Respiratory System

A brief tour
What is “respiration?”

- Ventilation (breathing)
- External respiration
- Gas transport
- Internal respiration
- Cellular respiration
Recall that aerobic respiration is cellular respiration (ATP production) that uses oxygen while anaerobic respiration is cellular respiration (ATP production) that does not require oxygen. Our cells are capable of carrying out either type, but aerobic respiration produces far more ATP (up to 19 times more!). Without oxygen, our cells cannot produce enough ATP to power the chemical reactions necessary for life. Carbon dioxide is a side product of aerobic respiration. While carbon dioxide itself is not harmful, when it is dissolved in water (such as in soft drinks or in blood plasma), it forms carbonic acid. An excess of carbonic acid (from an excess of blood carbon dioxide) lowers blood pH and results in a condition called acidosis. Fortunately, carbon dioxide diffuses out of the blood through the lungs just as oxygen diffuses in. By changing respiratory rate (and changing the speed at which carbon dioxide is removed from the blood), blood pH can be regulated.
The general pathway of inhaled air is to enter the nose through the external nares and move through the nasal cavity. The air then enters the pharynx through the internal nares and moves down past the larynx and into the trachea. The trachea bifurcates into left and right halves, called the primary bronchi, which split up many more times into smaller and smaller air passageways that make up the lungs. Everything down to the larynx is called the upper respiratory system and everything below the larynx is the lower respiratory system.
Organs of Respiration

- **Trachea**
  - C-shaped hyaline cartillages
  - Lined with ciliated mucousa

- **Bronchi**
  - Branches
  - Bronchioles
  - Alveoli

The **trachea** transmits inhaled air four or five inches before it splits into left and right primary bronchi. It is supported and protected by several C-shaped rings of cartilage. The rings are “stacked” but not attached so that we can bend our neck in any direction.

Why are the cartilages C-shaped? The esophagus (carrying food and liquids to the stomach, remember?) runs along the posterior (back) side of the trachea. If the cartilage rings were complete circles, the esophagus would not be able to expand when a large piece of food was being swallowed. The C shape of the cartilages allows the esophagus to expand into the trachea when necessary. (It’s ok to restrict the trachea like this temporarily since, when you’re swallowing no air is moving through the trachea in either direction.)

Like the rest of the respiratory passageways, the trachea is lined with ciliated respiratory mucosa. The cilia constantly move mucous up towards the throat, where it is swallowed.
The lungs are one of the largest organs in the body. They take up most of the space of the thoracic cavity (everything except the mediastinum). The base of the lungs rest on top of the diaphragm (at the bottom of the rib cage) while the apices are just deep to the clavicles. The left lung is smaller than the right lung, in order to make room for the heart. The lungs aren’t just big bags of air. The right lung has 3 lobes while the left lung has two.

Each lung is surrounded by two layers of pleural serous membrane – a visceral layer and a parietal layer. The space between the two layers is called the pleural cavity and is filled with serous fluid. The serous fluid serves two purposes. First, it is very slippery so the lung can slide easily across the chest wall without getting abraded. Second, the fluid makes the layers adhere together so that when the chest wall expands, it pulls the walls of the lungs along, causing the lungs to expand and inhale air. Think of two sheets of glass with water between them – the sheets of glass can slide across one another, but it's difficult to pull them apart.
Ventilation ("Breathing")

- Physics of ventilation:
  - $\uparrow$ volume $\rightarrow$ $\downarrow$ pressure (and vice-versa)
    - Boyle’s Law: $P_1V_1 = P_2V_2$
    - Air movement: higher pres. $\rightarrow$ lower pres.

The physiological term for “breathing” is **ventilation**. Ventilation is a completely mechanical process based on simple physics. Remember your gas laws from chemistry? There are two important physical concepts governing ventilation. First is Boyle’s law which says (basically) that as the volume of a container (such as the lungs) increases, the pressure of the air inside decreases, and vice versa. The second principle is that air (or any gas) generally moves from an area of high pressure to an area of low pressure. If you blow up a balloon, then pop the balloon, the air will move from the area of high pressure (inside the balloon) to the area of lower pressure (outside the balloon).
Ventilation

- Inspiration
  - Contraction of diaphragm & external intercostal muscles
  - \( \uparrow \) intrapulmonary volume. Air rushes in.

The two previously-mentioned principles explain how ventilation works. The muscles involved with ventilation include the diaphragm and the external intercostal muscles. The diaphragm is a large sheet of muscle attached to the bottom of the rib cage. When relaxed, it is parachute-shaped, so it domes upwards, making the volume of the thoracic cavity (and the lungs) small. During inspiration, the diaphragm contracts – it pulls downward and flattens out somewhat. At the same time, the external intercostal muscles contract, lifting the ribcage up and outward. The overall effect is an increase in the volume of the thoracic cavity, which means a lowered pressure. Since the pressure inside the lungs is now lower than the pressure outside the lungs, air from outside rushes into the lungs to equalize the pressure.
Expiration is normally a passive process. When the diaphragm and external intercostals relax, the lungs and rib cage just naturally recoil back to their original shape. (This occurs because of the semi-rigid and elastic connective tissue.) The decreased volume of the thoracic cavity causes an increase in air pressure inside the lungs. Since air moves from an area of high pressure to an area of low pressure, air rushes out of the lungs. It is also possible to forcefully exhale air from the lungs – this can happen voluntarily or when the lungs refuse to naturally recoil, such as during an asthma attack or when the lungs are clogged up. During forced expiration, the internal intercostal muscles contract, pulling the rib cage closed and forcing a smaller intrapulmonary volume.
Gas Exchange and Transport

- **External respiration**
  - Respiratory membrane
  - Partial pressures & diffusion

In addition to ventilation, respiration involves three other steps: external respiration (gas exchange between the air and the blood), gas transport, and internal respiration (gas exchange between the blood and the tissues). **External respiration** occurs across the respiratory membrane in the alveoli. There, alveolar oxygen has a higher partial pressure than the venous oxygen, so oxygen naturally diffuses into the blood. Vice-versa for carbon dioxide.
Gas Exchange and Transport

Gas Transport

- Oxygen: hemoglobin
- Carbon dioxide:
  - Bicarbonate (HCO$_3^-$) ions
  - Bound to hemoglobin
  - Dissolved in plasma

As you already know, oxygen is transported by hemoglobin molecules. Some carbon dioxide is carried by hemoglobin as well, but a vast majority of it is not. Most carbon dioxide is transformed and transported as bicarbonate ions. When carbon dioxide dissolves in water, much of it forms carbonic acid. The anion of carbonic acid is bicarbonate. Note that the more carbon dioxide there is in the blood, the more acidic (lower pH) the blood becomes because of the increased formation of carbonic acid. Some carbon dioxide remains dissolved in plasma as well.
Gas Exchange and Transport

- **Internal respiration**
  - Partial pressures & gas diffusion.

*Internal respiration* occurs in capillary beds of the tissues. Here, carbon dioxide moves out of the tissues and oxygen moves into the tissues.
Control of Respiration

- Chemical factors
  - Blood pH (↑CO₂)
  - Oxygen (less important)

- Other factors (neural, emotional, etc.)

The most important stimulus that controls breathing rate is blood pH, which is directly tied to carbon dioxide levels in the blood. When there is an increased amount of carbon dioxide in the blood, blood pH drops because more carbonic acid is being formed. The lowered pH is directly detected by the medulla, which then increases both rate and depth of breathing to eliminate the carbon dioxide more quickly.

While less important, oxygen levels also play a role in controlling breathing. Oxygen levels are detected by chemoreceptors in the aorta, which sends impulses to the medulla. However, oxygen levels are only play a significant role in respiratory control when oxygen levels are dangerously low.
You’ve seen pictures like these before, probably. The picture on the left is a healthy lung. The picture in the middle is a lung removed from a patient that has died from lung cancer. The picture on the right is a post-operative picture of a woman who has had her left lung removed as a result of lung cancer from smoking.