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Sustained Acclimatization in Chilean Mine Workers Subjected to Chronic Intermittent Hypoxia

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ABSTRACT

Farias, Jorge G., Jorge Osorio, Gustavo Soto, Julio Brito, Patricia Siques, and Juan G. Reyes. Sustained acclimatization in Chilean mine workers subjected to chronic intermittent hypoxia. *High Alt. Med. Biol.* 7:302–306, 2006—We wanted to know if sea-level mine workers exposed previously to chronic intermittent hypoxia reached a steady acclimatization at 36 months under hypobaric hypoxia. An intermittently exposed group of mine workers (IE, $n = 25$) were subjected to submaximal exercise (100 W) at 4500 m. Their systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), and hemoglobin oxygen saturation ($HbSatO_2$) were monitored. Two comparison groups of unacclimatized sea-level workers ($n = 17$) were studied. A nonexposed group (NE) performed 5 min of submaximal exercise at sea level. Some kind of exercise was performed both by an acutely exposed group (AE) and IE group at 4500 m. No statistical differences were found for HR, SBP, and DBP ($p > 0.05$) during exercise between IE and AE groups. Resting $HbSatO_2$ of IE (87 ± 6%) was lower than NE (97 ± 3%) ($p < 0.05$), but was higher than AE (82 ± 4%) ($p < 0.05$). In the exercise condition, $HbSatO_2$ of IE (85 ± 5%) was lower than NE (95 ± 3%) ($p < 0.05$), but was higher than AE (76 ± 2%) ($p < 0.05$). These responses were maintained through the 6 months of the study period. Thus, mine workers subjected to intermittent hypobaric condition for 3 years showed a good degree of acclimatization that was maintained through time.

Key Words: adaptation; stress; cardiovascular response; exercise; oxygen saturation

INTRODUCTION

The main incomes of Chile's workers are obtained in the Andes at high altitude, but the cities are in the plains. In effect, thousands of workers travel weekly to a high-altitude environment, labor for 7 days, and after that rest at sea level. Thus, the workers have to adjust to the requirements of hypobaric hypoxia for some days and then return to sea level. This new model, named the Chilean model or chronic intermittent exposure, has been studied recently (Richalet et al., 2002), and it was found that after 31 months of follow-up some

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acclimatization parameters are stabilized while others are still changing.

Thus, we considered it necessary to know if sea-level mine workers exposed previously to the chronic intermittent hypoxia condition reached a steady acclimatization at 36 months under hypobaric hypoxia.

METHODS

Experimental design

Three groups of male subjects were tested: an intermittently exposed group (IE, $n = 25$) without known disease and a working shift of 7 by 7 during 2.5 yr (7 days at 4500 m and 7 days off duty at sea level) previous to this study. A control group (NE, not exposed to high altitude, $n = 17$) of workers, all working at sea level, with similar age, weight, and body fat mass as the IE group and employed in similar jobs. A third group of 17 sea-level native workers not previously exposed to high altitude (unacclimatized) with similar general characteristics to IE and NE (Table 1) were acutely exposed to 4500 m (AE, acutely exposed group). All individuals participated as volunteers and signed an informed consent in agreement with the Helsinki Declaration. All subjects exposed to high altitude were medically tested with a physical examination previous to the study and were diagnosed as clinically healthy. This study was approved by the ethics committee of the Universidad Arturo Prat.

Anthropometry and body composition

Body weight was evaluated using a balance model BR9702 A (Camry, Taiwan, China). Height was measured with a standard tape graduated in centimeters, and body fat mass was estimated using a hand-held bioelectrical impedance analyzer (Omron BF302, IL, USA).

Incidence of acute mountain sickness

The incidence of acute mountain sickness (AMS) was evaluated with the Lake Louis AMS Scoring Consensus (1993) and was performed at day 4 of the shift work. Scores equal or higher than 4 points were classified as AMS.

Exercise tests and physiological parameters

To test the degree of acclimatization in months 0, 3, and 6, a submaximal exercise test was performed at day 4 of high-altitude exposure (4500 m) by the IE group. In the AE group, the exercise test was performed on day 4 of high-altitude exposure only in month 0. The exercise tests of the NE group were performed in Iquique city (sea level) in months 0, 3, and 6. The perceived intensity of the physical exercise was tested by the Borg scale (Borg, 1970).

The workload of the physical exercise test was 100 W and was performed in a leg ergometer model Recline 600 XTPRO-Cross-Training (Technogym, Gambettola, Italy). After 5 min of exercise, a stabilization of the heart rate (HR), hemoglobin oxygen saturation ($HbSatO_2$), systolic (SBP), and diastolic (DBP) blood pressure was obtained. The HR was evaluated with a monitor incorporated in the ergometer, and the SBP and DBP were evaluated with a digital sphygmomanometer model HEM-608 (Omron, IL, USA). The $HbSatO_2$ was evaluated using a finger pulse oximeter model Oxyn 9500 (Nonin, Plymouth, MA, USA)

Statistics

The groups were compared using an ANOVA test followed by Bonferroni analysis.

TABLE 1. ANTHROPOMETRIC DATA, BODY COMPOSITION, AND INCIDENCE OF ACUTE MOUNTAIN SICKNESS

	Age (yr)	*Weight (kg)*	*Height (cm)*	*Fat mass (%)*	*AMS (score)*
IE ($n = 25$)	34 ± 7	77 ± 5	169 ± 6	27 ± 1	1,1 ± 0,9
AE ($n = 17$)	36 ± 4	77 ± 13	172 ± 5	25 ± 3	3,5 ± 1,49[a,b]
NE ($n = 17$)	37 ± 10	74 ± 7	170 ± 6	26 ± 2	0,4 ± 0,5

Values are means ± SD; n, number of subjects. IE, intermittently exposed group; AE, acutely exposed group; NE, nonexposed group; AMS, incidence of acute mountain sickness.
[a]IE, AE vs. NE and [b]IE vs. AE. Significantly different, $p < 0.05$.

The Kruskal–Wallis test (nonparametric) was used to analyze $HbSatO_2$. In addition, the values of the parameters measured in the three periods (at 0, 3, and 6 months) were compared using a t test for paired data. A $p < 0.05$ was considered a significant difference. The data were analyzed using the GraphPad Prism software v 2.01 (San Diego, CA, USA). The data are presented as mean ± SD.

RESULTS

No statistical differences were found for the three groups (anthropometry and body composition; see Table 1). A perception of moderate intensity was recorded during physical exercise for all the groups according to the Borg index (data not shown). We found a statistical difference ($p < 0.001$) in the AMS score between IE (1,1 ± 0,9) and AE group (3,5 ± 1,49) (Table 1). Also, a statistical difference was found between AE and NE ($p < 0.001$).

The physiological responses to physical exercise, as heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP), were similar among all the groups. This trend was maintained through the 6 months of study (Table 2).

A significant difference for resting heart rate was found between IE and AE groups (75 ± 11 vs. 84 ± 13). Regarding O_2 saturation, significant differences were found both during rest (87 ± 6 vs. 82 ± 4) and exercise (85 ± 5 vs. 76 ± 2) between IE and AE groups. Resting $HbSatO_2$ was lower in the IE and AE workers at high altitude compared to the NE group ($p < 0.05$). $HbSatO_2$ in IE workers was significantly higher than in AE individuals tested under a physical exercise at high altitude, but lower than NE values under physical exercise at sea level (Table 2).

DISCUSSION

The shift work of miners in the north of Chile constitutes a new model of exposure to high altitude, and little is known about their response to high altitude, although a complete longitudinal report of 31 months of intermittent exposure was published by Richalet and colleagues (2002). Their research concluded that a continuous process of acclimatization is going

TABLE 2. PHYSIOLOGICAL PARAMETERS BEFORE AND AFTER THE EXERCISE TEST IN NORMOXIA (NE) AND HYPOXIA (IE, AE)

	Month 0		*Month 3*		*Month 6*	
	Rest	*Exercise*	*Rest*	*Exercise*	*Rest*	*Exercise*
SBP (mmHg)						
IE	118 ± 9	127 ± 10	114 ± 8	128 ± 8[a]	118 ± 12	128 ± 3
AE	119 ± 15	136 ± 18[a,b]	—	—	—	—
NE	115 ± 14	120 ± 13	118 ± 8	124 ± 9	118 ± 9	127 ± 9
DBP (mmHg)						
IE	62 ± 6	77 ± 10[a]	59 ± 14	78 ± 10[a]	58 ± 10	75 ± 9[a]
AE	66 ± 9	74 ± 8	—	—	—	—
NE	62 ± 7	76 ± 9[a]	62 ± 15	75 ± 11[a]	65 ± 9	72 ± 7
HR (beats/min)						
IE	75 ± 11[c]	136 ± 10[a]	72 ± 7	138 ± 7[a]	75 ± 9	139 ± 8[a]
AE	84 ± 13[b]	140 ± 10[a]	—	—	—	—
NE	65 ± 10	131 ± 7[a]	66 ± 9	134 ± 7[a]	69 ± 9	133 ± 5[a]
$HbSatO_2$ (%)						
IE	87 ± 6[b,c]	85 ± 5[b,c]	87 ± 3[b]	86 ± 3[b]	87 ± 5[b]	85 ± 4[b]
AE	82 ± 4[b]	76 ± 2[a,b]	—	—	—	—
NE	97 ± 3	95 ± 3	97 ± 3	94 ± 3	97 ± 2	95 ± 2

Values are means ± SD. IE, intermittently exposed group (n = 25); AE, acutely exposed group (n = 17); NE, nonexposed group (n = 17); SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; $HbSatO_2$, hemoglobin oxygen saturation.

[a]Exercise vs. rest; Significantly different, $p < 0.05$.

[b]IE, AE vs. NE; [c]IE vs. AE.

on, even after 2.5 yr of exposure to intermittent hypoxia.

This study attempts to supply additional information to help define the kind of acclimatization of workers with IE to high altitude. The cardiovascular response to mild physical exercise of individuals during hypobaric or isocapnic hypoxia has been utilized to evaluate signs of acclimatization (Bailey et al., 2000; Katayama et al., 2000). An evaluation of $HbSatO_2$ under submaximal exercise at high altitude appears to be a good indicator of acclimatization in men subjected to hypobaric hypoxia (Huang et al., 1984; Bender et al., 1989; Anholm et al., 1992; Stoneham and Pethybrige, 1993; Gamponia et al., 1998; Sutton et al., 1988; Richalet et al., 2002; Beidleman et al., 2003). Unfortunately, we did not measure minute ventilation.

The AE group showed a statistically higher pulse than the IE subjects, with a difference of 9 beats/min^{-1}. This change could be explained by the fact that the evaluation was performed at day 4 of arrival at high altitude when the effect of catecholamines is stabilized. However, no statistical difference was found in the exercise phase (136 ± 10 in the IE group and 140 ± 10 in the AE group). Mazzeo and colleagues (1994) found that resting heart rates increased initially and then declined steadily after day 4 at high altitude (4300 m).

Cardiovascular, respiratory, renal, and metabolic adjustments triggered by the low oxygen pressure are the first physiological strategies of acclimatization to high altitude (Lipsitz et al., 1995; Vats et al., 1999; Germack et al., 2002; Ledderhos et al., 2002). Later the enhancement in the production of red blood cells improves the oxygen transport capacity from the external environment to the tissues (Richalet and Rathat, 1991; Richalet and Leon Velarde, 1997). Richalet and colleagues (2002) found that hematocrit increased after 12 and 19 months of IE, but returned to values similar to preexposure after 2.5 yr. Because of company restrictions against invasive studies, we did not measure hematocrit.

The IE group showed a score of 1,1 ± 0,9 points in the AMS questionnaire. In the Richalet and colleagues (2002) report, AMS was evaluated during each day of their exposure to high altitude. We compare the AMS score only with day 4 of stay in that research and we see that our data are slightly higher than its results. We found a higher score ($p < 0.001$) in the AMS questionnaire in the AE group (3,5 ± 1,49 points) than in the IE group. The higher O_2 saturation in the IE group than in the AE group is consistent with results of previous research (Richalet et al., 2002).

Mine workers after 2-yr exposure to high altitude did not show significant differences in the cardiovascular response to submaximal exercise between days 1 and 4 of stay at 4500 m, and they showed the typical decrease in $HbSatO_2$ after a mild exercise session of individuals not acclimatized to high altitude (Jalil et al., 1994). Mine workers after 2.5 years of exposure to high altitude (3800 to 4600 m) showed a $HbSatO_2$ higher than mine workers exposed to intermittent hypoxia for 2 yr.

On the other hand, cardiovascular parameters such as mean arterial pressure, heart rate, and $HbSatO_2$ were not completely stabilized after 31 months of exposure to intermittent hypoxia (Richalet et al., 2002). Thus, these data suggest that mine workers after 2.5 yr of intermittent exposure to high altitude show signs of acclimatization that is not completely stabilized in terms of cardiovascular responses (Richalet et al., 2002).

Cardiovascular response under mild physical exercise (100 W) appears to be a good tool to estimate the degree of acclimatization of mine workers. Our results show that $HbSatO_2$ values of the IE group stabilized after 2.5 yr of intermittent hypoxic condition. This stabilization can be shown from the fact that these mine workers maintained their $HbSatO_2$ response to mild exercise for at least 6 months after that period. Furthermore, our results show that the IE workers responded to physical exercise similarly to a nonexposed group in terms of HR, SBP, and DBP. The values of $HbSatO_2$ were similar to previous report on subjects acclimatized to 4000 m (Gamponia et al., 1998). $HbSatO_2$ of IE workers after a mild exercise session did not show the typical decrease seen in individuals not acclimatized to hypobaric hypoxia (Stoneham and Pethybrige, 1993). Furthermore, $HbSatO_2$ and HR were very similar to reference values in schoolchildren and adolescents living at 4100 m (Huicho et al., 2001). At day 4 of altitude exposure the IE group showed a low score of AMS.

In conclusion, our results indicate that mine workers after 2.5 yr of exposure to high altitude and with a 7-day high altitude, 7-day at sea level working shift showed a good degree of acclimatization that was maintained after 6 months of a follow-up period under similar working conditions.

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