SEVERE INTERMITTENT HYPOXIA: HIGH-ALTITUDE MINES AND TELESCOPES AND THE CASE FOR OXYGEN ENRICHMENT

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RESUMEN: Hipoxia Intermitente: Minas de Altura y Telescopios y Argumentos a Favor del Enriquecimiento del Aire con Oxígeno

Se ha discutido previamente los problemas de la hipoxia intermitente en minas nuevas ubicadas entre 4000 y 5000 m de altura. Hay interés creciente en colocar telescopios en altura, especialmente en el norte de Chile, donde las condiciones de observación son excelentes. En una instalación típica propuesta, el telescopio estará a 5000 m y los trabajadores dormirán a 2500 m, dirigiéndose al telescopio cada día. El enriquecimiento del aire ambiental con oxígeno en las minas y los telescopios muestra un gran potencial para mejorar el bienestar y la productividad de los trabajadores.

Palabras claves: Hipoxemia severa, Calidad del sueño, Función psicométrica, Aclimatación.

RÉSUMÉ: Hypoxie intermittente sévère : Mines d'altitude et télescopes; importance d'un enrichissement en oxygène.

Ont été discutés préalablement les problèmes de l'hypoxie intermittente sévère qui se présentent dans de nouvelles mines situées entre 4 000 et 5 000 m. Il existe un intérêt croissant à installer des télescopes dans des zones de grande altitude, spécialement au nord du Chili où les conditions d'observation sont excellentes. Dans une installation type proposée le télescope se trouverait à 5 000 m, les travailleurs dormiraient à 2 500 m et remonteraient chaque jour sur le site du télescope. L'enrichissement en oxygène de l'air ambiant dans les mines d'altitude et sur les sites des télescopes représente un grand potentiel pour l'amélioration du bien-être et de la productivité des forces de travail.

Mots-clés : Hypoxémie sévère, Qualité du sommeil, Fonction psychométrique, Acclimatation.

SUMMARY: The problems of severe intermittent hypoxia in new mines at altitudes of 4000-5000 m have previously been discussed. There is increasing interest in placing telescopes at high alatude, especially in north Chile, where observing conditions are excellent. In a typical proposed installation, the telescope will be 5000 m and the workers will sleep at 2500 m and commute to the telescope each day. Oxygen enrichment of room air at the sites of the mines and telescopes shows great potential for improving the well-being and productivite of the work force.

Key words: Severe Hypoxemia, Sleep Quality, Psychometric Function, Acclimatization

INTRODUCTION

Recently there has been increasing interest in the physiological and medical aspects of severe intermittent hypoxia associated with high-altitude mines and telescopes. These facilities are typically at altitudes between 4000 and 5000 m though the old Aucanquilcha mine in north Chile is at 5950 m. Often workers commute to the facilities from lower altitudes, sometimes sea level. For example, at the new Collahuasi mine at an altitude of 4500-4600 m, most of the workers will live in Iquique at sea level, travel to the mine by bus for 7 days, and then return to their families at sea level for another 7 days with the cycle continuing indefinitely. The medical and physiological problems associated with this severe intermittent hypoxia are new and not well understood.

Proposed Telescopes at High Altitude

Several telescopes are now planned for high altitude, particularly in north Chile. Observing conditions are excellent, partly because the telescopes will be above so much of the interfering atmosphere, and partly because the atmosphere near the Atacama desert is extremely dry and therefore there is a very low concentration of water vapor which normally absorbs the radiation.

One proposed installation is the National Radio Astronomy Organization (NRAO) radiotelescope which will be situated at an altitude of 5000 m in the Andes of north Chile east of San Pedro de Atacama. At that altitude, the barometric pressure is about 415 torr, giving a PO_2 of moist inspired gas of only 77 torr compared with the sea level value of 149 torr. The plan is for the workers to sleep near San Pedro de Atacama at an altitude of about 2500m and commute each day to the telescope. This will be a formidable project with an investment of $200 million. Other similar installations are being considered by Japan and other countries.

The severe hypoxia of an altitude of 5000 m impairs central nervous system function, reduces the quality of sleep, and limits work capacity. The deleterious effects of hypoxia are reduced somewhat by acclimatization. However workers who are intermittently exposed to severe hypoxia will presumably never acclimatize as well as people who stay permanently at a given altitude. The earlier arrangement of setting up whole towns near facilities at high altitude, such as in Cerro de Pasco and Morococha in Peru, is no longer favored. It is unpleasant for families to live at these high altitudes, children grow more slowly, and in any event it is extremely expensive to set up whole communities together with schools, hospitals, etc. Thus it is likely that the new strategy of commuting with the inevitable exposure to severe intermittent hypoxia is the way of the future.

Potential of Oxygen Enrichment of Room Air

Some of the reasons why oxygen enrichment of room air at high altitude has such potential value have been analyzed previously (1). Briefly, relatively small amounts of oxygen enrichment confer very substantial gains. For example, every 1% rise in oxygen concentration (for example from 21 to 22%) results in a reduction in equivalent altitude of 300 m (equivalent altitude is that which has the same inspired PO_2 value). In addition, improvements in technology allow large amounts of oxygen to be produced relatively cheaply. This can either be done using oxygen concentrators which preferentially adsorb nitrogen and produce an enriched oxygen mixture, or using liquid oxygen itself.

Some of the advantages of oxygen enrichment of room air at high altitude have previously been discussed (1) but some interesting new information is now available. There are now a number of measurements of the arterial PO_2 in lowlanders who have gone to hirh altitude for several days. Typically the arterial PO_2 is lowest during the first day, and it rises by 2-5 mmHg over the next 4 or 5 days. The explanation for the rise is ventilatory acclimatization whereby the alveolar ventilation gradually increases in response to the stimulation from the peripheral chemoreceptors, and the initial inhibiting effects of alkalosis in the blood and cerebrospinal fluid are reduced as bicarbonate is removed from both compartments.

Compilation of the available data show that when lowlanders go to altitudes of 3800 m and above, and stay there for about 7 days, the arterial PO_2 settles out below 55 mmHg. Naturally the PO_2 falls as the altitude increases, and at an altitude of 5000 m, the arterial PO_2 after a few days of acclimatization is typically less than 50 mmHg.

An interesting feature of this degree of hypoxemia is that if it existed in a patient with chronic obstructive pulmonary disease (COPD) it would entitle the patient to continuous oxygen therapy. In other words, the modern management of a patient with severe COPD and an arterial PO_2 of less than 55 includes continuous oxygen therapy by nasal cannulas. Furthermore it has been shown that patients with COPD whose arterial PO_2 is less than 55 mmHg, and who are treated with continuous oxygen therapy, gradually improve their psychometric function (measured during air breathing) over several months (2). Heaton and his colleagues studied both continuous oxygen therapy and nocturnal oxygen therapy in patients with severe COPD and showed that in both instances the "Performance IQ," which is a measure of psychometric function breathing air, improved over the first 6 months, and in the case of continuous oxygen therapy, psychometric performance continued to improve over the subsequent 6 months.

These provocative data show that if workers had their arterial PO_2 reduced below 55 mmHg by COPD rather than living at high altitude, they would be entitled to receive continuous oxygen therapy. Moreover, the therapy would improve their central nervous system function when they were in their hypoxemic state. Given the demanding skills necessary in modern mining with its high degree of mechanization, and also the fact that the frequency of accidents in highaltitude mines is some 3 to 4 times greater than that in mines below 3000 m (Jimenez, personal communication), these data suggest an obligation for oxygen enrichment at high altitude.

Other recent measurements raise very interesting questions about the value of oxygen enrichment in dormitories at high altitude. After initial tests at the Collahuasi mine at 4500 m, an extensive study was carried out at El Tambo mine, altitude 4300 m. The oxygen concentration in the dormitories was raised from a normal value of 21% to about 25%. Sixteen dormitory rooms were used for oxygen enrichment, the oxygen being supplied from a liquid oxygen depot.

Studies of the quality of sleep showed that this improved with oxygen enrichment in that there were fewer apneas, the total time spent in apnea was reduced, there were fewer arousals, and the staging of the electroencephalogram was more like the sea level pattern. These results are hardly surprising because it is common experience that people sleep less well at high altitude than low altitude, and the effect of oxygen enrichment is to reduce the equivalent altitude.

A more provocative finding was that studies of psychometric performance during the day after sleeping in an oxygen-enriched atmosphere showed small but consistent improvements in psychometric performance (Jimenez, personal communication). At first sight this may appear surprising because the oxygen stores of the body are very small and it is difficult to believe that the PO_2 of the brain could be increased some hours later. However, as discussed, there is an improvement in psychometric performance in the COPD patients treated with continuous oxygen therapy (2). In addition, similar findings have been described in patients with disordered breathing during sleep at sea level. For example, Engleman et al. (3) showed that patients with obstructive sleep apnea who were treated with continuous positive airway pressure (CPAP) showed improved daytime psychometric function. Whether this is simply due to less fatigue or whether there is a more subtle explanation is not clear. However in the light of the results found in patients with disordered breathing during sleep at sea level the results at high altitude are not particularly surprlsmg.

The most provocative finding however is that some patients who have slept in an oxygen enriched environment apparently sometimes have a higher arterial PO_2 during the following day (Cantuarias, personal communication). It should be emphasized that this is a very preliminary finding which may or may not stand up to subsequent testing. At first sight it is very difficult to understand how the arterial PO_2 of a worker breathing air during the day could be affected by oxygen enrichment during the previous night. However again a similar finding has been reported in patient with sleep-disordered breathing at sea level. Leech et al. (3) studied 17 patients with obstructive sleep apnea who were treated with CPAP and showed that the daytime arterial PO_2 rose significantly from a mean of 69 mmHg to a mean of 82 mmHg over a period of 3 to 46 months of follow-up. A clue to the mechanism of this was supplied by Berthon-Jones and Sullivan (4) who showed that some patients with obstructive sleep apnea who were treated with CPAP improved their ventilatory response to carbon dioxide. Moreover, the change was seen within 1 or 2 nights of treatment.

It should be emphasized that much more work needs to be done on the physiological responses to oxygen enrichment at high altitude. However the dramatic results in patients with sleep-disordered breathing and consequent arterial hypoxemia at sea level after treatment with continuous positive airway pressure suggest that oxygen enrichment during sleep at high altitude may have a number of beneficial effects.

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