SICKNESS[RX] AT ALTITUDE

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PREDICTED SICKNESS ASSOCIATED WITH ALTITUDE

The best "Plans of Mice and Men" are predictably spoiled when exercise at altitude spins its nauseous entangling web, converting an anticipated *personal best* into a DNF or laborious *personal worst*! Nearly half of all athletes ascending to 8,000-14,000 ft. altitude experience headache, malaise, and decreased appetite. This is "*Sickness at Altitude*." Since elevation gain predictably induces sickness associated with altitude, the cause and the cure for managing these symptoms in order to reduce their effect on performance is a real and present concern. The preventatives discussed are *time* required for the body to adapt to less oxygen, adequate *hydration*, sufficient *carbohydrates*, *pace-associated calorie expense*, *devices* utilized to monitor or reduce altitude-associated edema, oral preventative *medication*, or over-the-counter *NSAIDS* (e.g. analgesics such as ibuprofen, aspirin).

WHY ALTITUDE CAUSES SICKNESS

Oxygen content at sea level is 21% at a barometric pressure averaging 760 mm Hg, but as altitude increases to 12,000 feet (3,658 meters) the barometric pressure drops a whooping 37% to 480 mm Hg. This means that the number of oxygen molecules per breath is reduced as the oxygen pressure drops just fewer than 40% less oxygen per breath. Oxygen deprivation forces an increased breathing rate. Extra breaths increase oxygen in blood, but never quite as high as PO_2 at sea level. Since the amount of oxygen required for energy is constant, the body must adapt to producing energy with less oxygen. At high altitude, fluids leak out of capillaries vessels into the lungs and brain tissues due directly to less PO_2 pressure. Continuing on to higher altitudes without time-assisted acclimatization may produce in a life-threatening illness. Excess levels of fluid accumulation results pulmonary or cerebral edema. Symptoms brain or lung edema is characterized by shortness of breath, cough, headache, confusion, and hallucinations. Either form of edema may deteriorate resulting in comatose, then death. Therefore the early warning symptoms of altitude-associated edema may result in a medical emergency that can be prevented. What is the preventative resolution? Immediate descent to lower altitude, administration of oxygen, and medical attention are mandatory. Onset of symptoms means to descend, do not ascend to higher altitudes. Prescription medication taken in anticipation may prevent or reduce the severity of altitude sickness. Headaches treated by prescription *Acetazolamide* alter the acidity of the blood and stimulate increased breathing rate. This drug also produces diuresis, which reduces capillary leaking or pockets of accumulating fluid (edema) in the lungs and brain. People using this drug urinate more frequently and need to constantly remind themselves, "hydrate, hydrate, hydrate!" Dehydration from thin dry air at altitude means extra fluids and electrolyte intake will combat losses.

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[1] Director Research & Product Development EMG 1-800-336-1977.

Dehydration always produces electrolyte deficiency and imbalances from either frequent urination or heavy sweat loss.

PREVENTATIVE & MONITORING DEVICES

Once mountain sickness is experienced, it will likely reoccur during subsequent altitude exposure. Nevertheless, treating reduced oxygen saturation levels can prevent altitude sickness. Finger pulse oximeters (below left) are noninvasive instruments that measure the oxygen content of arterial blood and heart rate. They detect altitude problems early and may be used to monitor an athlete's blood gases during Gamow Bag treatment. The "Gamow Bag" is a zippered bag (below right), which the person sick climbs into while persons outside the bag pump ambient air to a pressure reading of 2 lbs/sq in. It requires from 2-6 hours to relieve symptoms. The readings vary but provide information related to the individual's acclimatization and if the body's rate of adapting to altitude. This information can then be used as necessary, to decide if the athlete should continue the ascent, or descend for safety and health reasons. Prevention, early recognition (by finger pulse Oximeter), descent, or periodic periods spent in a Gamow Bag presents resolution of altitude sickness[2].

NONIN FINGER PULSE OXIMETER ↓ **GAMOW BAG ↓**

BLOOD SATURATION O_2 **FOOT PUMP ↑**

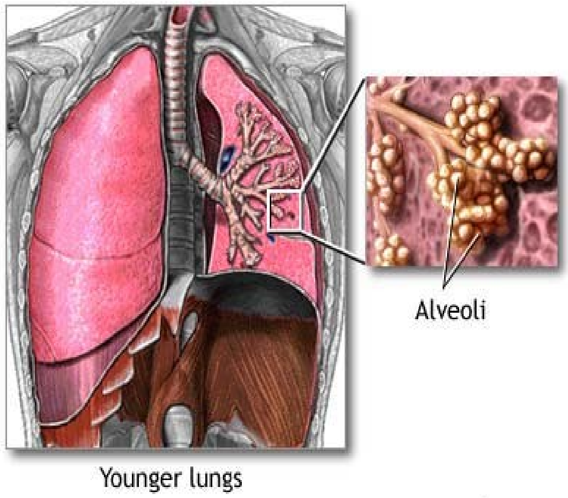
[2] By permission, courtesy of Chinook Medical Gear, Inc., 120 Rock Point Drive, Unit C, Durango, CO 81301, Phone: 970-375-1241, Toll Free: 800-766-1365.

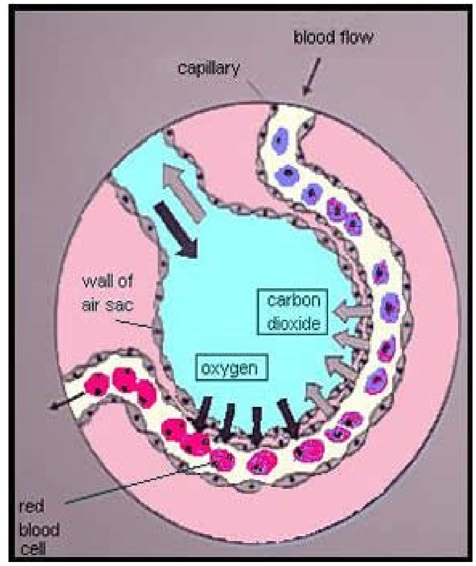
ACID-ALKALI CHEMISTRY AT ALTITUDE POORLY UNDERSTOOD
Author Jane Wilson Howarth believes altitude sickness is complex and not well understood[3]. She claims that acute mountain sickness (AMS) is caused by a failure of the body's biochemistry to maintain the correct balance of acid and alkaline in the blood, which in turn is necessary for controlling breath rate and crucial fluid balance. The acid/alkali balance is normally controlled by the concentration of carbon dioxide in the blood; thus the body's drive to breathe is controlled by build up of carbon dioxide (rather than a deficit of oxygen). At sea level this ensures that individuals breathe in enough oxygen, but at altitude, carbon dioxide is more soluble and the amount in the blood needs to be higher before its concentration is high enough to stimulate a higher breathing rate. Everyone needs to breathe faster at altitude so that adequate oxygen is extracted from low O_2 saturated air. Despite this, the carbon dioxide's drive to breathe mechanism initially lags behind our body's requirement for oxygen. When oxygen supplies to the brain are not maintained, headaches and confusion begin. A headache is the first sign of slight brain swelling.

MECHANICS OF AIR EXCHANGE
Professor Seiler explains, "The lung's challenge is to mix air and blood thoroughly and rapidly so that gas exchange can occur. Here comes another analogy. Take a gallon bucket of paint sitting with the lid open. It takes days and days for a bucket of paint to dry out. But, if we spread the paint as a very thin layer over a very large wall, it will be dry in no time. By spreading the paint out, the total area of exposed surface between the paint and the air is increased thousands of times and the water in the paint quickly evaporates. At any given instant at rest, the lungs spread about 70 ml of blood (less than half of the volume of a coke can) in a "sheet" of capillaries with a total surface area of 70 square meters. That is like spreading a gallon of paint thin enough to paint a football field! The capillaries are so narrow that the red blood cells actually have to squeeze through. This also insures that the gas exchange across the red blood cell and capillary membranes is lightning fast. Simultaneously the lungs move the inspired air down a system of 23 branches of air passages terminating with about 300 million tiny spherical alveoli that form the terminal exchange tissue in the bronchial system. These two exchange systems, the alveoli for air, and the capillaries for blood, are intertwined so microscopically close that oxygen and carbon dioxide molecules diffuse across the membranes and equilibrate almost instantaneously. Blood passes through the capillaries in about 0.8 seconds at rest and as little as 0.4 to 0.5 seconds during hard exercise. It is during this very brief exposure period that all the gas exchange between each red blood cell and the air in the lungs must take place before each return trip to the body!

HEALTHY LUNG ALVEOLI **O2 EXCHANGE IN CAPILLARIES[4]**

[3] Howarth JW, *BUGS, BITES, AND BOWELS*, Cadogan Books, London. 2nd edition (August 1999), 90-96.
[4] By permission, courtesy of Professor Stephen Seiler Ph.D. The Institute for Sport, Agder College, Kristiansand, Norway @: http://home.hia.no/~stephens/index.html





Though after a few days at altitude, the body's adaptive mechanisms turn on and the symptoms are reduced. Enzymatic and hormonal changes return breathing rate to a normal slower rate. Howarth calls this "adaptive acclimatization[5]." The higher the altitude, the longer it takes to adapt. Understanding the adaptation process and the things that you can do to "help it go away" make for a less taxing transition. A number of physiologic changes occur to allow for acclimatization at high altitude. These are divided into *immediate* changes, requiring several days, or *long term* changes, requiring a few weeks to a few months.

The first thing that happens at altitude is respiratory rate and heart rates speed up. This occurs both at rest and during sub-maximal exercise. This is the body's method for offsetting the lower pressure of oxygen than it is acclimatized. An athlete above their normal oxygen pressure environment will not be able to reach their maximal oxygen uptake (VO_2 Max) level. A faster breathing rate changes the acid-base balance, which takes the human body time to correct.

BLOOD-GAS TRANSPORT: DELIVERING OXYGEN TO THE MUSCLES

Now let's think about how the blood fits into all of this. Blood serves several important functions during exercise (heat removal, deacidification, glucose delivery, hormone communication to name a few), but the one I want to focus on is its role as a delivery truck for oxygen. About 40 to 50% of the total volume of blood is made up of red blood cells (RBCs). For example, if your "hematocrit" is 43, then 43% of your total blood volume is RBCs. More than anything else, RBCs are just tiny, flexible sacks of hemoglobin. Each RBC contains hundreds of hemoglobin molecules, and each hemoglobin molecule has room to carry exactly 4 oxygen molecules. The word "carry" means "bind.". There is some very fancy chemistry going on here that we would be in deep trouble without, but I will not try to explain it other than to say that hemoglobin molecules are engineered to hold on to oxygen tightly enough to carry it out of the lungs, but loosely enough to release it in the

[5] Ibid.

capillaries feeding the skeletal muscles (and other organs of course). This whole process is designed to function best when the atmospheric pressure is near sea level. At 1500 meters elevation or more higher, the system begins to break down, and hemoglobin leaves the lungs without a full load of oxygen. This is why it is more difficult to breathe and exercise at altitude.

The capacity for blood to deliver oxygen can be summed up using an equation:

Hemoglobin concentration X oxygen binding capacity of hemoglobin (ml O2/g hb) X percent saturation of hemoglobin = oxygen carried in a given volume of blood.

Hemoglobin concentration is expressed in grams of hemoglobin per deciliter of blood (g/dl). Typical values range between 12-14 for women and 14-16 for men. The binding capacity of hemoglobin for oxygen is a constant and equals 1.34 ml O2/g hemoglobin. Finally, the percent oxygen saturation of hemoglobin when it leaves the lungs is normally about 96% (it is not 100% largely because the lung tissue has its own blood supply and this small volume of deoxygenated blood mixes in with the fresh stuff).

So, for an average person with hemoglobin of 15, the oxygen volume contained in each liter of delivered blood will be:

15g/dl x 1.34 ml O2/g hgb x 0.96 saturation (x 10dl/l) = 193 ml O_2/ liter blood.

If we substitute in 12 for the hemoglobin concentration (someone with anaemia) and 18 (a very high value occasionally seen in trained athletes at high altitude), we see that for the same cardiac output, the volume of oxygen carried by the blood would vary between 154 and 232 ml per liter, depending on the hemoglobin value. It is not hard to see how the blood oxygen carrying capacity affects the VO_2 max. Remember, the muscles can only use what the heart can deliver. If hemoglobin concentration is higher, the blood can carry more oxygen. This is an important point with relevance to altitude training, illegal EPO use, gender differences in VO2 max, anaemia etc. (*Seiler notes here that there is a downside to increasing hemoglobin concentration in the blood and that is increased blood viscosity. The body normally maintains an appropriate balance. If the blood becomes too thick, flow resistance increases and the risk of blood embolism increases, hence the dangers of EPO use.*) Second, when the blood leaves the lungs it is normally fully saturated with oxygen. This means that the lungs are very effective at ventilating the blood, even in untrained folks. This is one of the reasons why in the big scheme of things we basically disregard lung function as an area for improvement in the athlete's endurance machine[6].

How long will it take to adapt to altitude?

HIGH ALTITUDE SICKNESS AFFECTS HUMAN PERFORMANCE

The underlying problem with high altitude (>2000 m) is that there is less oxygen and while this may not be that threatening to individuals at rest it presents a

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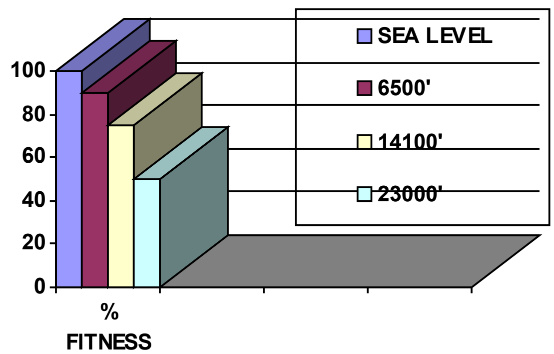
[6] By permission, courtesy of Professor Stephen Seiler Ph.D. The Institute for Sport, Agder College, Kristiansand, Norway @: http://home.hia.no/~stephens/index.html

physiological challenge to athletes. For a pure anaerobic sprinting, little or no adaptation is required, but endurance events proportionate to rate of pace and distance demand adaptation to less oxygen per breath. Being super fit does not guarantee exemption; it may be a hindrance, because fitter athletes ascend faster increasing the risk of mountain sickness onset. Athletes trying to prove a competitive edge find themselves sick early in an event while fit middle-aged lesser-fit athletes adapt better employing a moderate rate of ascent. Sharkey reported research[7] suggesting altitude limitations on exercise rates were based on barometric pressure-PO^2 in air-PO^2 in lungs-arterial O^2 saturation:



As altitude increases, fitness level decreases according to decrease oxygen saturation of higher altitude air.

PREVENTION TIPS...SLOW DOWN, RAISE ADAPTIVE EPO EFFICIENCY

Howarth suggests, "The only way to avoid it is to allow plenty of time for acclimatization and if you notice any symptoms, stop or at least slow down the ascent. A recommended safe rate of ascent is to take several days to reach 3500m(11,000 ft), and then a further week to reach 5500m (18,000ft). This is an average ascent or a rate of about 300m per day, but take rest days and pace yourself according to the slowest member of the party. Even at this rate, not everyone will be able to go high. Many people are too impatient to ascend at this rate, or it may be that accommodation or terrain make it difficult to slow down."[1] There exists a wide variation between how one individual responds to altitude stress and another reacts unfavorably. Moderate-altitude living (2,500 m), combined with low-altitude training (1,250 m) (i.e., live high-train low), results in a significantly greater improvement in maximal O2 uptake (VO2 max) and performance over equivalent sea-level training. To determine what factors contributed to this variability, 39 collegiate runners (27 men, 12 women) were retrospectively divided into 17 responders and 15 no responders to altitude training on the basis of the change in sea-level 5,000-m run time determined before and after 28 days of living at moderate altitude and training at either low or moderate altitude. Responders displayed a significantly larger increase in erythropoietin (EPO) concentration after 30 hours at altitude compared with no responders. After 14 days at altitude, EPO was still elevated in responders but was not significantly different from sea-level

[7] Sharkey BJ, *PHYSIOLOGY OF FITNESS*, Human Kinetics Publishers, Inc., Champaign, Ill., 1984: 196.

values in no responders. The EPO response led to a significant increase in total red cell volume and O2 max in responders; in contrast, the no responders failed to increase total red cell volume or O_2 max after altitude training. No responders demonstrated a significant slowing of interval-training velocity at altitude and thus achieved a smaller O2 consumption during those intervals, compared with responders. The acute increases in EPO and O2 max were significantly higher in the prospective cohort of responders, compared with no responders, to altitude training[8].

After a 28-day altitude training camp, a significant improvement in 5,000-m run performance is, in part, dependent on:

(1) Living at a high enough altitude to achieve a large acute increase in EPO, sufficient to increase the total red cell volume and O2 max
(2) Training at a low enough altitude to maintain interval training velocity and O2 volume near sea-level values

How are these EPO adaptive mechanisms reproduced?

EPO ADAPTATION

Long-term changes in EPO occur only with gradual altitude exposure:

(1) Decreased maximum cardiac output per heartbeat and reduced maximum heart rate
(2) Increased number of red blood cells
(3) Excretion of base alkaline donors controlled by the kidneys restore acid-base balance (The net result is better tolerance for lactic acid)
(4) A red blood cells' chemical change that makes them more efficient at unloading oxygen to the tissues
(5) An increase in the number of mitochondria and oxidative enzymes The rate EPO adaptation is highly individual noting this is a factor of time

PRACTICAL APPLICATIONS MINIMIZE ALTITUDE SICKNESS[9]

(1) DIET - A high carbohydrate, low salt diet stimulates physiological adaptation and lowers the risk of "Altitude Sickness." Some people experience significant decline in appetite resulting in loss of muscle. Iron is used to make oxygen-carrying hemoglobin. To make red blood cells our body requires iron-adequate foods. Most of us consume adequate levels of iron though females and vegetarians may lack the Vitamin B-12, Folate and Iron to make red blood cells at an increased rate for the blood's oxygen carrying needs at altitude.
(2) FLUIDS - Because mountain air is cool and dry you can lose a lot of water, be sure to maintain adequate hydration. Electrolytes should be added in moderately proportionate to fluid loss.

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[8] Chapman RF, Stray-Gundersen J, Levine BD. Individual variation in response to altitude training. J Appl Physiol. 1998 Oct;85(4):1448-56.

[9] By permission, courtesy of Dr. Mark A. Jenkins, M.D. @: http://www.rice.edu/~jenky

(3) AVOID ALCOHOL - It is best to avoid alcohol consumption during the acclimatization period, since it appears to increase the risk of "Altitude Sickness."

(4) RATE OF EXERCISE – Pace rate must be kept slow and easy until adaptation occurs. Pushing too hard may increase the risk of altitude sickness, dehydration, or pockets of lung or brain edema. Some athletes lack EPO levels to immediately adapt. No single training protocol works for everyone at altitude or sea level. Athletes should log their perceived rate of fatigue (not timed distances), during and after workout, morning resting heart rate, weight, and mood. These are then correlated actual intensity of workouts and to mold a flexible routine that employs setting exercise rate by "listening the body." The rate of exercise should be kept easy in order to support the desired adaptive cellular mechanisms onset as opposed to "pushing the envelope" and inhibiting results.

(5) ***SLOOOOOOW DOWN***[10] **The body's adaptation to high altitude helps significantly but doesn't fully compensate for the general lack of oxygen. There is a drop of 2% in VO2 Max for every 300 meters elevation above 1500 meters, even after allowing for full acclimatization. To fully appreciate this realizes that there aren't any world record times at high altitudes. Think about this for a moment. The air density and wind resistance is much lower. Wind resistance is the cyclist's biggest barrier to speed. If all other factors were equal, then there would be faster times at higher altitudes. Because there aren't, meaning that something else must have decreased. That something is the engine -- the human oxygen engine --telling us to slow down while it changes its cellular response to an oxygen-deprived environment.**

(6) ***NSAIDS*** **The symptoms after induced may be treated with over-the-counter aspirin, ibuprofen, or anti-inflammatory supplements such as MSM, glucosamine sulfate, chondroitin sulfate, boswellia serrata, devils claw, yucca root, or UC II. The use of these substances to reduce altitude-associated sickness is limited but has been reported anecdotally to reduce symptoms in endurance athletes.**

CONCLUSION

While it would seem reasonable to slow down when oxygen saturation volume is reduced due to the thin air at altitude, very few athletes possess the ability to restrain their competitive instincts to perform well. Fluid intake needs to be up to 30 fluid ounces per hour, including electrolytes (3-6 Endurolytes) per hour in divided dose in an isotonic solution containing between 240-280 calories. Acclimatizing to a given altitude for 10-14 days is ideal. If this is not convenient, the athlete is advised to show up the day the event starts in order to avoid performance-inhibiting gradual onset of pulmonary or cerebral edema that occurs prior to completing the ideal 10-14 days acclimatization. The athlete's physician in anticipation of cerebral or pulmonary edema may determine the prescription drug Acetazolamide.

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[10] SEE: Outdoor Action Guide to High Altitude: Acclimatization and Illnesses http://www.princeton.edu/~oa/safety/altitude.html

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