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Periodic breathing and oxygen supplementation in Chilean miners at high altitude (4200 m)

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ABSTRACT

Our objective was to determine the nocturnal ventilatory pattern and characterize the effect of oxygen enrichment on nocturnal ventilatory pattern and sleep quality in miners exposed to intermittent hypobaric hypoxia at 4200 m. A total of 16 acclimatized miners were studied. Nocturnal ventilatory pattern (plethysmographic inductance), arterial oxygen saturation and heart rate (pulse oximetry) were performed in 9/16 subjects. Sleep quality at high altitude was assessed by self-questionnaires in 16/16 subjects. All measurements were performed during at least 7 h of sleep. Subjects were studied while sleeping at high altitude without (control, C) and with oxygen supplementation ($FiO_2 = 0.25$, treated, T). Periodic breathing (%) C: 25 ± 18 vs T: 6.6 ± 5.6 ($p < 0.05$), apneas index (no./h) C: 34.9 ± 24.1 vs T: 8.5 ± 6.8 ($p < 0.05$); and sleep quality C: 17.8 ± 3.4 vs T: 12.1 ± 2.2 ($p < 0.0001$) were evaluated. In conclusion, periodic breathing with apneas was present in miners exposed to high altitude for 1 to 4 years and was reduced by treatment with supplementary oxygen.

1. Introduction

Exposure of humans to the environmental conditions at high altitude has become an increasingly common event. As many as 140 million people live at altitudes at or above 2500 m (Moore, 2001).

Recently, industrial and commercial activities at 3500–5000 m have substantially increased. Mining activities at altitudes above 4600 m are common in Peru and in the north of Chile. In Chile, until 1995 there were around 20,000 workers intermittently exposed to high altitude for a long period of time (Jiménez, 1995) and this number is expected to reach more than 120,000 for 2020 (http://www.fundacionchile.com/archivos/reporteccm31425187.pdf). Chronic intermittent hypobaric hypoxia (CIHH) constitutes a model of hypoxic exposure previously described by several authors (Jiménez, 1995; Jalil et al., 1995; Richalet et al., 2002) in miners that work at high altitude.

Sleep apneas occur during sleep in humans and animals exposed to hypoxia or high altitude (see Wickramasinghe and Anholm, 1999; Küpper et al., 2008). Apneas may appear as low as 2400 m and increase with increasing altitude (Waggener et al., 1984; Bloch et al., 2010) and decrease with acclimatization (Waggener et al., 1984; Goldenberg et al., 1992). The acclimatization process resulting from prolonged exposure to high altitude may also reduce sleep disturbances (Waggener et al., 1984; Goldenberg et al., 1992; Küpper et al., 2008). Furthermore, periodic breathing has a lower frequency in populations living at high altitudes such as Sherpas (Lahiri et al., 1983) and Aymaras (Lahiri and Data, 1992). However, until now there is no evidence that acclimatization in miners with CIHH may affect their ventilatory pattern.

The physiological consequences of initial exposure to high altitude include acute mountain sickness (Hackett et al., 1976; Vargas et al., 2001), deterioration in cognition and motor function (Mac Farland, 1937), impairment of sleep quality with an increase in periodic breathing, increase in awakenings, shorter stage 3 and 4

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sleep; all of which result in low productivity and altered general well-being (Gerard et al., 2000).

A possible way of avoiding the consequences of high altitude hypoxemia would be to reduce the equivalent altitude (altitude which provides the same PO_2 in moist inspired gas during ambient breathing) by oxygen supplementation. This procedure, which mimics the higher partial pressure of a lower altitude, has been shown to have beneficial effects on sleep, neuropsychological function, ventilation and performance in sea level natives acutely exposed to altitude hypoxia (Gerard et al., 2000; West, 1995; Luks et al., 1998; McElroy et al., 2000). However, these studies have been done in subjects with acute exposure to simulated hypobaric hypoxia and geographic altitude; but without experience of CIHH. Therefore, little is known regarding the effect of progressive acclimatization and the effect of O_2 on the ventilatory pattern during sleep at high altitude and sleep quality at 4200 m in this model of exposure. Our objective was to determine the ventilatory pattern during sleep and quality of sleep, as well as to evaluate the effect of oxygen supplementation during sleep in miners with variable experience (1–14 years) of chronic exposure to intermittent hypobaric hypoxia.

2. Subjects and methods

2.1. Subjects

Sixteen subjects living at low altitude (<1000 m) and working in a mine located at 4200 m ("El Tambo", El Indio mine company) were studied. Subjects were operators of heavy machines and had experience with CIHH between 1 and 14 years. Their shift pattern was 7 days of work at high altitude and 7 days of rest at sea level. All subjects were free of cardiovascular, pulmonary, hematological, renal or hepatic disease. This study was done according to the Helsinki guidelines and those of the Ethical Committee of the medical department of the mining company. All subjects gave their written informed consent to participate in the study.

2.2. Facilities

This study was carried out in 10 modified rooms for oxygen supplementation. The concentration of oxygen in the room air was controlled by an oxygen sensor and maintained between 24 and 26%, representing an equivalent altitude of 2700 and 3300 m, respectively (West, 1995). The flow of oxygen and the ventilation of the room was determined in agreement with the procedure describe by West (1995) and Luks et al. (1998).

2.3. Measurements at sea level

Body composition was determined in each participant: weight (kg), height (m), body mass index (BMI) and fat mass index (FMI) from the measurement of skin fold thickness in four locations (Durnin and Womersley, 1996).

2.3.1. Study protocol

Evaluations were performed 48–96 h after arrival to high altitude. Subjects were assigned to sleep in a room with ambient air with or without supplementary oxygen in a random order. All parameters were measured in two conditions:

Control: miners sleeping at 4200 m, without oxygen supplementation in room air.

Treatment: miners sleeping at 4200 m, with oxygen supplementation in room air (FiO_2 24 ± 0.5%). The administration of oxygen in the room was blind to each participant. The evaluations were consecutive, the first night without oxygen and the next night with supplemented oxygen.

2.4. Measurements at high altitude

Nocturnal ventilatory pattern was determined in 9/16 subjects through the measurement of thoracic and abdominal movements using plethysmographic inductance (Respitrace plus, Ardsley, NY USA). Simultaneously, oxygen saturation and heart rate were continuously recorded by pulse oximetry at the ear lobe (504-US Oximeter, Criticare, Waukesha, WI). Data were then transferred to a portable PC and analyzed by the RespiEvents software. Periodic breathing was defined by the presence of cycles of breath followed by an interval of at least 6 s without respiratory movements; central apneas were defined when no thoracic and abdominal movements occurred during at least 8 s (Lahiri et al., 1983). We measured the total sleep time (min) based on heart rate variations (falling asleep corresponded to a drop in heart rate, awakening corresponded to a rise in heart rate), the percentage of time spent in periodic breathing over total sleep time (%), the number of apneas, the apnea index (number of apneas/h), the mean cycle length of periodic breathing (s), and the mean duration of apneas (s). Duty ratio (DR) was used in this study as a surrogate for loop gain (Edwards et al., 2008; Sands et al., 2011; Andrews et al., 2012). This is defined as the duration of the ventilatory period divided by duration of the periodic breathing cycle (hyperpnea/hyperpnea + apnea); an increase in loop gain results in a decrease in DR. Sleep quality was evaluated in 16/16 subjects by a modified Spiegel self-questionnaire in Spanish (Jiménez, 1995; Richalet et al., 2002) on the morning following the night when sleep was recorded. This self-questionnaire evaluated six criteria: How long did it take you to fall asleep?, How long did you sleep?, How many times did you wake up?, Did you wake up before you needed to get up and could you fall asleep again?, How did you feel when you woke up?, How well did you sleep last night? Each criterion was scored from 1 to 5 points and the sum of six criteria was used to define sleep quality. Sleep quality was defined as normal when the sum score was <13 points, regular when the sum score was >13 but <18 points, poor when the sum score was >18 but <25 or very poor when the sum score was >25 but <30.

2.5. Statistical analysis

All results were expressed as mean ± standard deviation. The difference between means was compared by a Student paired t test. A difference was considered significant when $p < 0.05$. Relationship between apneas numbers vs. time experience was obtained by least squares nonlinear regression (Statistica, Statsoft).

3. Results

3.1. Evaluation at sea level

General characteristics of all the subjects were: age 38.6 ± 7.7 years; weight 81.2 ± 5.6 kg; height 1.70 ± 0.04 m; BMI 27.9 ± 1.7 kg/m^2 and FMI 24.9 ± 6.1%.

3.2. Evaluation at high altitude

3.2.1. Nocturnal ventilatory pattern

Nocturnal ventilatory pattern was studied in 9/16 miners. We observed periodic breathing in all subjects with a typical hyperventilation-apnea pattern. Fig. 1 shows a representative record of nocturnal cardioventilatory pattern of one miner that slept without and slept with oxygen supplementation. The panel on the left demonstrates a typical hyperventilation-apnea pattern associated with large oscillations in arterial oxygen saturation and