Acta Andina (1995):4:149-152

MEDICAL PROBLEMS OF WORKING AT ALTITUDES OF 4000-5000 m[1]

John B. West, M.D.,Ph.D.

UCSD Department of Medicine 0623-A
9500 Gilman Drive - La Jolla, CA 92093-0623

SUMMARY. Recently there have been increasing commercial activities at altitudes of 4000-5000 m, for example new mines in north Chile. Because the workers come from sea level, altitude intolerance is a major problem. This article addresses three areas: 1) Methods for selecting workers who can tolerate these high altitudes. 2) Optimal scheduling of time between the mine and the home at sea level. 3) Value of oxygen enrichment of room air in some parts of the mine. This last is remarkably effective. At these altitudes, each 1% increase in O_2 concentration (e.g. from 21 to 22%) reduces the equivalent the altitude by about 300 m. Control of the oxygen concentration can be regarded as a further logical step in man's control of his environment.

Key Words: altitude sickness, hypoxic ventilatory response, acclimatization, oxigen enrichment

RESUMEN. Recientemente se ha incrementado las actividades comerciales en altitudes de 4000-5000 m, como por ejemplo, las nuevas minas del norte de Chile. Debido a que los trabajadores vienen de nivel del mar, la intolerancia a la altura se constituye en una problema mayor. Este artículo enfoca tres aspectos: 1) Métodos para seleccionar trabajadores que puedan tolerar estas altas altitudes. 2) Fijación del tiempo óptimo entre la mina y la casa a nivel del mar. 3) El valor del enriquecimiento con oxígeno en algunos ambientes de la mina. Esto último es remarcablemente efectivo. En estas altitudes, cada 1% de aumento de la concentración de O_2 (ej. de 21 a 22%) se reduce el equivalente de 300 m de altura. El control de la concentración de oxígeno puede ser considerado como un siguiente paso lógico en el control del hombre sobre su medio ambiente.

Palabras claves: Enfermedad de altura, respuesta ventilatoria hipóxica, aclimatización, enriquecimiento de oxígeno.

INTRODUCTION

Recently there has been a substancial increase in commercial activities at altitudes of 3500-6000 m. Examples include new mines in north of Chile at altitudes of 4400 to 4700 m. Another example is the telescope facility at Mauna Kea, Hawaii at 4200 m.

Traditionally, high mines in the South American Andes have been worked by indigenous people who have been at high altitude for generations. Recently however, increasing use is being made of workers from sea level. One reason is that some mines require over a thousand workers and there are not enough people in these remote areas. Another reason is that as the mines become increasingly automated, indigenous people may not have the necessary skills to operate the complicated equipment.

Moving from sea level to altitudes of approximately 4500 m causes acute mountain sickness in many people. Tolerance of the altitude often improves after the first two or three days, but the hypoxia of these altitudes reduces work capacity, mental efficiency and sleep quality. There is considerable variability among individuals in their tolerance to high altitude. This paper deals with three challenging areas: 1) Selection of workers who are likely to tolerate the altitude. 2) Schedule of working between high altitude and family at sea level. 3) Oxygen enrichment of room air to relieve the

---

Received December 15, 1995; revised and accepted April 25, 1995.
Presented at the First World Congress on High Altitude Medicine and Physiology. La Paz, Bolivia, September 11 to 16, 1994.
Correspondence to: John B. West, M.D.,Ph.D.
UCSD Department of Medicine 0623-A
9500 Gilman Drive - La Jolla, CA 92093-0623
Telephone: 619-534-4192
e-mail: jwest@ucsd.edu

hypoxia of high altitude.

SELECTION OF WORKERS TO TOLERATE HIGH ALTITUDE

Little is known about predictors of tolerance to high altitude. The best predictor is probably previous experience at high altitude. If someone has been shown to tolerate high altitude well on one occasion, he is likely to do so on another. Conversely, someone who is unable to tolerate high altitude on one occasion is likely to have the same experience on another. Therefore a history of being able to work well at high altitude would be a valuable clue. However, clearly this criterion cannot be used for all workers because otherwise no new people would enter the high altitude pool.

Another possible predictor is the strength of the ventilatory response to hypoxia. This is easily measured at sea level, and there is some correlation with tolerance for high altitude. Schoene (1982) showed that 14 high altitude climbers had significantly higher hypoxic ventilatory response (HVR) than 10 controls. This work was extended on the 1981 American Medical Research Expedition to Everest where it was shown that HVR measured before and on the expedition correlated well with performance high on the mountain (Schoene et al., 1984). Matsuyama et al. (1986) reported that 5 climbers who reached ·8000m on Kangchenjunga had a higher HVR than 5 climbers who did not.

However this correlation is by no means universal. In a prospective study of 128 climbers going to high altitudes, a measure of HVR did not correlate with the height reached whereas the sea level measured V_{02max} did (Richalet et al., 1988). This study also suggested that the heart rate response to acute hypoxia migtht be a useful predictor of performance at high altitude. There have been other studies showing a poor correlation between HVR and performance at extreme altitude (Milledge et al., 1983; Schoene et al., 1987; Oelz et al., 1986).

Another possible predictor is work capacity during acute hypoxia at sea level. The general argument here is that someone who is not able to tolerate acute hypoxia is more likely to be intolerant to chronic hypoxia. There is little evidence for or against this hypothesis. Soviet physiologists used tolerance to acute hypoxia as one of the criteria for selection of climbers for their 1982 Everest expedition (Gazenko, 1987). On the other hand, the changes that occur with acclimatization are so profound that it may be that performance during acute hypoxia is poorly correlated with ability to work during chronic hypoxia.

Another possible predictor is the increase in pulmonary artery pressure during acute hypoxia at sea level. This can be measured in some people non-invasively by Doppler ultrasound. The rationale for this test is that there is a correlation between the development of high-altitude pulmonary edema, and the degree of hypoxic pulmonary vasoconstriction at high altitude (Hultgren et al., 1971). However, since high-altitude pulmonary edema is uncommon in this population, the value of this test is questionable.

The best to determine the possible value of these test of selection of workers is prospective study where the test are correlated with subsequent tolerance to high altitude. The usual way of measuring altitude intolerance is by questionnaries such as the Lake Louise (Hackett and Oelz, 1992). However it may be that in this population, questionnaries may be unreliable because of a worker's perception that if he admits to altitude intolerance, he might lose his job. There are objective measures of altitude intolerance such as quitting work, chest rales as an indication of subclinical pulmonary edema, and mild ataxia as an indication of subclinical high-altitude cerebral edema. However these features will only be seen in people with severe altitude intolerance, and a prospective study based solely on such measurements would be very insensitive.

SCHEDULING BETWEEN HIGH ALTITUDE AND SEA LEVEL

As indicated above, most of the workers in the new mines at high altitude will come from sea level where their families will reside. Designing the optimal schedule for moving between high altitude and sea level is a challenging problem.

The justification for spending several days at a time at high altitude is the advantage gained from acclimatization. Symptoms of acute mountain sickness usually go away after two to four days. The ventilatory response to hypoxia takes 7-10 days to reach a steady state (Lahiri, 1972; Dempsey and Foster, 1982), and therefore it is reasonable to recommend that the working period at high altitude be at least this long. However, other features of high-altitude acclimatization such as the development of polycythemia take several weeks to reach a steady state. On the other hand, the physiological value of polycythemia is unclear (Winslow and Monge, 1987).

Another important question is the rate of deacclimatization. Ideally the workers should not lose all the acclimatization that they have developed at high altitude during their period with their families at sea level. Relatively little information about the rate of deacclimatization is available although some measurements suggest that the rate of change of ventilatory response during deacclimatization is slower than during acclimatization (Lahiri, 1972).

Another factor which affects scheduling is the time required to move from sea level to high altitude and back. In the new mine at Collahuasi in north Chile, it only takes a few hours to reach the mine by bus from the coastal town of Iquique where most of the families are expected to live. However if a worker resides in Santiago, the trip will take over a day.

Although the physiological aspects of scheduling are important, it may be that social factors will be dominant. Experience has shown that miners are reluctant to leave their homes for more that 7 or 10 days, and it is probable that a schedule of 7 days at high altitude followed by 7 days at sea level, or 10 by 10 will be most acceptable.

OXYGEN ENRICHMENT OF ROOM AIR TO RELIEVE THE HYPOXIA OF HIGH ALTITUDE

This is a relatively new development that shows great promise (West, 1995). As pointed out earlier, even after period of acclimatization of several days at an altitude of 4500 m, the severe hypoxia reduces work capacity, mental efficiency and sleep quality. It would therefore be highly advantageous to reduce the degree of hypoxia in some parts of the mine if that were feasible.

The value of small amounts of oxygen enrichment to room air is remarkable. It has been shown that every 1% increase in oxygen concentration (e.g. 21 to 22%) reduces the equivalent altitude by 300 m. The equivalent altitude is that which has the same inspired Po_2 during air breathig as in the oxygen enriched room. Thus at an the altitude of 4500 m at the Collahuasi mine, raising the oxygen concentration of a room from 21 to 26% would reduce the equivalent altitude by 1500 m, and therefore take it down to 3000 m which is easily tolerated. The oxygen would be added to the normal room ventilation and would therefore be part of the air conditioning. We all expect that a room will provide a comfortable temperature and humidity. Control of the oxygen concentration can be considered a further logical step in man's control of his environment.

Oxygen enrichment has become feasible because of the introduction of oxygen concentrators that use molecular sieves. These devices preferentially adsorb nitrogen and thus produce an oxygen-enriched gas from air. They can work continuosly and only need electrical power which is in abundant supply at a modern mine. As a rough indication of the cost of oxygen enrichment, a small commercial device produces 300 L/hour of 90% oxygen with a power requirement of 350 watts and initial cost of about $ 1500. This would be sufficient to raise the oxygen concentration in a room by 3% for one person. It is also possible that liquid oxygen might be economical for a large facility.

There are several areas in a mine where oxygen enrichment might be considered. One would be the director's office or conference room where important decisions are being made. For example, if there is a crisis in the mine such as a serious accident, such a facility would probably result in clearer thinking than the normal hypoxic environment. Another place might be a laboratory where quality control measurements are being carried out. A further possibility is oxygen enrichment of dormitories to improve sleeping quality.

It has been suggested that oxygen enrichment over a long period would reduce the degree of acclimatization to higher altitude. This is probably true but the real issue is working effiency. Everybody would sleep at a lower altitude if they could, and oxygen enrichment of the air in dormitories is simply equivalent to moving to a lower altitude to sleep. It is likely that the improved quality of sleep would improve working efficiency during the following day. Fire hazard is another issue that has been raised. However it can be shown that the fire hazard during this degree of oxygen enrichment at high altitude is less than at sea level because, of course, although the PO_2 is increased, it is still far below the sea level value.

The potencial value of oxygen enrichment can only be proved by careful studies, and it would be simple to do these in a double blind manner. Both psychometric performance and sleep quality should be studied. The result of such a study would be of great interest.

ACKNOWLEDGMENTS

This work supported by NHLBI R01 HL 46910 .

REFERENCES

Dempsey J.A. and H.V. Foster. 1982. Medication of ventilatory adaptations. Physiol. Rev. 62:262-346

Gazenko O.G. Physiology of man at high altitude. Moscow:Nauka, 1987

Hackett P.H. and O. Oelz. The Lake Louise consensus on the definition and quantification of altitude illness. In: Hypoxia and Mountain Medicine, edited by J.R. Sutton, G. Coates and C.S. Houston. Burligton:Queen City Printers, 1992, p. 327-330

Hultgren N.H.,R.F. Grover and L.H. Hartley. 1971. Abnormal circulatory responses to high altitude in subjects with a previous history of high-altitude pulmonary edema. CIRCULATION; 44:759-770

Lahiri S. 1972. Dynamic aspect of regulation of ventilation in man during acclimatization to high altitude. Respir.Physiol. 16:245-258

Masuyama S., et al. 1986. Control of ventilation in extreme-altitude climbers. J. Appl. Physiol.; 61:500-506

Milledge J.S., et al.1983. Cardiorespiratory response to exercise in men repeatedly exposed to extreme altitude. J. Appl. Physiol.; 55:1379-1385

Oelz O., et al. 1986. Physiological profile of world-class high-altitude climbers. J. Appl. Physiolog.; 60:1734-1742

Ritchalet J.-P., et al. 1988. Physiological charactericsof high altitude climbers. Science & Sport; 3:89-108

Schoene R.B. 1982. Control of ventilation in climbers to extreme altitude. J. Appl. Physiol. 52:886-890

Schoene R.B., et al. 1984. Relationship of hypoxic ventilatory response to exercise performance on Mount Everest. J.Appl. Physiol.; 56:1478-1483

Schoene R.B., P.H. Hackett and R.C. Roach. Blunted hypoxic chemosensitivity at altitude and sea level in an elite high altitude climber. In: Hypoxia and Cold, edited by J.R. Sutton, C.S. Houston and G. Coates. New York:Praeger, 1987, p.532

West J.B. 1995. Oxygen enrichment of room air to relieve the hypoxic of high altitude. Resp. Physiol. (In Press)

Winslow R.M. and C.C. Monge. 1987. Hypoxia, Polycythemia, and Chronic Mountain Sickness. Baltimore: John Hopkinns University Press, p. 203