A Practical Approach to Altitude Training

Edmund R. Burke, Ph.D.
Director Exercise Science
University of Colorado at Colorado Springs

Over the last few decades many athletes and coaches have used altitude training in various forms to help improve an athletes performance both for competing at altitude and at sea level. The traditional approach was to move on a permanent basis to an area, which afforded an increased altitude (1,880 to 2,000 m/5,000 to 6,000ft) and adequate terrain to allow the athlete to train in their particular sport.

Communities, such as Boulder and Colorado Springs, CO, and Flagstaff, AZ, became popular training and residence sites for athletes to take advantage of the hypoxic (low oxygen) environment, climate, and training terrain.

However, this approach is not always feasible or affordable for most athletes to consider. Many individuals because of family, their profession, or schooling cannot take advantage of a permanent move to such training environments. Some athletes have used the concept of going to such sites for several weeks on a periodic basis during one's training cycle. This approach also leads to tremendous expense and logistical problems.

In the mid 1990's a new theory of altitude training began to become popular because of its scientific basis and ability of athletes to maintain quality/intensity training that is often compromised will training at altitude.

Several coaches and athletes now base their altitude training programs on the living high and training low hypothesis, whereby athletes live and recover at moderate altitude (2,500 m / 8,200 ft) but train at lower altitude or sea level. The rationale behind this hypothesis is that physiological benefits are attained by living at moderate altitude, while workout volume and intensity are maintained by training at a lower altitude (below 1,250 m / 4,100 ft).

Drs. Ben Levine, Jim Stray-Gundersen, Heikki Rusko and Dick Telford have conducted most of the research on the living high and training low hypothesis. Data collected by these scientists on collegiate distance runners and other athletes who completed several weeks of living high and training low training demonstrated the following results:

- Faster 5-kilometer run time.
- Improvement in maximal aerobic capacity.
- Improvements in critical blood markers.
- Lower submaximal heart rate and lactate.
- "Altitude effect" lasted for 2 weeks after returning to sea level.

LITERATURE ON THE EFFECTS OF LIVING HIGH, TRAINING LOW

Recently, Drs. Arnie Baker and Wil Hopkins, conducted a review of the literature on the effects of living high and training low on subsequent sea-level performance (1998). Here is their summary of some of these studies.

One group of researchers studied athletes who lived and trained at altitude but breathed oxygenenriched air during hard training to simulate training low. Five studies involved athletes living on a mountain at 2,500 m and descending to 1,250 m on most days to train. In the other two studies, the athletes trained at sea level but got altitude exposure equivalent to 2,200-3,000 m by spending most of the time in a "nitrogen house" flushed with air containing more nitrogen and less oxygen than normal. The average athlete in almost all of these studies showed an improvement in endurance performance within the first week of return from altitude, and in most studies the improvement was definite.

The only researchers to look beyond a week are Levine and Stray-Gundersen (1997), with a group of runners. After several weeks, the athletes in the high-low group showed a trend towards further improvement, the average improvement relative to performance before altitude exposure is probably 2-3%.

Drs. Baker and Hopkins go on to explain that the average athlete can expect an enhancement of performance of a few percent from living high and training low, but it is now clear that some athletes get an even bigger boost, while others may get no benefit at all. Chapman et al. (1998) have analyzed these differences between athletes, using data for sub-elite runners from several previous studies as well as data from a new group of elite runners. They classified the sub-elites as non-responders (no improvement in performance of a 5000-m run 3 days after return from altitude) or high responders (better than the average improvement of 1.4%). Of 26 sub-elites who lived high and did at least their high-intensity training at a lower altitude, 31% were nonresponders and 54% were high responders. The new group of 22 elite runners, who did their high-intensity training low but otherwise lived and trained high, had a similar average improvement (1.2%) and comparable proportions of non-responders (23%) and high responders (41%). In contrast, of 13 athletes who lived and trained high, 54% were non-responders and only 23% were high responders. These data reinforce the advantage of living high and training low over the traditional high-high training. What's more, the true differences between the proportions of non-responders in each group are likely to be somewhat greater for two reasons. First, they are based on a test performed within a few days of return from the altitude camps, when the athletes had either not re-acclimatized to the Dallas heat or had not recovered from the detraining effect of reduced training intensity. Second, the usual 1-2% variation in an athlete's performance between tests will tend to smear out the true differences in proportions of responders and non-responders.

What accounts for the individual differences in the response to altitude exposure? There's always been a concern that better athletes might respond less because they might have less headroom for improvement, but that's clearly not the case here. Previous work by the Dallas group had identified inadequate iron stores as a contributing factor (Stray-Gundersen et al., 1992): extra iron is needed for the increase in production of red cells stimulated by exposure to altitude. But in their more recent work, all athletes had been given iron supplements to offset any iron deficiency. The authors could not identify any other blood test, lab test, or physical characteristic that would help predict which athletes were more likely to benefit from an altitude camp. There were clear differences after the camp: the high responders had a greater and more sustained increase in the concentration of erythropoietin, and they also ended up with a substantial increase in volume of red blood cells and in maximum oxygen uptake.

These differences between responders and non-responders show that the mechanism of enhancement of endurance performance is probably an increase in the capacity to transport oxygen to the muscles. The differences also provide a strong argument against the possibility that the enhancement in performance is due entirely to a placebo effect, whereby athletes are motivated to perform better through knowing they have had a special treatment that is supposed to work. Differences in performance due entirely to a placebo effect are most unlikely to be associated with changes in a physiological variable, especially when the athlete isn't aware of the changes.

According to scientific research reported above and studies sponsored by the U.S. Olympic Committee living at high altitude and training at low altitude provides improvements in speed and endurance. That's because your body adapts to altitude by increasing the blood's oxygen carrying capacity, as well as your ability to use that oxygen. And that helps you go faster, longer and more efficiently at any elevation, from sea level to high altitude.

PHYSIOLOGICAL EFFECTS OF ALTITUDE

The well-documented physiological effects of altitude include:

- Increased natural hormone erythropoietin (EPO) production, which in turn increases red blood cell mass for delivering oxygen to muscle cells and converting it into energy.
- A boost in total blood volume to move oxygen more efficiently through your bloodstream.
- An increase in V02 max-the maximum amount of oxygen the body can convert to work, giving you more stamina for the long haul.
- Cranked-up hematocrit levels to provide a greater percentage of cells carrying oxygen.
- Elevated capillary volume, creating more blood pathways to muscle cells for improved muscle oxygenation.
- A higher volume of mitochondria--the powerhouses in cells that help your body turn oxygen into energy.
- An increase in the lungs' ability to exchange gases efficiently - so that every breath you take more oxygen gets into the bloodstream.

As with either permanently moving to moderate altitude or taking periodic trips to altitude this approach also has it logistical problems. The ability of someone to move and live to a place such as Park City, UT., and periodically train at a lower altitude such as Salt Lake City, has much of the drawbacks financially and logistically as was the original practice of moving to altitude.

The main problem is a shortage of suitable high altitude training venues, so for most athletes this option means the expense and stress of international travel and of living away from home for up to a month. Loss of heat acclimatization may also be a problem if the high and low training venues are too cool.

ARTIFICIAL ALTITUDE ENVIRONMENTS

In an effort to reduce the financial and logistical challenges of traveling to altitude training sites, scientists and manufactures have developed artificial altitude environments that simulate the hypoxic conditions of moderate altitude.

HOW IT WORKS

While you are sleeping in the thin air inside your high altitude environment, reduced quantities of oxygen diffuse across your lungs' walls into the blood. Once this modestly oxygenated blood reaches your kidneys, special kidney cells sense the lower than-normal oxygen levels and stimulate the production EPO. EPO journeys through the blood stream to the bone marrow, where it steps up the production of red blood cells. The number of red cells in your blood gradually increases, and repeated sleeps in your high-altitude bedroom eventually leave you with blood as viscous as a high altitude native's. Your blood's oxygen-carrying capacity is up, and you've become a better runner the easy way - by "training" while you sleep.

Here is a listing of the altitude training devices and procedures being used to increase one's red blood cell mass and endurance capacity in addition to "live high, train low" and training at altitude:

Nitrogen House/Room

The nitrogen house is located in Finland and was built because of that country's lack of an altitude-training site. The nitrogen house is a standard-sized living structure that simulates the reduced oxygen level conditions of 2,500-m (8,200-ft) altitude by maintaining the air inside the house at higher levels of nitrogen and lower levels of oxygen in the house. Research conducted by Finnish sport physiologist Heikki Rusko on six elite cross-country skiers suggests that training in the nitrogen house is just as effective as training at altitude. Specifically, Dr. Rusko found that changes in critical blood markers, submaximal heart rate, and submaximal. Lactate were similar among athletes who trained in the nitrogen house compared to athletes who trained at an altitude camp (Rusko, 1996).

A nitrogen house can be built almost anywhere as a fixed or mobile facility. It may be the most cost-effective way to deal with teams of athletes. Athletes will have to tolerate living in a dormitory environment away from home.

Supplemental Breathing of Oxygen During Exercise

Supplemental oxygen is used to simulate either normoxic (sea level) or hyperoxic conditions during high-intensity workouts at altitude. This method is a modification of the 'high-low' strategy, since athletes live in a natural terrestrial altitude environment but train at 'sea level' with the aid of supplemental oxygen breathe in by mask during exercise. Limited data regarding the efficacy of hyperoxic training suggests that high intensity workouts at moderate altitude (1,860m/6,100ft) and endurance performance at sea level may be enhanced when supplemental oxygen training is utilized at altitude over a duration of several weeks (Morris, 2000).

Certain sports such as swimming and team sports would find it impossible to train with supplemental oxygen.

Brief Exposures to Intermittent Hypoxic Exposure

Several devices are available that allows one to breath oxygen-depleted air through a face mask for an hour or two, several times a day. The air has an oxygen content of 10-12%, equivalent to approximately 5,000 m (17,000 ft).

Intermittent Hypoxic Exposure (IHE) is based on the assumption that brief exposures to hypoxia (1.5 to 2.0 hours) are sufficient to stimulate the release of EPO, and ultimately bring about an increase in RBC concentration. Athletes typically use IHE while at rest, or in conjunction with a training session. Data regarding the effect of IHE on hermatological indices and athletic performance are minimal and inconclusive (Rodriguez, 2000).

Use Erythropoietin (EPO) or Blood Doping

There is no doubt that some top athletes have been taking injections of erythropoietin to get the increase in red blood cell mass that normally accompanies altitude exposure. There are no published scientific reports of its effectiveness with athletes, but non-athletes experienced an enhancement in peak running speed of 17% (Ekblom and Berglund, 1991). Intravenous infusion of extra red cells (blood doping) has a similar effect (Sawka et al., 1996).

However, both strategies are dangerous: the blood becomes so thick that there is a risk of sudden death from blood clotting. In addition, altitude exposure may be more effective anyway, if the increased buffering capacity of muscles that seems to occur with altitude exposure contributes to the enhancement of performance.

Lastly, The International Olympic Committee and practically all sports governing bodies bans the use of EPO.

Hypoxic Tent/Room

A version of a nitrogen house, in the form of a tent, has recently appeared on the market. These tents simulate altitudes of up to 2700 m (9000 ft) and can be modified to simulate up to 4000 m (14,000 ft). The tent is set around a bed or on the floor. The advantages are substantial: it is truly portable; it can be used with little or no disruption of family life, study, or work; and it is easily the best way to establish the altitude and program of exposure that suits the individual. The units are moderately expensive, but comparable to the cost of a trip to a mountain and similar in price to other equipment used by top athletes.

The hypoxic tent system creates an hypoxic environment within the tent via a patented air separation unit that continually pumps low oxygen content air into the tent. Inside the tent the total pressure stays the same, and the oxygen content (%) reduces - so the partial pressure of oxygen is reduced. This allows the user to obtain the advantages of altitude training from any location. It's like having your own portable mountain. A CO_2 scrubber is also used to remove the build up of carbon dioxide being produced by metabolism.

There is also the option of adapting and sealing off a bedroom of one's house into a hypoxic room. This is more expensive than a tent, but affords the opportunity of having a bedroom in one's house set-up as a high altitude environment to not only sleep in, but as an area to spend additional hours during the day reading, working or watching television.

An hypoxic tent or room can be used to assist in the acclimatization process for individuals who live at or near sea level and plan to travel to higher altitude destinations. Skiers, runners, mountain bikers, and non-athletes often travel to higher altitudes and are affected by the reduced oxygen concentration at altitude. By using the system before traveling to higher altitudes, acclimatization can start weeks ahead of time. This produces a more comfortable and enjoyable trip.

Recent research has shown hypoxic tents to be an effect way to use the "sleep high, train low" model of altitude training (Shannon, 2001 and Ingham, 2001).

Altitude Sleeping Chamber

A hypobaric chamber that can simulate altitudes of up to 5,500 m (18,000 ft) and is designed to allow athletes to "sleep high, train low." This device consists of a rigid cylinder little bigger than a person, with windows at each end and a vacuum pump attached. It has been available commercially for several years. Like the nitrogen tent, it can be used at home, but it's too cramped to accommodate a partner. It's also twice the price of a nitrogen tent, less easy to use, and less transportable. It may also be more noisy and uncomfortably warm.

THE PRACTICAL APPROACH TO ALTITUDE TRAINING

Endurance athletes in many sports have recently started using hypoxic tents and rooms as part of their altitude training programs. The practically of this is seen in the ease of using these devices, portability, cost and effectiveness of long term use in releasing EPO, significantly increasing RBC count and improving performance.

Traveling to altitude for training camps, particularly for athletes who are coming from sea level, creates greater than normal stress on the body due to the decreased availability of oxygen in the air. Consequently, training volume and intensity levels must be reduced. This causes a detraining effect that can often negate the positive physiological adaptations that occur as a result of being at altitude.

Unlike the constant hypoxic exposure to living and training in the mountains, the "intermittent" hypoxia of living/sleeping for approximately 10 hours a day gradually adapts the body to perform better not only in a low-oxygen (altitude) environment, but also substantially better in a normal oxygen, or "normoxic," environments of sea level.

The practicality of moving to a high altitude sleeping location and traveling several times per week to a lower altitude to train is also impractical. The cost, time and logistics are beyond the means of most athletes.

Using a hypoxic sleeping devices lets you sleep high and train low wherever an athlete calls home by converting your existing bedroom into a an altitude room. The portability of these devices also allows them to be transported to a university dorm, training camp or competition.

ETHICS OF ALTITUDE TRAINING AND USE OF ALTITUDE SIMULATORS

There is some concern among coaches, athletes and the scientific community that the use of high altitude tents and rooms may be unsafe and unethical for use in sports. A legitimate concern in these days of increased drug use by athletes in many sports.

International governing bodies of sports will declare a sporting practice banned if it causes injury, or it gives the athlete a technological advantage that is too expensive or too new for most other competitors to use. There have been discussion recently as to whether the different methods of altitude exposure are dangerous or offer a technological advantage that should be banned for use by athletes (Baker and Hopkins, 1998).

Nitrogen houses, hypoxic rooms and tents would be dangerous if the simulated altitude was high enough and long enough to raise the viscosity (thickness) of blood to an unsafe level. For example, an individual using a hypoxic tent might set the altitude to high, but so far there have been no reports for banning these devices on the grounds of health, safety or medical incidences.

It also seems unlikely they will be banned as an expensive innovation, because they are no more expensive than the high-tech equipment used in training or performance by many athletes in sports such as cycling, skiing, bobsled, etc.

If they aren't unsafe, are they unethical? No, because you can't ban normal altitude training, so it's unfair to ban a safe practice that makes it easier or cheaper for athletes to achieve the same effect. There is no physiological difference between altitude in a tent or in the mountains - it is the same oxygen level. Recently, the Norwegian Olympic Committee has come forward with a position statement supporting the use of altitude houses falls within the ethical norms which sport follows (Norwegian Olympic Committee, 1998).

Recently Dr. David Martin, physiologist at Australia Institute of Sports gave a summary of his thoughts on the use of altitude training and use of altitude tents for training by athletes.

He states that he and his colleagues at the Australia Institute have read many scientific studies published in reputable journals suggesting that some moderate altitude exposure protocols are beneficial for the elite athletes. The use of a simulated altitude chamber is safe, legal and potentially effective. Many of the coaches and athletes I work with would consider me unethical if I did not do everything in my power (legally of course) to ensure that they were not at a disadvantage at major competitions because they did not use altitude effectively.

Further, he points out that injecting EPO bypasses the stimulus - physiological response association and this is the problem because the stimulus - physiological response association and the genetic and environmental factors that influence this relationship is essentially what training for sport is all about.

The basic goal of training is to use a variety of external stimuli (exercise, environmental conditions, nutritional therapies, etc.) to produce a physiological adaptation.

The key point is that injecting EPO bypasses the training stimulus, and the same goes for taking any other drug. Also, it is easily possible to increase athletes' EPO concentrations beyond their natural limits using an injection. However, an altitude chamber does not do this, although it does make it a lot easier for athletes to increase their EPO levels - just not beyond their natural limits.

In summary, governing bodies are unlikely to outlaw altitude simulation for 4 reasons:

1. Regulations are motivated by a concern for safety. When used properly hypoxic tents/rooms are completely safe and creates no ill side effects.
2. Altitude is a natural alternative to drugs. Many officials at Governing Bodies see altitude simulation as a godsend that improves performance without risk to the athletes' health. Altitude training may supplant the use of illegal and dangerous drugs.
3. Governing bodies seldom like to pass unenforceable regulations. Enforcing a ban on altitude or altitude simulation would be nearly impossible . There are no tests for altitude or altitude simulation. Unless governing bodies institute midnight raids on residences, it would be difficult to enforce a rule that essentially regulates where a person sleeps, or trains.
4. There are no intellectual arguments to distinguish between true altitude and altitude simulation - both work by inducing low oxygen levels in the blood, triggering the body's natural acclimatization response.

SLEEP HIGH, TRAIN LOW EVERYWHERE

Professional and amateur athletes and Olympic Training Centers worldwide use nitrogen houses, or hypoxic rooms and tents to reach peak performance. When it comes to effectiveness, ease of use and ethical considerations they offer the athlete a fair, safe and cost effective altitude training system.

In conclusion, the altitude house can be used to simulate moderate altitude living atmosphere at sea level and to stimulate EPO at sea level in athletes, and the living high and training low approach seems to give all the benefits of altitude acclimatization and seems to have the potential to avoid the problems related to normal altitude training. Finally, these new aspects - the altitude tent and room and the living high and training low approach - seem to provide the best approach for the enhancement of the sea-level performance in athletes.

REFERENCES:

Allan G. Hahn, A G. and Gore, C. J. The Effect of Altitude on Cycling Performance Sports Medicine. 31(7): 533-557, 2001.

Baker, A. and Hopkins, W. G. (1998). Live-high train-low altitude training for sea-level competition In: Sportscience Training & Technology. Internet Society for Sport Science. http://sportsci.org/traintech/altitude/wgh.html

Chick, T.W., Stark, D.M., and Murata, G.H. Hyperoxic training increases work capacity after maximal training at moderate altitude. Chest. 104, 1759-1762, 1993.

Ekblom, B., & Berglund, B. Effect of erythropoietin administration on maximal aerobic power. Scandinavian Journal of Medicine and Science in Sports. 1, 88-93, 1991.

Ingham, E. A., Pfitzinger, P. D, et. al. Running performance following intermittent altitude exposure simulated with nitrogen tents. Medicine and Science in Sports and Exercise. 33(5): S2, 2001.

Levine, B.D., Stray-Gundersen, J., Duhaime, G., et al. "Living high - training low": the effect of altitude acclimatization/normoxic training in trained runners. Medicine and Science in Sports and Exercise. 23, S25 (Abstract 145), 1991.

Levine, B.D., and Stray-Gundersen, J. "Living high-training low": effect of moderate-altitude acclimatization with low-altitude training on performance. Journal of Applied Physiology. 83, 102112, 1997.

Matttila, V., & Rusko, H. Effect of living high and training low on sea level performance in cyclists. Medicine and Science in Sports and Exercise. 28, S156 (Abstract 928), 1996.

Morris, D. M, Kearney, J. T. and Burke, E. The Effects of breathing supplemental oxygen during altitude training on cycling performance. Journal of Science and Medicine. 3(2): 165-175, 2000.
Norwegian Ministry of Sport Steering Committee. Press release. May. 1998

Nummela, A., Jouste, P., and Rusko, H. Effect of living high and training low on sea level anaerobic performance in runners. Medicine and Science in Sports and Exercise. 28, S124 (Abstract 740), 1996.

Nummela, A and Rusko, H. Acclimatization to altitude and normoxic training improve 400-m running performance at sea level. Journal of Sports Sciences. 18, 411-419, 2000.

Rodriguez FA, Ventura JL, Casas M, et al. Erythropoietin acute reaction and hernatological adaptations to short, intermittent hypobaric hypoxia. European Journal of Applied Physiology. 82: 170-177, 2000.

Rusko, H. R. New aspects of altitude training. The American Journal of Sports Medicine. 24(6): S48-S52, 1996.

Shannon, M. P., Wilber, R., and Kearney, J. T. Normobaric-hypoxia: Performance characteristics of simulated altitude tents. Medicine and Science in Sports and Exercise. 33(5): S60, 2001.

Stray-Gundersen, J., and Levine, B.D. Altitude acclimatization/normoxic training (High/Low) improves sea level endurance immediately on descent from altitude. Medicine and Science in Sports and Exercise. 26, S64 (Abstract 360), 1994.

Stray-Gundersen, J., and Levine, B.D. "Living high-training high and low" is equivalent to "living high-training low" for sea-level performance. Medicine and Science in Sports and Exercise. 29, S136 (Abstract 783) 1997.

Sawka, M.N., Joyner, M.J., Miles, D.S., et al. The use of blood doping as an ergogenic aid. Medicine and Science in Sports and Exercise, 28(6), i-viii, 1996 Wilber, R. Current trends in altitude training. Sports Medicine. 31(4): 249-265, 2001