22.6: Modifications in Respiratory Functions

Skills to Develop

- Define the terms hyperpnea and hyperventilation
- Describe the effect of exercise on the respiratory system
- Describe the effect of high altitude on the respiratory system
- Discuss the process of acclimatization

At rest, the respiratory system performs its functions at a constant, rhythmic pace, as regulated by the respiratory centers of the brain. At this pace, ventilation provides sufficient oxygen to all the tissues of the body. However, there are times that the respiratory system must alter the pace of its functions in order to accommodate the oxygen demands of the body.

Hyperpnea

Hyperpnea is an increased depth and rate of ventilation to meet an increase in oxygen demand as might be seen in exercise or disease, particularly diseases that target the respiratory or digestive tracts. This does not significantly alter blood oxygen or carbon dioxide levels, but merely increases the depth and rate of ventilation to meet the demand of the cells. In contrast, hyperventilation is an increased ventilation rate that is independent of the cellular oxygen needs and leads to abnormally low blood carbon dioxide levels and high (alkaline) blood pH.

Interestingly, exercise does not cause hyperpnea as one might think. Muscles that perform work during exercise do increase their demand for oxygen, stimulating an increase in ventilation. However, hyperpnea during exercise appears to occur before a drop in oxygen levels within the muscles can occur. Therefore, hyperpnea must be driven by other mechanisms, either instead of or in addition to a drop in oxygen levels. The exact mechanisms behind exercise
hyperpnea are not well understood, and some hypotheses are somewhat controversial. However, in addition to low oxygen, high carbon dioxide, and low pH levels, there appears to be a complex interplay of factors related to the nervous system and the respiratory centers of the brain.

First, a conscious decision to partake in exercise, or another form of physical exertion, results in a psychological stimulus that may trigger the respiratory centers of the brain to increase ventilation. In addition, the respiratory centers of the brain may be stimulated through the activation of motor neurons that innervate muscle groups that are involved in the physical activity. Finally, physical exertion stimulates proprioceptors, which are receptors located within the muscles, joints, and tendons, which sense movement and stretching; proprioceptors thus create a stimulus that may also trigger the respiratory centers of the brain. These neural factors are consistent with the sudden increase in ventilation that is observed immediately as exercise begins. Because the respiratory centers are stimulated by psychological, motor neuron, and proprioceptor inputs throughout exercise, the fact that there is also a sudden decrease in ventilation immediately after the exercise ends when these neural stimuli cease, further supports the idea that they are involved in triggering the changes of ventilation.

### High Altitude Effects

An increase in altitude results in a decrease in atmospheric pressure. Although the proportion of oxygen relative to gases in the atmosphere remains at 21 percent, its partial pressure decreases (Table 22.6.1). As a result, it is more difficult for a body to achieve the same level of oxygen saturation at high altitude than at low altitude, due to lower atmospheric pressure. In fact, hemoglobin saturation is lower at high altitudes compared to hemoglobin saturation at sea level. For example, hemoglobin saturation is about 67 percent at 19,000 feet above sea level, whereas it reaches about 98 percent at sea level.

#### Table 22.6.1

<table>
<thead>
<tr>
<th>Example location</th>
<th>Altitude (feet above sea level)</th>
<th>Atmospheric pressure (mm Hg)</th>
<th>Partial pressure of oxygen (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York City, New York</td>
<td>0</td>
<td>760</td>
<td>159</td>
</tr>
<tr>
<td>Boulder, Colorado</td>
<td>5000</td>
<td>632</td>
<td>133</td>
</tr>
<tr>
<td>Aspen, Colorado</td>
<td>8000</td>
<td>565</td>
<td>118</td>
</tr>
<tr>
<td>Pike’s Peak, Colorado</td>
<td>14,000</td>
<td>447</td>
<td>94</td>
</tr>
<tr>
<td>Denali (Mt. McKinley), Alaska</td>
<td>20,000</td>
<td>350</td>
<td>73</td>
</tr>
<tr>
<td>Mt. Everest, Tibet</td>
<td>29,000</td>
<td>260</td>
<td>54</td>
</tr>
</tbody>
</table>

As you recall, partial pressure is extremely important in determining how much gas can cross the respiratory membrane.
and enter the blood of the pulmonary capillaries. A lower partial pressure of oxygen means that there is a smaller
difference in partial pressures between the alveoli and the blood, so less oxygen crosses the respiratory membrane. As
a result, fewer oxygen molecules are bound by hemoglobin. Despite this, the tissues of the body still receive a sufficient
amount of oxygen during rest at high altitudes. This is due to two major mechanisms. First, the number of oxygen
molecules that enter the tissue from the blood is nearly equal between sea level and high altitudes. At sea level,
hemoglobin saturation is higher, but only a quarter of the oxygen molecules are actually released into the tissue. At high
altitudes, a greater proportion of molecules of oxygen are released into the tissues. Secondly, at high altitudes, a greater
amount of BPG is produced by erythrocytes, which enhances the dissociation of oxygen from hemoglobin. Physical
exertion, such as skiing or hiking, can lead to altitude sickness due to the low amount of oxygen reserves in the blood at
high altitudes. At sea level, there is a large amount of oxygen reserve in venous blood (even though venous blood is
thought of as “deoxygenated”) from which the muscles can draw during physical exertion. Because the oxygen
saturation is much lower at higher altitudes, this venous reserve is small, resulting in pathological symptoms of low blood
oxygen levels. You may have heard that it is important to drink more water when traveling at higher altitudes than you
are accustomed to. This is because your body will increase micturition (urination) at high altitudes to counteract the
effects of lower oxygen levels. By removing fluids, blood plasma levels drop but not the total number of erythrocytes. In
this way, the overall concentration of erythrocytes in the blood increases, which helps tissues obtain the oxygen they
need.

**Acute mountain sickness (AMS),** or altitude sickness, is a condition that results from acute exposure to high altitudes
due to a low partial pressure of oxygen at high altitudes. AMS typically can occur at 2400 meters (8000 feet) above sea
level. AMS is a result of low blood oxygen levels, as the body has acute difficulty adjusting to the low partial pressure of
oxygen. In serious cases, AMS can cause pulmonary or cerebral edema. Symptoms of AMS include nausea, vomiting,
fatigue, lightheadedness, drowsiness, feeling disoriented, increased pulse, and nosebleeds. The only treatment for AMS
is descending to a lower altitude; however, pharmacologic treatments and supplemental oxygen can improve symptoms.
AMS can be prevented by slowly ascending to the desired altitude, allowing the body to acclimate, as well as
maintaining proper hydration.

**Acclimatization**

Especially in situations where the ascent occurs too quickly, traveling to areas of high altitude can cause AMS. **Acclimatization** is the process of adjustment that the respiratory system makes due to chronic exposure to a high
altitude. Over a period of time, the body adjusts to accommodate the lower partial pressure of oxygen. The low partial
pressure of oxygen at high altitudes results in a lower oxygen saturation level of hemoglobin in the blood. In turn, the
tissue levels of oxygen are also lower. As a result, the kidneys are stimulated to produce the hormone erythropoietin
(EPO), which stimulates the production of erythrocytes, resulting in a greater number of circulating erythrocytes in an
individual at a high altitude over a long period. With more red blood cells, there is more hemoglobin to help transport the
available oxygen. Even though there is low saturation of each hemoglobin molecule, there will be more hemoglobin
present, and therefore more oxygen in the blood. Over time, this allows the person to partake in physical exertion
without developing AMS.

**Chapter Review**

Normally, the respiratory centers of the brain maintain a consistent, rhythmic breathing cycle. However, in certain cases,
the respiratory system must adjust to situational changes in order to supply the body with sufficient oxygen. For example, exercise results in increased ventilation, and chronic exposure to a high altitude results in a greater number of circulating erythrocytes. Hyperpnea, an increase in the rate and depth of ventilation, appears to be a function of three neural mechanisms that include a psychological stimulus, motor neuron activation of skeletal muscles, and the activation of proprioceptors in the muscles, joints, and tendons. As a result, hyperpnea related to exercise is initiated when exercise begins, as opposed to when tissue oxygen demand actually increases.

In contrast, acute exposure to a high altitude, particularly during times of physical exertion, does result in low blood and tissue levels of oxygen. This change is caused by a low partial pressure of oxygen in the air, because the atmospheric pressure at high altitudes is lower than the atmospheric pressure at sea level. This can lead to a condition called acute mountain sickness (AMS) with symptoms that include headaches, disorientation, fatigue, nausea, and lightheadedness. Over a long period of time, a person’s body will adjust to the high altitude, a process called acclimatization. During acclimatization, the low tissue levels of oxygen will cause the kidneys to produce greater amounts of the hormone erythropoietin, which stimulates the production of erythrocytes. Increased levels of circulating erythrocytes provide an increased amount of hemoglobin that helps supply an individual with more oxygen, preventing the symptoms of AMS.

Review Questions

Q. Increased ventilation that results in an increase in blood pH is called ________.
   
   A. hyperventilation  
   B. hyperpnea  
   C. acclimatization  
   D. apnea  
   Answer: A

Q. Exercise can trigger symptoms of AMS due to which of the following?
   
   A. low partial pressure of oxygen  
   B. low atmospheric pressure  
   C. abnormal neural signals  
   D. small venous reserve of oxygen  
   Answer: D

Q. Which of the following stimulates the production of erythrocytes?
   
   A. AMS
B. high blood levels of carbon dioxide
C. low atmospheric pressure
D. erythropoietin

Answer: D

Critical Thinking Questions

Q. Describe the neural factors involved in increasing ventilation during exercise.

A. There are three neural factors that play a role in the increased ventilation observed during exercise. Because this increased ventilation occurs at the beginning of exercise, it is unlikely that only blood oxygen and carbon dioxide levels are involved. The first neural factor is the psychological stimulus of making a conscious decision to exercise. The second neural factor is the stimulus of motor neuron activation by the skeletal muscles, which are involved in exercise. The third neural factor is activation of the proprioceptors located in the muscles, joints, and tendons that stimulate activity in the respiratory centers.

Q. What is the major mechanism that results in acclimatization?

A. A major mechanism involved in acclimatization is the increased production of erythrocytes. A drop in tissue levels of oxygen stimulates the kidneys to produce the hormone erythropoietin, which signals the bone marrow to produce erythrocytes. As a result, individuals exposed to a high altitude for long periods of time have a greater number of circulating erythrocytes than do individuals at lower altitudes.

Glossary

acute mountain sickness (AMS)
condition that occurs as a result of acute exposure to high altitude due to a low partial pressure of oxygen

acclimatization
process of adjustment that the respiratory system makes due to chronic exposure to high altitudes

hyperpnea
increased rate and depth of ventilation due to an increase in oxygen demand that does not significantly alter blood oxygen or carbon dioxide levels

hyperventilation
increased ventilation rate that leads to abnormally low blood carbon dioxide levels and high (alkaline) blood pH

Contributors