Keywords Oxygen/Carbon dioxide/ Diffusion/Lungs/Respiration

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In this article...

- Purpose of obtaining air from the environment
- Purpose of external and internal gas exchange in the human body
- Mechanical and chemical processes involved in breathing

Every breath you take: the process of breathing explained

Key points

Energy in our bodies is obtained by breaking the chemical bonds in molecules

Oxygen sourced from the air is a vital ingredient in the process of energy synthesis

The respiratory system is designed to facilitate gas exchange, so that cells receive oxygen and get rid of carbon dioxide

Breathing changes throughout the day according to our activities

In an acute situation, one of the first interventions is to check the airways are clear so air can be drawn into the lungs

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Abstract Breathing uses chemical and mechanical processes to bring oxygen to every cell of the body and to get rid of carbon dioxide. Our body needs oxygen to obtain energy to fuel all our living processes. Carbon dioxide is a waste product of that process. The respiratory system, with its conduction and respiratory zones, brings air from the environment to the lungs and facilitates gas exchange both in the lungs and within the cells. Nurses need a solid understanding of how breathing works, and of vital signs of breathing and breathing patterns, to be able to care for patients with respiratory problems and potentially save lives in acute situations.

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The first question asked in an emergency situation is: "Is the person breathing?". It is also often the first question asked about newborns and the last one asked about the dying. Why is breathing so important? What is in the breath that we need so much? What happens when we stop breathing? These might seem obvious questions, but the mechanisms of respiration are often poorly understood, and their importance in health assessments and diagnostics often missed. This article describes the anatomy and physiology of breathing.

Collaborating with green plants

We need energy to fuel all the activities in our bodies, such as contracting muscles and maintaining a resting potential in our neurons, and we have to work to obtain the energy we use.

Green plants take their energy directly from sunlight and convert it into carbohydrates (sugars). We cannot do that, but we can use the energy stored in carbohydrates to fuel all other reactions in our bodies. To do this, we need to combine sugar with oxygen. We therefore need to accumulate both sugar and oxygen, which requires us to work. As a matter of fact, we spend much of our energy obtaining the sugar and oxygen we need to produce energy.

We source carbohydrates from green plants or animals that have eaten green plants, and we source oxygen from the air. Green plants release oxygen as a waste product of photosynthesis; we use that oxygen to fuel our metabolic reactions, releasing carbon dioxide as a waste product. Plants use our waste product as the carbon source for carbohydrates.

Breaking chemical bonds

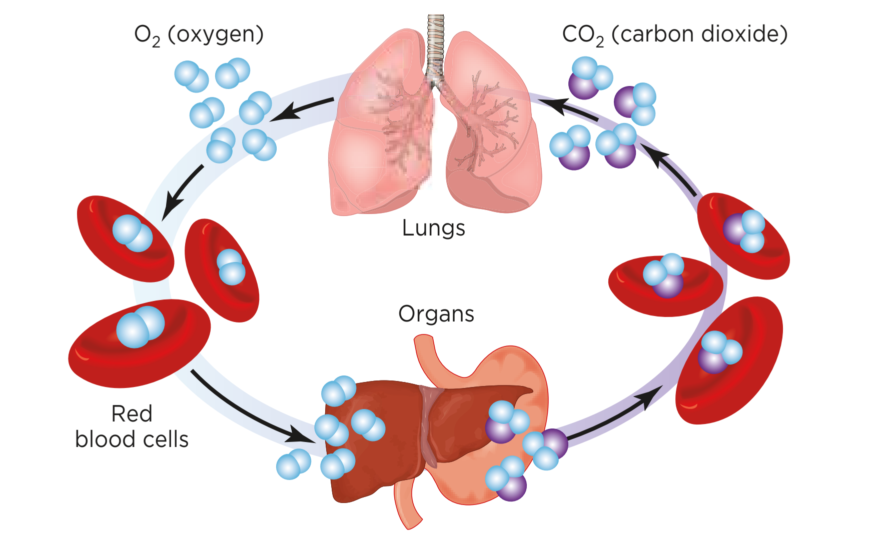
To obtain energy we must release the energy contained in the chemical bonds of molecules such as sugars. The foods we eat (such as carbohydrates and proteins) are digested in our gastrointestinal tract into molecules (such as sugars and amino acids) that are small enough to pass into the blood. The blood transports the sugars to the cells, where the mitochondria break up their chemical bonds to release the energy they contain. Cells need oxygen to be able to carry out that process. As every cell in our body needs energy, every one of them needs oxygen.

The energy released is stored in a chemical compound called adenosine triphosphate (ATP), which contains three phosphate groups. When we need energy to carry out an activity, ATP is broken down into adenosine diphosphate (ADP), containing only two phosphate groups. Breaking the chemical bond between the third phosphate group and ATP releases a high amount of energy.

Internal and external respiration

Our lungs supply oxygen from the outside air to the cells via the blood and cardiovascular system to enable us to obtain energy. As we breathe in, oxygen enters the lungs and diffuses into the blood. It is taken to the heart and pumped into the cells. At the same time, the carbon dioxide waste from the breakdown of sugars in the cells of the body diffuses into the blood and then diffuses from the blood into the lungs and is expelled as we breathe out. One gas (oxygen) is exchanged for another (carbon dioxide). This exchange of gases takes places both in the lungs (external respiration) and in the cells (internal respiration). Fig 1 summarises gas exchange in humans.

Fig 1. **Gas exchange in humans**



Bringing air into the lungs

Our respiratory system comprises a conduction zone and a respiratory zone. The conduction zone brings air from the external environment to the lungs via a series of tubes through which the air travels. These are the:

- Nasal cavity;
- Pharynx (part of the throat behind the mouth and nasal cavity),
- Larynx (voice box),
- Trachea (windpipe);
- Bronchi and bronchioles.

Aside from conducting air to the lungs, these tubes also:

- Warm the incoming air;
- Filter out small particles from it;
- Moisten it to ease the gas exchange in the lungs.

The nasal cavity has a large number of tiny capillaries that bring warm blood to the cold nose. The warmth from the blood diffuses into the cold air entering the nose and warms it.

The lining of the pharynx and larynx (which form the upper respiratory tract) and the lining of the trachea (lower respiratory tract) have small cells with little hairs or cilia. These hairs trap small airborne particles, such as dust, and prevent them from reaching the lungs.

The lining of the nasal cavity, upper respiratory tract and lower respiratory tract contains goblet cells that secrete mucus. The mucus moistens the air as it comes in, making it more suitable for the body's internal environment. It also traps particles, which the cilia then sweep upwards and away from the lungs so they are swallowed into the stomach for digestion, rather than getting trapped in the lungs. This mechanism of moving trapped particles in this way is known as the mucociliary escalator.

The lungs are a little like balloons: they do not inflate by themselves, but only do so if air is blown into them. We can blow into the lungs and inflate them – which is one of the two techniques used for cardiopulmonary resuscitation – but that does not happen in the normal daily life of healthy people. We have to inhale and exhale air by ourselves. How do we do that?

Controlling the volume of air in the lungs

We have two lungs (right and left) contained in the thoracic cavity (chest). Surrounding the lungs are ribs, which not only protect them from damage but also serve as anchors for the intercostal muscles. Beneath the lungs is a very large dome-shaped muscle, the diaphragm. All these muscles are attached to the lungs by the parietal and visceral membranes (also called parietal and visceral pleura).

The parietal membrane is attached to the muscles and the visceral membrane is attached to the lungs. The liquid between these two membranes, pleural fluid, sticks them together just as panes of glass become stuck together when wet.

As the visceral membrane covers, and is part of, the lungs and is stuck by pleural fluid to the parietal membrane, when the muscles in the thorax move, the lungs move with them. If air gets between the membranes, they become unstuck and, although the muscles can still contract and relax, they are no longer attached to the lung – as a result, the lung collapses. This abnormal collection of air in the pleural space is called a pneumothorax. If the pleural fluid liquid becomes infected, the person develops pleurisy.

When the intercostal muscles contract, they move up and away from the thoracic cavity. When the diaphragm contracts, it moves down towards the abdomen. This movement of the muscles causes the lungs to expand and fill with air, like a bellows (inhalation). Conversely, when the muscles relax, the thoracic cavity gets smaller, the volume of the lungs decreases, and air is expelled (exhalation).

Equalising pressure

When the thoracic muscles contract, the volume of the lungs expands so there is suddenly less pressure inside them. The air already in the lungs has more space, so it is not pushing against the lung walls with the same pressure. To equalise the pressure, air rushes in until the pressure is the same inside and outside. Conversely, when the muscles relax, the volume of the lungs decreases, the air in the lungs has less space and is now at high pressure, so the

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air is expelled until pressure is equalised. In short:

- When volume (V) increases, pressure (P) decreases, resulting in air rushing into the lungs – we inhale;
- When V decreases, P increases, resulting in air being squeezed out of the lungs – we exhale.

Gas exchange

The job of the conduction zone is to get air into the lungs while warming, moistening and filtering it on the way. Once the air is in the respiratory zone (composed of the alveolar ducts and alveoli), external gas exchange can take place (Fig 2).

The lungs contain thin layers of cells forming air sacs called alveoli, each of which is surrounded by pulmonary blood capillaries that are linked to the pulmonary arteries coming out of the heart. The alveoli are kept open by liquid secretions (pulmonary surfactant) so they do not stick together when air is expelled from the lungs. Premature babies do not have enough pulmonary surfactant, so they need some sprayed into their lungs.

During inhalation, each alveoli receives air that contains various gases: nitrogen (almost 80%), oxygen (almost 20%) and other gases including 0.04% carbon dioxide. External gaseous exchange then takes place, using the principle of diffusion:

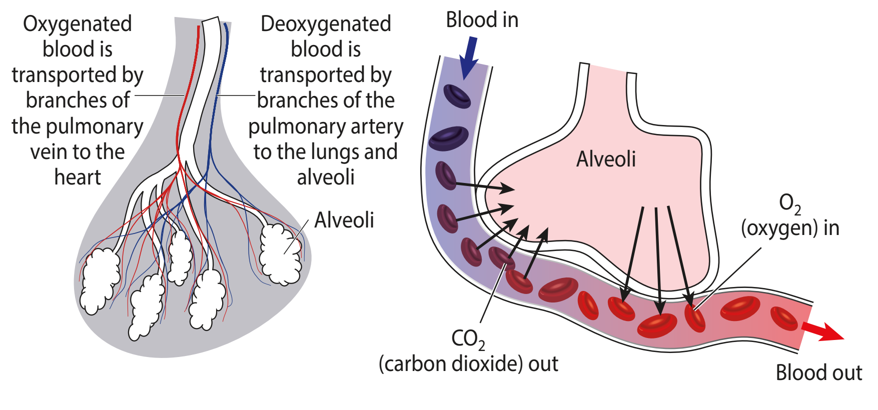
- Oxygen diffuses from the alveoli into the pulmonary capillaries because there is a high concentration of oxygen in the lungs and a low concentration in the blood;
- Carbon dioxide diffuses from the pulmonary capillaries into the alveoli because there is a high concentration of carbon dioxide in the blood and a low concentration in the lungs;
- Nitrogen diffuses both ways.

In other words: we inhale, high concentrations of oxygen which then diffuses from the lungs into the blood, while high concentrations of carbon dioxide diffuses from the blood into the lungs, and we exhale. Once in the blood, the oxygen is bound to haemoglobin in red blood cells, taken through the pulmonary vein to the heart, pumped into the systemic vascular system and, finally, taken to all the cells of the body.

Controlling breathing

The main cue that we are not breathing is not so much the lack of oxygen as the accumulation of carbon dioxide. When our muscles carry out activities, oxygen is used up and carbon dioxide – the waste

Fig 2. **Gas exchange in the lungs**



product – accumulates in the cells. Increased muscle activity means increased use of oxygen, increased production of glucose-forming ATP and, therefore, increased levels of carbon dioxide.

Carbon dioxide diffuses from the cells into the blood. Deoxygenated blood is carried by the veins towards the heart. It enters the right side of the heart and is pumped into the pulmonary system. Carbon dioxide diffuses into the lungs and is expelled as we exhale.

While the deoxygenated blood travels in the veins, detectors in the brain and blood vessels (chemoreceptors) measure the blood's pH. The peripheral chemoreceptors – although sensitive to changes in carbon dioxide levels and pH, as well as oxygen levels – mainly monitor oxygen. The central chemoreceptors, located in the brain constitute the control centres for breathing, as they are especially sensitive to pH changes in the blood. As carbon dioxide levels rise, blood pH falls; this is picked up by the central chemoreceptors and, through feedback mechanisms, signals are sent to alter breathing.

Altering breathing

We change our breathing to match our activity. When we move skeletal muscles, we use energy and therefore need more sugar and oxygen. Muscles have a good blood supply, bringing oxygen and glucose and taking away carbon dioxide. As muscles move more – for example, if we go from walking to running – the heart pumps faster (increased heart rate) to increase the blood supply and we breathe more quickly (increased respiratory rate) to get more oxygen into the blood.

The respiratory rate can be increased or decreased to suit the amount of oxygen needed. To increase the respiratory rate, effectors in the lungs are triggered to ventilate (inhale and exhale) faster, so carbon dioxide is removed and oxygen brought in more quickly. At the same time, the brain sends messages to the heart to beat faster, pumping oxygenated blood to the cells more quickly. The depth of breathing can also be altered so that a larger or smaller volume of air is taken into the lungs.

Respiratory rate is one of the respiratory vital signs (Box 1). To diagnose any respiratory problem, these vital signs need to be measured at rest and at work (Cedar, 2017). Respiratory rate is hard to measure, because when patients are told it is going to be measured, they usually start to breathe slower or faster than normal. It may be beneficial for nurses to tell patients that they are going to measure their temperature, and then measure their respiratory rate at the same time.

Accurately measuring breathing rate and depth at rest gives a key measure of pulmonary function and oxygen flow. Changes in breathing rate and depth at rest not only tell us about physical changes in the body, but also about mental and emotional changes, as our state of mind and our feelings have an effect on our breathing.

A lifetime of breathing

Our respiratory vital signs not only change during the course of one day according to our activities, but also during the course of our lifetimes.

Before birth, the embryo and then the foetus draw oxygen from the mother's blood through the placenta. Haemoglobin changes take place to enable the embryo/foetus to take oxygen from blood at lower concentration than it will find in the air

Box 1. **Vital signs of breathing**

- Respiratory rate (RR) – number of breaths taken per minute. Adults breathe in and out approximately 12-18 times per minute
- Tidal volume (TV) – amount of air inhaled and exhaled per breath (about 500ml in adults)
- Expiratory reserve volume (ERV) – volume of air that can be exhaled after normal breathing
- Inspiratory reserve volume (IRV) – volume of air that can be inhaled after normal breathing
- Residual volume (RV) – the air that remains in the lungs; the lungs are never completely empty, otherwise they would collapse and stick together
- Lung capacities (depth and volume of breathing), which can be measured using a spirometer:
  - Vital capacity = ERV + TV + IRV
  - Inspiratory capacity = TV + IRV
  - Functional residual capacity = ERV + RV
  - Total lung capacity = RV + ERV + TV + IRV
- Oxygen saturation: percentage of oxygen-saturated haemoglobin relative to total haemoglobin in the blood (around 98% in adults); lower saturations increase RR and/or lung capacities

after birth. Immediately after birth, the newborn has to switch from drawing oxygen from the blood to inflating its lungs and taking air into them (Schroeder and Matsuda, 1958; Rhinesmith et al, 1957).

Babies have a much faster heart rate and respiratory rate than adults: they take about 40 breaths per minute because they have smaller lungs (Royal College of Nursing, 2017). Heart rate and respiratory rate slow down with advancing age, partly because the lungs become less able to expand and contract. Becoming less elastic with age, all our muscles – not only skeletal muscle but also smooth muscle and cardiac muscle – reduces the speed at which they expand and contract (Sharma and Goodwin, 2006).

When we die, one of the signs of death is the cessation of breathing. Oxygen stops diffusing into the blood and, as ATP is used up and we are unable to synthesise more, we become cyanotic. We run out of energy and all of the body's processes cease. In the brain, the potential difference (measured in volts) becomes the same inside and outside the neurons, and electrical activity stops. The brain ceases all activity, including the involuntary activity that is needed to sustain life.

Box 2. **Breathing patterns**

- **Regular breathing: breaths are similar in amplitude, duration, wave shape and frequency**
- **Irregular breathing: breaths vary in one or more of the following: amplitude, duration, wave shape and frequency**
- **Hypopnea: breathing at reduced breath (tidal) volume and/or frequency**
- **Apnoea: cessation of breathing**
- **Periodic breathing: a sequence of several breaths followed by apnoea, then a sequence of breaths, then apnoea, and so on**
- **Cheyne-Stokes breathing: similar to periodic breathing; breath amplitude starts low and gradually increases, then decreases to apnoea, and the pattern repeats**

Source: Adapted from Neuman (2011)

Respiratory conditions

Health professionals are likely to encounter patients with breathing problems in any setting. Common respiratory conditions are:

- Asthma – often caused by certain chemicals or pollution, asthma affects the bronchioles, which become chronically inflamed and hypersensitive;
- Chronic obstructive pulmonary disorder – often caused by smoking or pollution;
- Pneumonia – usually caused by a bacterial infection, pneumonia is the swelling of tissues in one or both lungs;
- Lung cancers – the predominant tissue in the lungs is epithelial tissue, so lung cancers are mostly carcinomas (squamous cell carcinomas, adenocarcinomas, small cell carcinomas), which are cancers of epithelial tissue.

Lung disease can appear at any age but susceptibility increases with age because, as we age:

- The elasticity of our lungs decreases;
- Our vital capacity decreases;
- Our blood-oxygen levels decrease;
- The stimulating effects of carbon dioxide decrease;
- There is an increased risk of respiratory tract infection.

Respiratory emergencies

Patients who are rapidly deteriorating or critically ill must be assessed immediately, and nursing interventions can go a long way to ensure recovery (Fournier, 2014). In an acute situation, one of the first interventions is to ensure the airways (upper respiratory tract) are clear so air can be drawn into the lungs. This is the first step of the ABCDE checklist. ABCDE stands for:

- Airway;
- Breathing;
- Circulation;
- Disability;
- Exposure.

The ABCDE approach is outlined in more detail at: Bit.ly/RCUKABCDApproach.

An inability to breathe normally is extremely distressing and the more distressed a person becomes, the more likely it is that their breathing will be compromised. If one of our lungs collapses, we can manage without it, but we do need at least one functioning lung. We have about 90 seconds worth of ATP stored in our bodies, which we constantly use, so we need to be able to get oxygen.

A solid understanding of vital respiratory signs, as well as human breathing patterns (Box 2) is key. Armed with such knowledge, nurses can react quickly to acute changes, potentially saving lives and restoring health (Fletcher, 2007). **NT**

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