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Respiration

Student Laboratory Kit

Introduction

Respiration consists of breathing and cellular respiration. *Breathing* is the intake of air (inhaling) and the letting out of carbon dioxide and water vapor (exhaling). *Cellular respiration* is a complex process by which energy is released from nutrient molecules.

Concepts

- Cellular respiration
- Respiration
- Biofeedback mechanisms

Background

Inhalation and exhalation involve multiple systems of the body. A complex set of signals from the nervous system to various muscles must coordinate to create the pressure necessary for air to enter and exit the lungs. Muscular contractions change the size of the chest cavity (its volume) and create a difference in air pressure between the chest cavity and the atmospheric air pressure outside the body. Pressure and volume have an inverse relationship—when one increases, the other decreases. When the pressure outside the body is greater than the pressure inside the lungs, air enters the lungs (see Figure 1A). After inhalation the pressure inside the lungs becomes greater than the pressure outside the body. This reversal of the pressure differential causes air to leave the lungs (see Figure 1B).

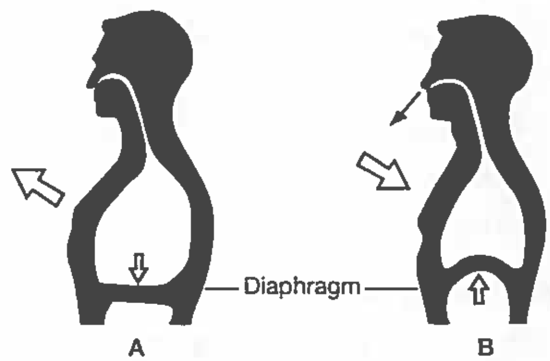

Figure 1. Respiration

A. *Inhalation*—with the diaphragm and chest muscles contracted, the rib cage is raised causing increased volume and decreased air pressure.

B. *Exhalation*—with the diaphragm and chest muscles relaxed, the rib cage is lowered, causing decreased volume and increased air pressure.

Oxygen (O_2) and carbon dioxide (CO_2) inside the lungs are exchanged by diffusion across a single layer of cells called *alveoli*. In the alveoli, oxygen is more concentrated than in the surrounding capillaries. Oxygen diffuses from the air across the cell membranes of the alveoli and into the blood in the capillaries. In contrast, CO_2 is more concentrated in the capillaries of the lungs than in the alveoli. Therefore, CO_2 diffuses out of the capillaries into the alveoli, where it can be exhaled by the lungs.

Hemoglobin is the major transporter of oxygen and carbon dioxide in the blood. Hemoglobin releases oxygen and picks up carbon dioxide as the blood flows through the body. Oxygen is required by cells for the complex set of biochemical reactions that must take place to release the energy from nutrients absorbed by the digestive system. Specifically, oxygen is required by the mitochondria inside cells to make adenosine triphosphate or ATP by way of the oxidation of glucose. The production of ATP is called *cellular respiration*. Carbon dioxide produced by the mitochondria as a waste product of ATP production must be transported out of the cell, to the blood, and back to the lungs for exhalation.

It is the production of this CO_2 byproduct by the mitochondria that regulates one's breathing rate. The CO_2 dissolves in the blood, forming carbonic acid (H_2CO_3). Carbonic acid then breaks down into bicarbonate (HCO_3^-) and hydrogen ions (H^+). The more hydrogen ions that are in the blood, the lower the pH of the blood will be. This is important to the biosensors in the body. Blood that is high in CO_2 has a lower pH than blood that is low in CO_2.

Biofeedback mechanisms in the body monitor the pH of the blood. If a drop in the blood pH is detected, nerve signals are sent to the breathing center in the brain. The breathing center sends signals to the muscles that control breathing—triggering faster, deeper breathing and increasing the removal of CO_2.

An acid–base indicator such as bromthymol blue (BTB) may be used to indicate the pH of blood and hence the relative amount of CO_2 dissolved in water. Bromthymol blue solution is blue when its pH greater than 7.6, green between 7.6 and 6.0, and yellow at a pH less than 6.0. By capturing exhaled air and bubbling it through a solution of BTB, the relative CO_2 concentration present may be determined visually based on the color and pH of the resulting solution.

Experiment Overview

The purpose of this laboratory activity is to determine the amount of carbon dioxide in exhaled air when the body is at rest compared to the amount present after moderate exercise.

Pre-Lab Questions

1. Create a diagram which indicates the relative pressure differences inside the body versus outside the body during both inhalation and exhalation.
2. If the pH of blood were tested immediately after it exited the lungs and then again just prior to entering the lungs, which sample would be expected to have a lower pH value? Explain.

Materials

Bromthymol blue solution (BTB), 100 mL

Balloon, 12-inch

Cups, clear plastic, 2

Graduated cylinder, 100-mL

Marker

Ruler

Stopwatch or timer

Straw

String, 18-inch pieces, 2

Tape

Safety Precautions

Although latex is not considered hazardous, it may be an allergen. Wear safety glasses or goggles whenever working with chemicals, heat or glassware in the laboratory. Do not share balloons. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Procedure

1. Read the procedure completely before beginning the activity.
2. Using the 100-mL graduated cylinder, measure and add 50 mL of bromthymol blue solution into each of the two cups.
3. Inflate and deflate the balloon once to stretch the latex.
4. Insert the straw into the neck of the balloon.
5. Securely tape the straw to the balloon—ensure that no air can escape around the straw.
6. One partner should take a deep breath and exhale completely into the straw with *one* full breath of air. Empty the lungs as much as possible. Pinch off the straw and balloon. Do not let any air escape the balloon. *Note:* The largest volume of air that can be inhaled and exhaled is called the *vital capacity*. The volume of a normal breath is called the *tidal volume*.
7. Without allowing any air to escape, wrap the string around the widest part of the balloon.
8. Mark the string to show the width of the balloon. Using a ruler, measure the circumference of the balloon in millimeters, and record the result in the data table.
9. Insert the free end of the straw into the bottom of one cup containing the BTB solution.

10. *Slowly* release the exhaled air from the balloon so that it bubbles through the BTB solution.
11. As soon as the BTB solution turns yellow or yellow-green, pinch off the straw and balloon to keep any additional air from escaping.
12. Wrap the same string around the widest part of the balloon.
13. Mark the string to the final circumference of the balloon. Allow the balloon to deflate.
14. Using a ruler, measure the final circumference marked on the string in millimeters and record the result in the data table on the Respiration Worksheet. Note that the values obtained in steps 8 and 14 are both before exercising.
15. The same partner should run in place for one full minute.
16. Repeat steps 6–9 using the second piece of string and the second cup of BTB solution. Record the initial circumference of the balloon "after exercising" in the data table.
17. Slowly release the air from the balloon into the second cup until the BTB solution turns exactly the same shade of yellow or yellow-green as the solution in step 11. This is very important to ensure accurate comparisons can be made of the CO_2 in exhaled air before and after exercising.
18. Pinch off the straw and balloon to keep any additional air from escaping. *Note:* Save both cups with solution to complete question 3 of the *Post-Lab Questions*.
19. Wrap the same string around the widest part of the balloon.
20. Mark the string again to measure the final circumference of the balloon after exercising. Allow the balloon to deflate.
21. Use a ruler to measure the final circumference marked on the balloon. Record the result in the data table on the Respiration Worksheet.

Name: ______________________________

Respiration Worksheet

Data Table

Initial circumference before exercising	mm
Final circumference before exercising	mm
Change in circumference (initial – final)	mm
Initial circumference after exercising	mm
Final circumference after exercising	mm
Change in circumference (initial – final)	mm

Post-Lab Questions

1. Using both the before- and after-exercising results, calculate the change in circumference of the balloon to determine how much air was needed to cause the BTB color change. Which situation caused the larger change in circumference of the balloon—before or after exercising?

2. Which exhaled breath (before or after exercising) contained a higher concentration of carbon dioxide? Explain.

3. Compare the color of your two cups of BTB solution to those of your classmates. Did everyone choose the same color for an endpoint?

4. Why was it important to stop adding exhaled air after exercise when the BTB color matched that of your initial sample?

5. Compare your circumference results to those of your classmates. Did everyone get the same result? Describe some of the factors that would influence the results.

6. Athletes train to increase their breathing efficiency. Would you expect trained athletes to have a higher or lower concentration of carbon dioxide in their exhaled breaths? Explain.