SECTION 8 - RESPIRATION AND METABOLISM

EXERCISE 8.1 MEASUREMENTS OF PULMONARY FUNCTION

Approximate Time for Completion: 1-3 hours

Introduction

This exercise is designed to introduce students to the instrumentation and techniques used to measure pulmonary function. Physicians and respiratory therapists use spirometry results to determine various pulmonary volumes and capacities measured of selected patients. It is appropriate during this exercise to discuss respiratory disorders such as asthma and emphysema and the effects these disorders have on vital capacity (VC) and forced expiratory volume (FEV). These procedures are often combined with exercise 8.2 (observing the effects of physical activity) and the other exercises from section 8 for a longer respiration laboratory.

Materials

1. Spirometer (Collins, Inc. 9-liter respirometer)
2. Disposable mouthpieces and nose clamp
3. Alternatively, the Biopac system may be used with the set up to Biopac lesson 12 (for part A) and lesson 13 (for part B).
4. Alternatively, the iWorx system may be used as described in iWorx exercise 10. Once set up, part A of this exercise may be performed.

Textbook Correlations: Chapter 16 – Physical Aspects of Ventilation, Mechanics of Breathing

Answers to Questions

1. vital capacity (VC)
2. expiratory reserve volume (ERV)
3. inspiratory capacity (IC)
4. residual volume
5. obstructive disorders
6. bronchitis, asthma
7. forced expiratory volume (FEV)
8. (a) 880 ml
   (b) 3,410 ml
   (c) 1,595 ml
   (d) 5,005 ml
9. 77%
10. Obstructive disorders are seen when there is an abnormally high resistance to airflow through the bronchioles due to such conditions as bronchoconstriction or mucus. In obstructive disorders, the vital capacity is normal but since airflow is affected the FEV_1 is low. Restrictive disorders occur when the alveoli are adversely affected by disease. In restrictive disorders, vital capacity is reduced but the FEV_1 may be normal.
11. Your lungs inflate because your chest expands. Contraction of the diaphragm and intercostal muscles must occur first, increasing the volume of the thoracic cavity. According to Boyle's law, this increased volume creates a pressure lower than that of the atmosphere. As a result, atmospheric air exerting greater pressure pushes into the lower pressure area that exists in the alveoli of the lungs causing them to inflate.

12. Intermittent positive pressure breathing (IPPB) must be used whenever surgery requires that an opening be made into the thoracic cavity. With the chest open, the lungs will collapse due to higher atmospheric pressure. Consequently, positive pressure must be used during open chest surgery to force air into the lungs during inspiration in order to ventilate the alveoli. The expiration phase is passive as the IPPB device intermittently stops the positive pressure inflow and the lungs collapse due to the higher atmospheric pressure.

EXERCISE 8.2 EFFECT OF EXERCISE ON THE RESPIRATORY SYSTEM

Approximate Time for Completion: 1 hour

Introduction

This exercise is designed to examine the effects of physical activity on respiration. A discussion of how the increased production of CO_2 affects respiration would be very helpful. Other topics that can be introduced here are basal metabolic rate (BMR), central and peripheral chemoreceptors, hyperpnea versus hyperventilation, total minute volume, oxygen consumption, and oxygen debt. This exercise could be combined with other exercises from unit 8 for a laboratory period on respiration.

Materials

1. Spirometer (Collins 9-liter respirometer)
2. Disposable mouthpieces and noseclips
3. Alternatively, the Biopac system may be used with the set up for exercise 12.
4. Alternatively, the iWorx system may be used with the set up described in iWorx exercise 10.

Textbook Correlations: Chapter 16 – Gas Exchange in the Lungs, Regulation of Breathing, Ventilation During Exercise

Answers to Questions

1. gas exchange
2. millimeters of air inspired or expired with each breath
3. tidal volume; frequency of breathing (breaths per minute)
4. aortic and carotid bodies
5. rise in plasma CO_2 (and consequent fall in pH)
6. Hyperpnea is increased breathing that can occur prior to and with early exercise as brain areas and sensory feedback from exercising muscles contribute excitement and anticipation.
7. Hypoventilation may be operationally defined as an abnormally increased plasma carbon dioxide level above 40 Torr, or 40 mmHg.
8. During physical activity the increase in the rate of metabolism within the exercising muscles prompts an increase in the rate of oxygen consumption and an increase in the production of carbon dioxide. The respiratory system keeps pace with the changes in demand by changing the total minute volume.
9. The total minute volume increased during exercise and remained high immediately after exercise. The increase in total minute volume during exercise is partially due to chemoreceptor stimulation (increased CO_2 and H^+ production) of the medulla oblongata that, in turn, stimulates neural reflexes that result in increased activity of the respiratory muscles. The continued high total minute volume after exercising is produced through the continued chemoreceptor stimulation by the increased production of carbon dioxide and lowered pH generated by metabolism in the muscles.

10. The term oxygen debt refers to the increased amount of oxygen consumed by the warmed muscle tissues of the body after exercise has ceased. This increased oxygen is required to metabolize the lactic acid produced during exercise and to support the increased metabolism of the muscles warmed during exercise. This is accomplished by the continued increase in total minute volume and increased oxygen consumption. Immediately after exercise, the rate of oxygen consumption remains elevated as a result of the increased need for oxygen in the metabolism of lactic acid (oxygen debt) and the continued increase in the amount of oxygen consumed by the muscles warmed during exercise.
11. In hyperpnea, the high total minute volume seen during mild to moderate exercise is matched by a high rate of metabolism. As a result, the rate at which increased carbon dioxide production by the tissues is matched by the increased rate at which it is "blown off." Consequently, arterial CO_2 concentrations remain near normal. During hyperventilation, by contrast, increased ventilation exceeds the metabolic rate and causes the blood CO_2 concentrations to fall in the absence of increased CO_2 production.
12. An endurance-trained person could perform a particular exercise with less metabolic demand on both the muscles and the cardiopulmonary system. The untrained person would have to exert more effort to perform the same exercise. The increase in metabolic demand in the untrained person would increase plasma carbon dioxide and lactic acid levels. These plasma changes would stimulate the chemoreceptors that in turn, would stimulate the medulla oblongata and result in a greater total minute volume.

EXERCISE 8.3 OXYHEMOGLOBIN SATURATION

Approximate Time for Completion: 30 minutes

Introduction

This exercise provides a simple method for introducing the concept of percent saturation of hemoglobin and for demonstrating the oxygen-hemoglobin loading and unloading reactions. Compared to the high cost of clinical blood gas instruments that measure these variables, this exercise presents a simpler, less expensive method that demonstrates the theoretical basis by which these instruments operate.

Materials

1. Graduated cylinder, 1 cc syringe
2. Test tubes and distilled water
3. Colorimeter and cuvettes
4. Sodium dithionite (hydrosulfite), 1.0 g per 100 ml
5. Alcohol swabs and lancets for preparing fingertip blood. Alternatively, dog or cat blood (obtained from a veterinarian) may be used.

Textbook Correlations: Chapter 16 – Partial Pressure of Gases in Blood, Hemoglobin and Oxygen Transport

Answers to Questions

1. deoxyhemoglobin; oxyhemoglobin
2. carboxyhemoglobin
3. methemoglobin
4. 97%
5. absorption spectrum
6. colors that absorb different amounts of light at each wavelength

7. In carbon monoxide poisoning the blood absorption spectrum measurement of carboxyhemoglobin would be abnormally increased. Carbon monoxide binds to the iron groups of heme, as oxygen does. The bond between heme and carbon monoxide, however, is a much stronger bond than exists between heme and oxygen. In the presence of CO, therefore, carboxyhemoglobin is formed as oxygen is displaced from hemoglobin. As the carboxyhemoglobin saturation rises, therefore, the oxyhemoglobin saturation decreases. The decreased oxygen-carrying capacity of the blood that occurs under these conditions may damage vital organs, particularly the heart and brain.
8. Carbon monoxide poisoning is different from anemia in that standard measurement of red blood cell count, hematocrit, or total blood hemoglobin does not detect CO poisoning. The absorption spectrum of CO poisoning however, would reveal a drop in the percent oxyhemoglobin saturation of arterial blood below normal. They are similar in that both disorders result in an inadequate delivery of oxygen to the body cells. In this way, CO poisoning may be thought of as a functional anemia. The hemoglobin and red blood cell counts are normal, but the red blood cells are not transporting normal amounts of oxygen.
9. During exercise the venous percent oxyhemoglobin saturation decreased from 75% to 35% because the exercising muscles caused hemoglobin to unload oxygen at the capillaries, resulting in the reduction in oxyhemoglobin in venous blood. The arterial percent oxyhemoglobin saturation in the normal, healthy person should remain fairly constant since the concomitant rise in carbon dioxide production with exercise should stimulate an increase in ventilation resulting in an increase in oxygen supply to the alveoli. The aerated alveoli should be able to quickly raise the blood oxyhemoglobin saturation from 35% to the more normal arterial value of 97% before blood returns to the exercising muscles.
10. The percent oxyhemoglobin saturation measurements provide an index of how effectively the lungs are oxygenating the blood. In both RDS and in patients undergoing general anesthesia the percent hemoglobin saturated with oxygen should fall. In respiratory distress the difficulty inflating and deflating the affected alveoli reduces the total amount of oxygen reaching the babies' blood, whereas general anesthesia depresses the respiratory control centers, thereby reducing overall ventilation and requiring a positive pressure ventilator to assist in respiration. By establishing acceptable lower limits for the oxyhemoglobin saturation in these patients, the medical staff can monitor each type of condition using sensing devices that sound an alarm if these values were to fall dangerously low.

EXERCISE 8.4 RESPIRATION AND ACID-BASE BALANCE

Approximate Time for Completion: 30 minutes-1 hour

Introduction

This exercise is designed to introduce students to the regulation of whole-body acid-base balance by the respiratory system. This is a good opportunity to review the concepts of pH, buffering, acidosis, and alkalosis. This exercise may be performed in conjunction with exercise 8.2, if desired, to emphasize the chemoreceptor regulation of breathing.

Materials

1. pH meter, droppers, beakers, straws
2. Buffer, pH = 7 (made from purchased concentrate); concentrated HCl
3. Concentrated NaOH
4. Phenolphthalein solution (saturated)

Textbook Correlations: Chapter 16 – Regulation of Breathing, Carbon Dioxide Transport and Acid-Base Balance, Ventilation During Exercise

Answers to Questions

1. nine
2. acidosis; alkalosis
3. a. An acid donates free protons (H^+) to solution.

   b. A base removes free protons from solution, usually by releasing OH^-, which combines with H^+ to form H_2O.

   c. Acidosis is the condition in which the blood pH is less that 7.35.

   d. Alkalosis is the condition in which the blood pH is greater than 7.45.
4. 40 mmHg
5. buffer
6. carbonic anhydrase
7. Hypoventilation results in increased CO_2 concentrations which drive the following equation to the right:

   $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$

   The concentration of carbonic acid will rise initially following the rise in carbon dioxide, then fall as carbonic acid molecules dissociate. Subsequently, the concentration of both H^+ and HCO_3^- (bicarbonate) will rise; and the pH value will fall.
8. Hyperventilation, with an increase in ventilation and a loss of carbon dioxide from the body will cause the equation to shift to the left. Loss of carbon dioxide causes an abnormal decrease in carbonic acid and a corresponding decrease in hydrogen ion concentration. The lower hydrogen ion concentration produces a rise in blood pH (respiratory alkalosis). Hypoventilation, by contrast, shifts the equation to the right as decreased ventilation allows carbon dioxide levels to accumulate. The increased levels of carbonic acid result in dissociation, forming greater numbers of hydrogen ions and a subsequent drop in pH value (respiratory acidosis).
9. Following hyperventilation, the breathing rate should have decreased significantly. Breathing rate is related to blood carbon dioxide levels and pH. Hyperventilation results in the excessive elimination of CO_2, lowered carbonic acid, and a rise in pH. The rise in pH reduces the desire to breathe until the amount of CO_2 in the blood again rises adequately high to restore a more normal pH. The normal pH should restore normal influence over the respiratory centers in the medulla oblongata, resulting in a more normal breathing pattern.
10. Breathing into a paper bag would force expired CO_2 back into the hyperventilated person. During hyperventilation the person has a high pH value (respiratory alkalosis) that is ultimately causing the dizziness. Rebreathing exhaled CO_2 would drive the equation to the right, resulting in a rise in hydrogen ion concentration and a fall in pH. In this way the normal pH level is restored, removing the dizziness and hopefully, the anxiety.
11. A rise in the blood bicarbonate levels produced by the intravenous infusion combines with and buffers the abnormally high free H^+ concentration that is causing the acidosis: $HCO_3^- + H^+ \rightarrow H_2CO_3$. The fall in hydrogen ion concentration reduces the stimulation of the respiratory centers and breathing slows. Too much bicarbonate would drive the equation to the left resulting in lowered hydrogen ion concentration and a rise in pH (metabolic alkalosis), lowering the urge to breathe.