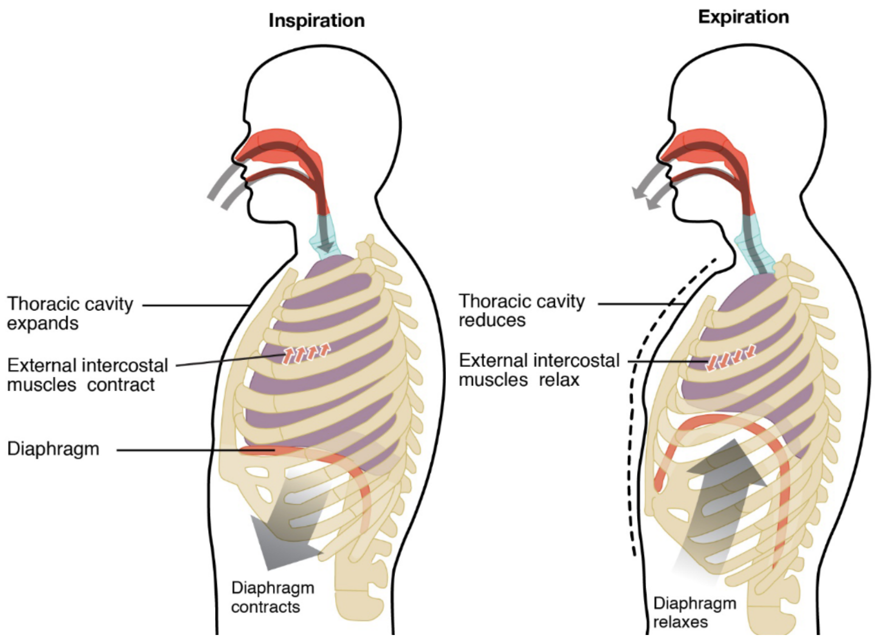

Figure 4: Diaphragm movement causing inspiration and expiration

- The lung is surrounded by a self-contained sac (membrane)
  - This is made of 2 layers of membrane; from the inside of the lung: the visceral pleura, a pleural cavity (space), and then a parietal pleura which then connects to the intercostal muscles
- External intercostal muscles contract and expand the ribcage during inspiration
- Internal intercostal muscles pull and contract the ribcage
- During expiration, muscles relax and the recoil from the fluid pulls the lung back
- A range of muscles can affect inspiration and expiration
  - About 75% of inspiration is due to diaphragm alone; the other 25% is due to extra intercostal muscles

    - The intercostal muscles are only used during active (forceful) expiration; otherwise, expiration is due to the recoil alone

Mechanics of Ventilation

- Pressure gradient drives air flow
    - Main pressures: atmospheric pressure (considered as 0), alveolar pressure P_A, pleural pressure P_{pl} (inside the pleural cavity), the lung recoil (aka transmural, transpulmonary) pressure, $P_{\text{recoil}} = P_A - P_{pl}$
        * P_{pl} is lower than atmospheric pressure during normal breathing (the lung wants to collapse and the chest wall wants to expand)
    - A pressure difference between atmospheric pressure and P_A is needed to drive ventilation