21.11B: Adjustments at High Altitude

The human body can adapt to high altitude through immediate and long-term acclimatization processes.

Learning Objectives

• Evaluate the respiratory adjustments to high altitude

Key Points

• At high altitude, in the short term, the lack of oxygen is sensed by the peripheral chemoreceptors, which causes an increase in ventilation. An increase in heart rate and decrease in stroke volume also occurs.

• During acclimatization over a few days to weeks, the body produces more red blood cells to counteract the lower oxygen saturation in blood in high altitudes.

• Full adaptation to high altitude is achieved when the increase of red blood cells reaches a plateau and stops.

• Increased red blood cell levels remain for about two weeks after acclimatization, which makes it a popular training regimen for athletes.

Key Terms

• **acclimatization**: Long-term adjustment to high altitude, which is primarily due to increased red blood cell production and capillary tissue perfusion.

• **hematocrit**: This is the amount of red blood cells in a given volume of blood.

The human body can adapt to high altitude through immediate and long-term acclimatization. At high altitude there is
lower air pressure compared to a lower altitude or sea-level altitude.

Due to Boyle’s law, at higher altitude the partial pressure of oxygen in the air is lower, and less oxygen is breathed in with every breath. The partial pressure gradients for gas exchange are also decreased, along with the percentage of oxygen saturation in hemoglobin.

Humans can survive at high altitudes with impaired short-term functions that eventually adjust in the long term. Some altitudes are too high for acclimatization to work, and can cause death if people stay there for too long.

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**Short-Term Adjustments**

At high altitude, in the short term, the lack of oxygen is sensed by the peripheral chemoreceptors, which causes an increase in breathing rate (hyperventilation). However, hyperventilation also causes the adverse effect of alkalosis due to increasing the rate by which carbon dioxide is removed from the body, which inhibits the respiratory center from enhancing the respiratory rate to meet the oxygen demands.

Additionally, the peripheral chemoreceptors cause sympathetic nervous system stimulation, which causes the heart rate to increase while stroke volume decreases, and digestion is impaired. Shortness of breath is common, and urination increases.

Along with alkalosis, these effects make up the symptoms of altitude sickness, which become worse during exercise at high altitudes (which involves more anaerobic respiration than at lower altitudes), but falls off during acclimatization.

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**Acclimatization**

Acclimatization to high altitude requires days, or even weeks. Gradually, the body compensates for the respiratory alkalosis by kidney excretion of bicarbonate, which allows adequate respiration to provide oxygen without risking alkalosis. It takes about four days at any given altitude, and can be enhanced by drugs such as acetazolamide (which decreases fluid retention).

Staying hydrated during acclimatization is important to minimize altitude sickness symptoms and to counteract increased urination. The heart rate and ventilation rate at rest both remain elevated despite the acclimatization, while heart rate at maximum activity level will be reduced.

The main difference brought about by acclimatization that explain why it makes high altitudes more comfortable for the body is increased levels of circulating red blood cells, which improve the carrying capacity of oxygen by hemoglobin in the body. This is an adaptive response due to erythropoietin secretions in the kidneys (from lack of oxygen in the tissues) that act on the liver to increase erythrocyte (red blood cell) production.

Blood volume decreases, which also increases the hematocrit, which is the concentration of hemoglobin in blood. This increase in red blood cells remains for a few weeks after one returns to lower altitude, so those who acclimatize to high altitude will experience improved athletic performance at lower altitudes. Capillary density and tissue perfusion also increase.
These physiological changes make high-altitude athletic training popular for athletes, such as Olympic athletes. Full hematological adaptation to high altitude is achieved when the increase of red blood cells reaches a plateau and stops.

The length of full hematological adaptation can be approximated by multiplying the altitude in kilometers by 11.4 days. For example, to adapt to 4,000 meters (13,000 ft.) of altitude would require 45.6 days.

The upper altitude limit of this linear relationship has not been fully established, in part because extremely high altitudes have such little oxygen content that they would be fatal regardless of acclimatization.
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