The Respiratory Process

Diagram of the respiratory system with labeled parts.
Diffusion is the movement of molecules from an area of high concentration to low concentration and plays an integral part in the movement of gases in the human respiratory system.

There are several stages and forms of respiration:

1. **Breathing** - moving air into and out of lungs (inhalation/exhalation)

2. **External Respiration** - exchange of $O_2$ and $CO_2$ between lungs and blood. (Occurs by diffusion)

3. **Circulation** - movement of dissolved gases by the blood to and from the body cells.

4. **Internal Respiration** - exchange of $CO_2$ and $O_2$ between blood and body cells. (Occurs by diffusion)

5. **Cellular Respiration** - nutrients are broken down and released in the mitochondria of cells.

\[ Glucose + Oxygen \rightarrow Carbon\ dioxide + water + Energy \ (ATP) \]
The Respiratory Surface

The respiratory surface must have the following characteristics:

- It must be thin walled so diffusion occurs rapidly
- It must be moist so that oxygen and carbon dioxide will dissolve
- It must be in contact with an environmental source of oxygen
- In most multicellular organisms it must be in close contact with a transport system
- It must have a large surface area

The Human Respiratory System

The respiratory system of humans consists of:

i) Passages that transport air to and from the lungs
ii) The air sacs of the lungs in which gas exchange occurs

The respiratory system includes the following structures:

1. The Nose

   - Supported by bone and cartilage
   - Provides primary entrance for air

2. Nasal Cavity

   - Divided by the nasal septum
   - Nasal conchae divide the cavity into passageways
   - Mucous membrane filters, warms and moistens incoming air
   - Particles become trapped in mucous and hair; are carried to the pharynx and swallowed
3. The Sinuses

- **Spaces** in the bones of the skull that open into the nasal cavity
- Lined with *mucous membranes*

4. The Pharynx

- Located behind the mouth (*back-up airway*) and between the nasal cavity and the larynx
- Functions as a common passage for air and food

5. The Larynx

- Enlargement at the top of the trachea
- Composed of muscles and cartilage
- Passageway for air and helps prevent foreign objects from entering the trachea (*epiglottis*)
- Contains **vocal cords** which produce sounds by *vibrating* as air passes - pitch is related to tension on the cords; *intensity* is related to the force of air passing over the cords

6. The Trachea

- Moves air from the pharynx to the bronchi
- Supported by *cartilaginous* rings
- *Mucous* lining and cilia filters air
- Divides into right and left bronchi

7. The Bronchus/Bronchioles

- The Bronchus moves air from the trachea to the bronchioles and the bronchioles move air from the bronchi to the alveoli
- Branching tubes that become smaller and smaller (bronchioles are microscopic) to increase *surface area*
- Lined with mucous - mucus *filters* foreign particles and *dissolves* gases

8. Alveoli

- One cell thick and surrounded by *capillaries* for *diffusion of gases*
- *Gas exchange* occurs here
Mechanisms and Control of Breathing

**Gas Exchange and Transport**

In the human body, the right lung is composed of 3 lobes and the left, 2 lobes. Both lungs are contained within a pleural sac (membrane).

It is at the end of an extensive branching network within the lungs where gas exchange occurs in a region known as the alveoli.

Gases are exchanged through the process of diffusion, but only when they are dissolved in water. Diffusion is the movement of molecules from a region where they are more concentrated to one where they are less concentrated. Small, uncharged molecules like oxygen can easily move through cell membranes as a result of this process.

In addition to diffusion, as much as 30% of the oxygen transferred across the alveoli is done through facilitated diffusion (specialized pathways that move oxygen across the alveoli). This allows the blood to take up oxygen more.

**Oxygen Transport**

Oxygen moves from the lungs, where there is a high concentration of the gas, to the blood within the capillaries that surround the alveoli. Within the blood that is returning to the lungs there is a low concentration of oxygen.

Once in the blood, oxygen forms a bond with iron atoms in the protein hemoglobin on the red blood cells (forming oxyhemoglobin).

**Hemoglobin (Hb) + Oxygen (O₂) ⇌ Oxyhemoglobin (HbO₂)**

**Carbon Dioxide Transport**

When carbon dioxide, the waste product of cellular respiration, diffuses from body cells into the blood it can:

1. Combine with Red Blood Cells forming carboxyhemoglobin (occurs 20% of the time).
2. Be carried as a dissolved gas in the plasma (occurs 10% of the time).
3. Combine with water to form carbonic acid (H₂CO₃). The carbonic acid then dissociates into hydrogen (H⁺) ions and bicarbonate (HCO₃⁻) ions (70% of the time). This creates a buffer system in our blood that helps to regulate blood pH.
Mechanism of Breathing

1. Inspiration

Inspiration occurs when air is taken into the lungs.

i) Diaphragm contracts and moves downward

ii) Thoracic cage (ribs) moves upward and outward when intercostal muscles contract

As the volume **increases**, pressure **decreases**. Air is forced into the lungs by atmospheric pressure as air will flow from an area of **high** pressure to **low** pressure.

2. Expiration

Expiration occurs when air is removed from the lungs.

i) Diaphragm relaxes and moves up

ii) Thoracic cage moves downward and inward when intercostal muscles relax

Air is forced out of the lungs by the **squeezing** action of the chest cavity and is aided by:

i) Elastic recoil of tissues

ii) Thoracic and abdominal wall muscles
Respiratory Air Volumes

The volume of air that passes in and out of the lungs can be measured using a spirometer. A number of different volumes can be measure to determine the efficiency of the respiration process.

Tidal Volume

The volume of gas inspired or expired in a normal unforced breathing cycle.

Inspiratory Reserve

The maximum volume of gas that can be inspired from the end of a tidal inspiration.

Expiratory Reserve

The maximum volume of gas that can be expired beyond the end of a tidal expiration.

Residual Volume

The volume of gas remaining in the lungs after a maximum expiration.

Vital Capacity

The maximum amount of gas that can be expired after a maximum inspiration.

Figure 8.20. The graph shows the maximum volume of air that can be moved in and out of the lungs during a single breath: the vital capacity. The pattern shown in this graph is called a spirograph.
Control of Breathing

Normal breathing is **involuntary**, but the muscles can be **controlled voluntarily**. The respiratory center is located in the brain stem, and includes parts of the **medulla oblongata** and **pons**.

The respiratory centre performs two main respiratory functions:

i) Initiates impulses that travel via nerves to the breathing muscles (diaphragm and intercostal muscles)

ii) Adjusts the rate and depth of breathing

Factors Affecting Breathing

i) Tissue stretching (joints), presence of chemicals (alcohol, nicotine etc…) and emotional state affect breathing

ii) Increasing levels of carbon dioxide and hydrogen ions cause the breathing rate to increase

iii) Decreasing level of oxygen causes the rate to increase

iv) Hyperventilation causes the CO₂ level to decrease, decreasing breathing rate
Respiratory Disorders

All respiratory disorders **decrease** the supply of **oxygen** to the body.

**Sleep Apnea**

Sleep apnea is a common disorder in which you have one or more **pauses in breathing** or shallow breaths while you sleep. Breathing pauses can last from a few **seconds** to **minutes**. Typically, normal breathing then starts again, sometimes with a loud **snort** or **choking sound**.

Sleep apnea usually is a chronic (**ongoing**) condition that disrupts your sleep 3 or more nights each week. You often move out of **deep** sleep and into **light** sleep when your breathing pauses or becomes shallow. This results in **poor sleep quality** that makes you tired during the day. Sleep apnea is one of the leading causes of **excessive daytime sleepiness**.

The most common type of sleep apnea is **obstructive** sleep apnea. This means that the airway has **collapsed** or is **blocked** during sleep. When you try to breathe, any air that squeezes past the blockage can cause loud **snoring**. Obstructive sleep apnea happens more often in people who are **overweight**, but it can affect anyone.

**Asthma**

Doctors define asthma as a "**chronic inflammatory disease of the airway**" that causes shortness of breath, tightness in the chest, coughing and wheezing.

When someone with asthma has asthma symptoms, it means that the flow of air is **obstructed** as it passes in and out of the lungs. This happens because of one or both of the following:

- The lining of the airways becomes **inflamed** (irritated, reddened and swollen), and may produce **more mucous**. The more inflammation the more sensitive the airway becomes, and the more symptoms.
- The **muscles** that surround the airways become **sensitive** and start to **twitch** and **tighten**, causing the airways to **narrow**. This usually occurs if the inflammation is not treated.

**Pleurisy**

The lungs are surrounded by a layer of tissue called **pleura**. Pleurisy is when the pleura become **inflamed**, typically as a secondary infection related to pneumonia or other thoracic diseases.
**Bronchitis**

When the bronchi and bronchioles become irritated or infected, inflammation will occur, along with the production of additional mucous. This results in the narrowing of the air passageways, making breathing and gas exchange more difficult. As mucous accumulates, the coughing reflex is triggered to help clear these airways.

**Cystic Fibrosis**

Cystic fibrosis (CF), is an inherited disease of your secretory glands, including the glands that make mucus and sweat. CF mostly affects the lungs, pancreas, liver, intestines, sinuses, and sex organs.

Normally, mucus is a slippery, watery substance. It keeps the linings of certain organs moist and prevents them from drying out or getting infected. However, if you have CF, your mucus becomes thick and sticky. The mucus builds up in your lungs and blocks your airways — the tubes that carry air in and out of your lungs. The build-up of mucus makes it easy for bacteria to grow. This leads to repeated, serious lung infections. Over time, these infections can severely damage your lungs. The thick, sticky mucus also can block tubes, or ducts, in your pancreas. As a result, the digestive enzymes that your pancreas makes can’t reach your small intestine.

A defect in the CFTR gene causes cystic fibrosis (CF). This gene makes a protein that controls the movement of salt and water in and out of your body’s cells. In people who have CF, the gene makes a protein that doesn’t work right. This causes thick, sticky mucus and very salty sweat.

**Drowning**

If fresh water enters the lungs, it will wash away the lipoprotein lubricating film that coats the alveoli, causing them to collapse and gas exchange to stop.

If salt water enters the lungs it will cause water to be drawn out of the capillaries and into the lungs, preventing oxygen from reaching the walls of the alveoli.

In up to 10% of deaths that occur in water, the victim actually suffers from laryngospasm, or reflex closing of the larynx. In these cases, death actually occurs from asphyxiation.
Carbon monoxide Poisoning

Carbon monoxide, sometimes called the silent killer, is a dangerous air pollutant because you cannot see, smell or taste it, so you cannot tell if you are breathing it in. Carbon monoxide is produced during the incomplete combustion of organic material.

What makes carbon monoxide so deadly is the fact that it binds to hemoglobin more efficiently than oxygen (approximately 200 times better!), preventing red blood cells from delivering oxygen to the cells of the body.

Early symptoms of carbon monoxide poisoning include headaches, weakness, dizziness and nausea. Coma, damage to internal organs and death will soon follow if the person isn’t allowed to get fresh air.

High Altitude Breathing

As you increase altitude, pressure decreases, allowing oxygen molecules to spread further apart, making the amount of oxygen available in each breath decrease. When a person moves to a higher elevation, their body cannot extract enough oxygen from the air to meet their metabolic needs and the result is, "altitude sickness" or hypoxia. Symptoms will include shortness of breath from even the slightest exertion, along with headaches and nausea.

The body will respond first by increasing the rate of breathing, which helps to bring more oxygen in contact with the alveoli. Over time, the body will respond by producing more red blood cells to enable the body to take up enough oxygen from the air to carry on normal and even athletic endeavours.

Scuba Diving

Under normal atmospheric pressure, nitrogen does not dissolve in water and therefore is not able to diffuse into our bloodstream. Therefore we will exhale all of the nitrogen that we take in with each inhalation.

When scuba diving, pressure increases as the diver goes further underwater. As the pressure increases, the diver’s bloodstream and body tissues absorb high volumes of gases, including nitrogen. Beyond depths of 40-60 metres, the increased nitrogen in the bloodstream can cause nitrogen narcosis also known as "rapture of the deep". A diver may experience blissful giddiness, along with disorientation and impaired judgement. A diver may also experience irrational fear or even panic.

If a diver returns to the surface of the water too quickly, these extra dissolved gases can escape from the blood as bubbles in the diver’s blood vessels. These bubbles can block the flow of blood and produce a painful and potentially fatal condition known as, "the bends".
**Cold and Flu Viruses**

The symptoms of both the common cold (rhinovirus) and the flu (influenza virus) are caused as the viruses, if not killed by the host’s immune system, replicate in the respiratory tract of humans and damage or destroy the host’s cells.

**Effects of Smoking on the Respiratory System**

Nicotine can paralyze cilia and interfere with mucous production, preventing the cleaning of air as it enters the lungs.

Chemical substances are deposited on the bronchial walls, which can lead to mutated cells. This is a region where cancer frequently develops.

Smoking will lead to emphysema. Emphysema is when the alveoli lose their elasticity, causing air to get trapped in the lungs, preventing fresh air from getting in.

Smokers may also experience a high occurrence of the following:

**Bronchitis** - caused by infection from smoke and dirt particles. Excessive mucous is secreted in the bronchi and the airways become partially clogged. This is the cause of "smokers cough" that is accompanied by a thick discharge.

**Heart Disease** - decreased concentration of oxygen in the blood means the heart has to work harder.

**Liver Disorders** - the liver filters out chemicals, which then damages the liver tissue.

**Radiation Exposure** - radioactive particles in the smoke can lead to cancer.

**Premature Aging** - wrinkling of the skin earlier.
The Heart and Blood Vessels

Arteries (usually high O₂, low CO₂)
- Carries blood away from the heart to the body tissues
- Thick muscular, and highly elastic walls; thinner inner diameter
- When the walls expand then contract, they help to propel blood through the arteries

Veins (usually low O₂, high CO₂)
- Carries blood to the heart from organs and tissues
- Thinner muscular and slightly elastic walls; thicker inner diameter
- Contain flap-like valves to prevent backflow of blood - defective valves can cause blood to pool and result in varicose veins
- Muscle contraction around the veins help to keep the blood moving back to the heart.

Capillaries
- The smallest vessels
- The arterioles and venules are connected by a network of microscopic capillaries
- One cell thick and allow for exchange of materials between cells and the blood by diffusion

Figure 9.12. Sections through an artery, capillary, and vein. At any given moment, about 30% of the blood in your systemic circulation will be found in the arteries, 5% in the capillaries, and 65% in the veins.
The Heart

- The human heart pumps constantly (average of 70 times/minute)
- 90,000 times per day
- With each beat it pumps blood about through about 160,000 km of vessels

The human heart is a double pump - one side pumps blood to the lungs (right) and one side pumps blood to the body cells (left).

Figure 9.26 The flow of blood through the heart. Note that the atria contract at the same time, and the ventricles contract at the same time. Thus, only two contractions are required to force blood through all four chambers.
Controlling your Heartbeat

The heart is controlled by the combined action of:

1. **Sensory nerves** - Detect changes in:
   - Blood vessel walls (stretch)
   - Acidity (CO₂),
   - Temperature
   - Hormonal levels
   - Chemical (e.g. nicotine, caffeine, alcohol)

Sensory nerves in the **Vena Cava and Aorta** send messages to the Medulla Oblongata and **speed-up** the heart.

Sensory nerves in the **aorta or carotid arteries** send messages to the Medulla Oblongata and **slow down** the heart.

2. **Medulla Oblongata**
   Processes the **messages** sent by the sensory nerves and relays the appropriate message to the **pacemaker**.

3. **Pacemaker and Atrioventricular Node**
   The Pacemaker or **Sinoatrial Node** (S-A node) generates a signal that causes both **atria** to contract pushing blood into the **ventricles**. Once both atria have contracted the **Atrioventricular Node** (A-V Node) is stimulated. The A-V node sends a signal down the **Bundle of His** and to the **Purkinje Fibres**. The Purkinje Fibres cause the **ventricles** to contract from the **bottom** and spread up pushing blood out of the ventricles.

   - Impulses from the **vagus nerve** slow down the pacemaker.
   - Impulses from **cardioaccelerator** nerves speed it up.
Circulation and Blood

Circulation is the movement of materials within an organism.

A circulatory system usually consists of:

1) A fluid in which materials are dissolved (plasma)
2) A network of tubes or body spaces in which the fluid flows (vessels)
3) A means of driving or moving the fluid (pump)

Humans (like many other vertebrates) have a closed, double circulatory system:

- A single heart pumps blood through a network of blood vessels that carries the blood to and from all of the cells of the body
- Blood passes through the heart twice in a single circuit

General Functions of the Circulatory System

1) Carries food molecules to all of our cells (e.g. monosaccharides, amino acids etc...)
2) Carries O₂ to all of our cells
3) Carries CO₂ away from all of our cells
4) Carries waste (ammonia, uric add and urea) from our cells to the kidney
5) Maintains our body temperature and pH
6) Clots blood to heal wounds
7) Carries white blood cells and antibodies to help fight infections
8) Carries control chemicals (i.e. hormones to their active sites)
Blood Components

1) Plasma

i) Water (90%)

ii) Proteins (8%)
   a) Albumin - regulates blood volume
   b) Gamma Globulin - helps antibody formation and action in the blood
   c) Fibrinogen - takes part in the blood clotting process
   d) Hormones, Antibodies and Enzymes

ii) Organic acids (1%) - includes nutrients and waste products (urea)

iv) Inorganic ions (1%) - act as electrolytes and regulate pH balance (e.g. Na, K, Mg, HCO₃ etc...)
2) **Erythrocytes (Red Blood Cells)**

- Formed in the bone marrow
- After 120 days they are trapped in the spleen and broken down mainly by phagocytic cells

**Structure:**

- Do not have a nucleus
- Bi-concave disc shape
- Contain HEMOGLOBIN which has a strong chemical affinity for OXYGEN

**Function:**

- Carry $O_2$ from lungs to the body cells
- Carry $CO_2$ from the body cells back to the lungs

**Disorders**

Anemia, one of the more common blood disorders, occurs when the level of healthy red blood cells (RBCs) in the body becomes too low. This can lead to health problems because RBCs contain hemoglobin, which carries oxygen to the body’s tissues. This failure of oxygen to get to body cells can cause a variety of complications, including fatigue and stress on bodily organs.

Anemia can be caused by many things, such as:

- Excessive destruction of RBCs
- Blood loss
- Inadequate production of RBCs
- Low iron levels
- Inherited disorders
- Infections

Sickle cell anemia is a serious disease in which the body makes sickle-shaped red blood cells. "Sickle-shaped" means that the red blood cells are shaped like a "C." Normal red blood cells move easily through your blood vessels. Sickle-shaped cells don't move easily through your blood vessels. They're stiff and sticky and tend to form clumps and get stuck in the blood vessels. The clumps of sickle cells block blood flow in the blood vessels that lead to the limbs and organs. Blocked blood vessels can cause pain, serious infections, and organ damage.
3) Leukocytes (White Blood Cells)

The 5 main types of leukocytes are formed in the bone marrow (granular WBC) and in lymphoid tissue (non-granular WBC). They are far less numerous than red blood cells. (1 WBC: 7 RBC).

**Structure:**
- Larger than red cells
- Contain a nucleus (often with lobes)

**Functions:**
- Destroying bacteria and damaged cells
- Producing enzymes to detoxify foreign proteins and viruses
- Produce antibodies to fight infections

**Disorders**

Leukemia is a cancer that starts in the stem cells of the bone marrow that make blood cells. Bone marrow is the soft, spongy material that fills the centre of most bones (where blood cells are made). Blood stem cells (immature blood cells) develop into either myeloid stem cells or lymphoid stem cells.

Leukemia develops when the blood stem cells in the bone marrow make abnormal blood cells. These abnormal cells are called leukemia cells. Over time, the leukemia cells crowd out normal blood cells. This makes it hard for the white blood cells, red blood cells and platelets to do their jobs.
4) Platelets

Platelets are found in the blood system at a frequency of 250 000/mm³ of blood.

**Structure:**
- Small bits of cytoplasm produced in the **bone marrow**

**Function:**
- Involved in the **clotting** mechanism when blood vessels are **injured**

**Blood Clotting**

- Broken **blood vessel** causes platelets to stick to injured site
- Chemicals released from platelets react with plasma to produce **thromboplastin**
- Thromboplastin reacts with **prothrombin** to produce **thrombin** (reaction aided by calcium ions)
- Thrombin reacts with **fibrinogen** to produce **fibrin**
- Fibrin creates a **mesh** that traps blood cells
- A clot is formed

**Blood Groups, Blood Typing and Blood Transfusions**

Blood types are determined by the presence of **antigens** (surface proteins) on the red blood cell.

Antibodies are found in blood plasma are **opposite** to the antigen.

A blood transfusion will work if a person who is going to receive blood has a blood group that doesn't have any **antibodies** against the donor blood's antigens.

If antigens and antibodies of the same type come together, clumping occurs (agglutination). Clumping will cause **blood clots** and **death** if an incompatible blood type is given.
<table>
<thead>
<tr>
<th>Blood Group</th>
<th>Antigens (on red blood cells)</th>
<th>Antibodies (in the plasma)</th>
<th>Can give blood to</th>
<th>Can receive blood from</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>B (anti-B)</td>
<td>A and AB</td>
<td>A and 0</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>A (anti-A)</td>
<td>B and AB</td>
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<td>A and B</td>
<td>None</td>
<td>AB</td>
<td>AB, A, B, 0</td>
</tr>
<tr>
<td>0</td>
<td>None</td>
<td>A and B (anti-A, anti-B)</td>
<td>AB, A, B, 0</td>
<td>0</td>
</tr>
</tbody>
</table>

Blood Type O - can be given to anyone (universal donor)

Blood Type AB - can receive all types (universal recipient)

**Rh Factor**

Rh factor - a group of possible antigens found on red blood cells.

Rh positive - those who have the antigen; approximately 85% of the Canadian population.

Rh negative - those who DO NOT have the antigen.

**Hemolytic Disease**

This disease will occur if the father is Rh+ and the mother is Rh- and the baby is Rh+. After the first child, the mother will develop Rh antibodies against the Rh factor (following the mixing of the baby’s and mother’s blood at birth).

In a future pregnancy, the mother’s antibodies will attach the Rh+ cells in the baby’s body. The baby’s cells then clump and it may result in a stillborn. This can be prevented by injection of Rh immunoglobulin into the mother before the second pregnancy.