The effects of altitude on human physiology

Changes in altitude have a profound effect on the human body. The bodyattempts to maintain a state of homeostasis or balance to ensure the optimaloperating environment for its complex chemical systems. Any change from thishomeostasis is a change away from the optimal operating environment. The bodyattempts to correct this imbalance. One such imbalance is the effect ofincreasing altitude on the body's ability to provide adequate oxygen to beutilized in cellular respiration. With an increase in elevation, a typicaloccurrence when climbing mountains, the body is forced to respond in variousways to the changes in externalenvironment. Foremost of these changes is the diminished ability to obtainoxygen from the atmosphere. If the adaptive responses to this stressor areinadequate the performance of body systems may decline dramatically. Ifprolonged the results can be serious or even fatal. In looking at the effectof altitude on body functioning we first must understand what occurs in theexternal environment at higher elevations and then observe the importantchanges that occur in the internal environment of the body in response.

HIGH ALTITUDEIn discussing altitude change and its effect on the body mountaineersgenerally define altitude according to the scale of high (8, 000 – 12, 000feet), very high (12, 000 – 18, 000 feet), and extremely high (18, 000+ feet),(Hubble, 1995). A common misperception of the change in external environmentwith increased altitude is that there is decreased oxygen. This is notcorrect as the concentration of oxygen at sea level is about 21% and staysrelatively unchanged until over 50, 000 feet (Johnson, 1988).

What is really happening is that the atmospheric pressure is decreasing andsubsequently the amount of oxygen available in a single breath of air issignificantly less. At sea level the barometric pressure averages 760 mmHgwhile at 12, 000 feet it is only 483 mmHg. This decrease in total atmosphericpressure means that there are 40% fewer oxygen molecules per breath at thisaltitude compared to sea level (Princeton, 1995).

HUMAN RESPIRATORY SYSTEMThe human respiratory system is responsible for bringing oxygen into thebody and transferring it to the cells where it can be utilized for cellularactivities. It also removes carbon dioxide from the body. The respiratorysystem draws air initially either through the mouth or nasal passages. Bothof these passages join behind the hard palate to form the pharynx. At thebase of the pharynx are two openings. One, the esophagus, leads to thedigestive system while the other, the glottis, leads to the lungs. Theepiglottis covers the glottis when swallowing so that food does not enter thelungs. When the epiglottis is not covering the opening to the lungs air maypass freely into and out of the trachea.

The trachea sometimes called the “ windpipe” branches into two bronchi whichin turn lead to a lung. Once in the lung the bronchi branch many times intosmaller bronchioles which eventually terminate in small sacs called alveoli.

It is in the alveoli that the actual transfer of oxygen to the blood takesplace.

The alveoli are shaped like inflated sacs and exchange gas through amembrane. The passage of oxygen into the blood and carbon dioxide out of theblood is dependent on three major factors: 1) the partial pressure of thegases, 2) the area of the pulmonary surface, and 3) the thickness of themembrane (Gerking, 1969). The membranes in the alveoli provide a largesurface area for the free exchange of gases. The typical thickness of thepulmonary membrane is less than the thickness of a red blood cell. Thepulmonary surface and the thickness of the alveolar membranes are notdirectly affected by a change in altitude. The partial pressure of oxygen, however, is directly related to altitude and affects gas transfer in thealveoli.

GAS TRANSFERTo understand gas transfer it is important to first understand somethingabout thebehavior of gases. Each gas in our atmosphere exerts its own pressure andacts independently of the others. Hence the term partial pressure refers tothe contribution of each gas to the entire pressure of the atmosphere. Theaverage pressure of the atmosphere at sea level is approximately 760 mmHg.

This means that the pressure is great enough to support a column of mercury(Hg) 760 mm high. To figure the partial pressure of oxygen you start with thepercentage of oxygen present in the atmosphere which is about 20%. Thusoxygen will constitute 20% of the total atmospheric pressure at any givenlevel. At sea level the total atmospheric pressure is 760 mmHg so the partialpressure of O2 would be approximately 152 mmHg.

760 mmHg x 0. 20 = 152 mmHgA similar computation can be made for CO2 if we know that the concentrationis approximately 4%. The partial pressure of CO2 would then be about 0. 304mmHg at sea level.

Gas transfer at the alveoli follows the rule of simple diffusion. Diffusionis movement of molecules along a concentration gradient from an area of highconcentration to an area of lower concentration. Diffusion is the result ofcollisions between molecules. In areas of higher concentration there are morecollisions. The net effect of this greater number of collisions is a movementtoward an area of lower concentration. In Table 1 it is apparent that theconcentration gradient favors the diffusion of oxygen into and carbon dioxideout of the blood (Gerking, 1969). Table 2 shows the decrease in partialpressure of oxygen at increasing altitudes (Guyton, 1979).

Table 1ATMOSPHERIC AIRALVEOLUSVENOUS BLOODOXYGEN152 mmHg (20%)104 mmHg (13. 6%) 40 mmHgCARBON DIOXIDE 0. 304 mmHg (0. 04%)40 mmHg (5. 3%) 45 mmHgTable 2ALTITUDE (ft.) BAROMETRIC PRESSURE (mmHg)Po2 IN AIR (mmHg)Po2 IN ALVEOLI(mmHg) ARTERIAL OXYGEN SATURATION (%)0 760159*104 9710, 000523 110 67 9020, 000349 73 40 7030, 000226 47 21 2040, 000141 29 8550, 00087 18 11*this value differs from table 1 because the author used the value for theconcentration of O2 as 21%.

The author of table 1 choose to use the value as 20%.

CELLULAR RESPIRATIONIn a normal, non-stressed state, the respiratory system transports oxygenfrom the lungs to the cells of the body where it is used in the process ofcellular respiration. Under normal conditions this transport of oxygen issufficient for the needs of cellular respiration. Cellular respirationconverts the energy in chemical bonds into energy that can be used to powerbody processes. Glucose is the molecule most often used to fuel this processalthough the body is capable of using other organic molecules for energy.

The transfer of oxygen to the body tissues is often called internalrespiration (Grollman, 1978). The process of cellular respiration is acomplex series of chemical steps that ultimately allow for the breakdown ofglucose into usable energy in the form of ATP (adenosine triphosphate). Thethree main steps in the process are: 1) glycolysis, 2) Krebs cycle, and 3)electron transport system. Oxygen is required for these processes to functionat an efficient level. Without the presence of oxygen the pathway for energyproduction must proceed anaerobically. Anaerobic respiration sometimes calledlactic acid fermentation produces significantly less ATP (2 instead of 36/38)and due to this great inefficiency will quickly exhaust the available supplyof glucose. Thus the anaerobic pathway is not a permanent solution for theprovision of energy to the body in the absence of sufficient oxygen.

The supply of oxygen to the tissues is dependent on: 1) the efficiency withwhich blood is oxygenated in the lungs, 2) the efficiency of the blood indelivering oxygen to the tissues, 3) the efficiency of the respiratoryenzymes within the cells to transfer hydrogen to molecular oxygen (Grollman, 1978). A deficiency in any of these areas can result in the body cells nothaving an adequate supply of oxygen. It is this inadequate supply of oxygenthat results in difficulties for the body at higher elevations.

ANOXIAA lack of sufficient oxygen in the cells is called anoxia. Sometimes theterm hypoxia, meaning less oxygen, is used to indicate an oxygen debt. Whileanoxia literally means “ no oxygen” it is often used interchangeably withhypoxia. There are different types of anoxia based on the cause of the oxygendeficiency. Anoxic anoxia refers to defective oxygenation of the blood in thelungs. This is the type of oxygen deficiency that is of concern whenascending to greater altitudes with a subsequent decreased partial pressureof O2. Other types of oxygen deficiencies include: anemic anoxia (failure ofthe blood to transport adequate quantities of oxygen), stagnant anoxia (theslowing of the circulatory system), and histotoxic anoxia (the failure ofrespiratory enzymes to adequately function).

Anoxia can occur temporarily during normal respiratory system regulation ofchanging cellular needs. An example of this would be climbing a flight ofstairs. The increased oxygendemand of the cells in providing the mechanicalenergy required to climb ultimately produces a local hypoxia in the musclecell. The first noticeable response to this external stress is usually anincrease in breathing rate. This is called increased alveolar ventilation.

The rate of our breathing is determined by the need for O2 in the cells andis the first response to hypoxic conditions.

BODY RESPONSE TO ANOXIAIf increases in the rate of alveolar respiration are insufficient to supplythe oxygen needs of the cells the respiratory system responds by generalvasodilation. This allows a greater flow of blood in the circulatory system.

The sympathetic nervous system also acts to stimulate vasodilation within theskeletal muscle. At the level of the capillaries the normally closedprecapillary sphincters open allowing a large flow of blood through themuscles. In turn the cardiac output increases both in terms of heart rate andstroke volume. The stroke volume, however, does not substantially increase inthe non-athlete (Langley, et. al., 1980). This demonstrates an obvious benefitof regular exercise and physical conditioning particularly for an individualwho will be exposed to high altitudes. The heart rate is increased by theaction of theadrenal medulla which releases catecholamines. These catecholamines workdirectly on the myocardium to strengthen contraction. Another compensationmechanism is the release of renin by the kidneys. Renin leads to theproduction of angiotensin which serves to increase blood pressure (Langley, Telford, and Christensen, 1980). This helps to force more blood intocapillaries. All of these changes are a regular and normal response of thebody to external stressors. The question involved with altitude changesbecomes what happens when the normal responses can no longer meet the oxygendemand from the cells? ACUTE MOUNTAIN SICKNESSOne possibility is that Acute Mountain Sickness (AMS) may occur. AMS iscommon at high altitudes. At elevations over 10, 000 feet, 75% of people willhave mild symptoms (Princeton, 1995). The occurrence of AMS is dependent uponthe elevation, the rate of ascent to that elevation, and individualsusceptibility.

Acute Mountain Sickness is labeled as mild, moderate, or severe dependent onthe presenting symptoms. Many people will experience mild AMS during theprocess of acclimatization to a higher altitude. In this case symptoms of AMSwould usually start 12-24 hours after arrival at a higher altitude and beginto decrease in severity about the third day. The symptoms of mild AMS areheadache, dizziness, fatigue, shortness of breath, loss of appetite, nausea, disturbed sleep, and a general feeling of malaise (Princeton, 1995). Thesesymptoms tend to increase at night when respiration is slowed during sleep.

Mild AMS does not interfere with normal activity and symptoms generallysubside spontaneously as the body acclimatizes tothe higher elevation.

Moderate AMS includes a severe headache that is not relieved by medication, nausea and vomiting, increasing weakness and fatigue, shortness of breath, and decreased coordination called ataxia (Princeton, 1995). Normal activitybecomes difficult at this stage of AMS, although the person may still be ableto walk on their own. A test for moderate AMS is to have the individualattempt to walk a straight line heel to toe. The person with ataxia will beunable to walk a straight line. If ataxia is indicated it is a clear signthat immediate descent is required. In the case of hiking or climbing it isimportant to get the affected individual to descend before the ataxia reachesthe point where they can no longer walk on their own.

Severe AMS presents all of the symptoms of mild and moderate AMS at anincreased level of severity. In addition there is a marked shortness ofbreath at rest, the inability to walk, a decreasing mental clarity, and apotentially dangerous fluid buildup in the lungs.

ACCLIMATIZATIONThere is really no cure for Acute Mountain Sickness other thanacclimatization ordescent to a lower altitude. Acclimatization is the process, over time, wherethe body adapts to the decrease in partial pressure of oxygen molecules at ahigher altitude. The major cause of altitude illnesses is a rapid increase inelevation without an appropriate acclimatization period. The process ofacclimatization generally takes 1-3 days at the new altitude. Acclimatizationinvolves several changes in the structure and function of the body. Some ofthese changes happen immediately in response to reduced levels of oxygenwhile others are a slower adaptation. Some of the most significant changesare: Chemoreceptor mechanism increases the depth of alveolar ventilation. Thisallows for an increase in ventilation of about 60% (Guyton, 1969). This is animmediate response to oxygen debt. Over a period of several weeks thecapacity to increase alveolar ventilation may increase 600-700%.

Pressure in pulmonary arteries is increased, forcing blood into portions ofthelung which are normally not used during sea level breathing.

The body produces more red blood cells in the bone marrow to carry oxygen.

This process may take several weeks. Persons who live at high altitude oftenhave red blood cell counts 50% greater than normal.

The body produces more of the enzyme 2, 3-biphosphoglycerate that facilitatesthe release of oxygen from hemoglobin to the body tissues (Tortora, 1993).

The acclimatization process is slowed by dehydration, over-exertion, alcoholand other depressant drug consumption. Longer term changes may include anincrease in the size of the alveoli, and decrease in the thickness of thealveoli membranes. Both of these changes allow for more gas transfer.

TREATMENT FOR AMSThe symptoms of mild AMS can be treated with pain medications for headache.

Some physicians recommend the medication Diamox (Acetazolamide). Both Diamoxand headache medication appear to reduce the severity of symptoms, but do notcure the underlying problem of oxygen debt. Diamox, however, may allow theindividual to metabolize more oxygen by breathing faster. This is especiallyhelpful at night when respiratory drive is decreased. Since it takes a whilefor Diamox to have an effect, it is advisable to start taking it 24 hoursbefore going to altitude. The recommendation of the Himalayan RescueAssociation Medical Clinic is 125 mg.

twice a day. The standard dose has been 250 mg., but their research shows nodifference with the lower dose (Princeton, 1995). Possible side effectsinclude tingling of the lips and finger tips, blurring of vision, andalteration of taste. These side effects may be reduced with the 125 mg. dose.

Side effects subside when the drug is stopped. Diamox is a sulfonamide drug, so people who are allergic to sulfa drugs such as penicillin should not takeDiamox. Diamox has also been known to cause severe allergic reactions topeople with no previous history of Diamox or sulfaallergies. A trial course of the drug is usually conducted before going to aremote location where a severe allergic reaction could prove difficult totreat. Some recent data suggests that the medication Dexamethasone may havesome effect in reducing the risk of mountain sickness when used incombination with Diamox (University of Iowa, 1995).

Moderate AMS requires advanced medications or immediate descent to reversethe problem. Descending even a few hundred feet may help and definiteimprovement will be seen in descents of 1, 000-2, 000 feet. Twenty-four hoursat the lower altitude will result in significant improvements. The personshould remain at lower altitude until symptoms have subsided (up to 3 days).

At this point, the person has become acclimatized to that altitude and canbegin ascending again. Severe AMS requires immediate descent to loweraltitudes (2, 000 – 4, 000 feet). Supplemental oxygen may be helpful inreducing the effects of altitude sicknesses but does not overcome all thedifficulties that may result from the lowered barometric pressure.

GAMOW BAGThis invention has revolutionized field treatment of high altitudeillnesses. The Gamow bag is basically a portable sealed chamber with a pump.

The principle of operation is identical to the hyperbaric chambers used indeep sea diving. The person is placed inside the bag and it is inflated.

Pumping the bag full of air effectively increases the concentration of oxygenmolecules and therefore simulates a descent to lower altitude. In as littleas 10 minutes the bag creates an atmosphere that corresponds to that at 3, 000– 5, 000 feet lower. After 1-2 hours in the bag, theperson’s body chemistry will have reset to the lower altitude. This lasts forup to 12 hours outside of the bag which should be enough time to travel to alower altitude and allow for further acclimatization. The bag and pump weighabout 14 pounds and are now carried on most major high altitude expeditions.

The gamow bag is particularly important where the possibility of immediatedescent is not feasible.

OTHER ALTITUDE-INDUCED ILLNESSThere are two other severe forms of altitude illness. Both of these happenlessfrequently, especially to those who are properly acclimatized. When they dooccur, it is usually the result of an increase in elevation that is too rapidfor the body to adjust properly. For reasons not entirely understood, thelack of oxygen and reduced pressure often results in leakage of fluid throughthe capillary walls into either the lungs or the brain. Continuing to higheraltitudes without proper acclimatization can lead to potentially serious, even life-threatening illnesses.

HIGH ALTITUDE PULMONARY EDEMA (HAPE)High altitude pulmonary edema results from fluid buildup in the lungs. Thefluid in the lungs interferes with effective oxygen exchange. As thecondition becomes more severe, the level of oxygen in the bloodstreamdecreases, and this can lead to cyanosis, impaired cerebral function, anddeath. Symptoms include shortness of breath even at rest, tightness in thechest, marked fatigue, a feeling of impending suffocation at night, weakness, and apersistent productive cough bringing up white, watery, or frothy fluid(University of Iowa, 1995.). Confusion, and irrational behavior are signsthat insufficient oxygen is reaching the brain. One of the methods fortesting for HAPE is to check recovery time after exertion. Recovery timerefers to the time after exertion that it takes for heart rate andrespiration to return to near normal. An increase in this time may mean fluidis building up in the lungs. If a case of HAPE is suspected an immediatedescent is a necessary life-saving measure (2, 000 – 4, 000 feet).

Anyonesufferingfrom HAPE must be evacuated to a medical facility for proper follow-uptreatment. Early data suggests that nifedipine may have a protective effectagainst high altitude pulmonary edema (University of Iowa, 1995).

HIGH ALTITUDE CEREBRAL EDEMA (HACE)High altitude cerebral edema results from the swelling of brain tissue fromfluid leakage. Symptoms can include headache, loss of coordination (ataxia), weakness, and decreasing levels of consciousness including, disorientation, loss of memory, hallucinations, psychotic behavior, and coma. It generallyoccurs after a week or more at high altitude. Severe instances can lead todeath if not treated quickly. Immediate descent is a necessary life-savingmeasure (2, 000 – 4, 000 feet). Anyone suffering from HACE must be evacuatedto a medical facility for proper follow-uptreatment.

CONCLUSIONThe importance of oxygen to the functioning of the human body is critical.

Thus the effect of decreased partial pressure of oxygen at higher altitudescan be pronounced. Each individual adapts at a different speed to exposure toaltitude and it is hard to know who may be affected by altitude sickness.

There are no specific factors such as age, sex, or physical condition thatcorrelate with susceptibility to altitude sickness. Most people can go up to8, 000 feet with minimal effect. Acclimatization is often accompanied by fluidloss, so the ingestion of large amounts of fluid to remain properly hydratedis important (at least 3-4 quarts per day). Urine output should be copiousand clear.

From the available studies on the effect of altitude on the human body itwould appear apparent that it is important to recognize symptoms early andtake corrective measures. Light activity during the day is better thansleeping because respiration decreases during sleep, exacerbating thesymptoms. The avoidance of tobacco, alcohol, and other depressant drugsincluding, barbiturates, tranquilizers, and sleeping pills is important.

These depressants further decrease the respiratory drive during sleepresulting in a worsening of the symptoms. A high carbohydrate diet (more than70% of your calories from carbohydrates) while at altitude alsoappears to facilitate recovery.

A little planning and awareness can greatly decrease the chances of altitudesickness. Recognizing early symptoms can result in the avoidance of moreserious consequences of altitude sickness. The human body is a complexbiochemical organism that requires an adequate supply of oxygen to function.

The ability of this organism to adjust to a wide range of conditions is atestament to its survivability. The decreased partial pressure of oxygen withincreasingaltitude is one of these adaptations.

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