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Research

Usefulness of Oxygen at Height Altitude Evaluated by Polysomnography in Mining Workers

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Abstract

Background: Rotary miners who have shifts at high altitudes, with breaks at sea level, are exposed to chronic intermittent hypoxemia. This phenomenon has different repercussions at work, such as increased muscle fatigue and accident risk, impaired memory and ability to calculate, and decreased performance. Therefore, in this study, we assessed how intermittent hypobaric conditions affected the results of split-night polysomnography (PSG) and the usefulness of using oxygen, test carried out at 3200 m above sea level in workers at a mine in northern Chile.

Materials and Methods: In total, 312 patients underwent PSG at the miner camp. A subgroup of 51 patients with split-night PSG was analyzed with oxygen titration between 1 and 3 L/min.

Results: With oxygen therapy, the percentage of REM sleep was increased, whereas arousal was decreased. Additionally, we observed higher minimum oxygen saturation (SpO2; 76.4% versus 83.7%), lower average apnea-hypopnea index (46.5/h versus 7.8/h), average SpO2 that was best at different oxygen levels, and lower average saturation time percentage of 90% (88.4% baseline versus 16.8%).

Conclusion: Changes in PSG patterns with oxygen use could be caused by ventilatory instability related to intermittent chronic hypoxia; thus, low-dose oxygen therapy may be an alternative treatment for sleep apnea.

***Keywords:** polisomnography, mining workers, high altitude, sleep apnea, oxygen*

Introduction

At higher geographical altitudes, all activities require greater amounts of oxygen because height is increased above sea level; thus, barometric pressure, and hence the partial oxygen pressure of the ambient air, gradually decreases, resulting in reduced labor performance [1]. Moreover, in people whose elevation changes rapidly to above 2500 m above sea level (masl), acute mountain sickness can result because of a lack of time for adequate acclimatization, which requires ascents of only 300 masl per day [2,3]. In acute mountain sickness, a wide spectrum of alterations in both neurological and respiratory systems [2,4] can occur progressively.

Among mine workers, those with rotating shifts, with sea-level breaks, are exposed to chronic intermittent hypoxemia. In these patients, central periodic breathing has been observed at high altitudes [1,5]. This phenomenon has been attributed to inhibition of central nervous system functions related to respiratory control, also called hypoxic ventilatory depression [5]. Moreover, in the workplace, hypoxic ventilatory depression can result in increased muscle fatigue, disturbances in mental function, and increased risk of accidents [6,7] owing to alterations in memory, calculation ability, decision-making, judgment, and performance [8,9].

In these patients, obstructive sleep apnea-hypopnea syndrome (OSA) often coexists with high cardiovascular risk and excessive daytime sleepiness [10, 11], making this cohort a particularly complex and interesting group for analysis.

Untreated chronic OSA is associated with mild to moderate pulmonary hypertension owing to the effects of chronic intermittent hypoxemia [12] and increased susceptibility to hypoxic pulmonary vasoconstriction. Polysomnography (PSG) in approximately 150 patients for each altitude (1421, 1808, and 2165 masl) resulted in better tolerance to continuous positive airway pressure (CPAP) titration after oxygen use versus CPAP or bilevel positive airway pressure alone in patients with moderate or severe prior diagnosis of OSA [13].

In this study, we evaluated whether oxygen use modified PSG parameters in split-night studies carried out at a height of 3200 masl in mine workers in northern Chile.

Materials and Methods

Data for 1,039 patients who entered the fatigue and sleepiness program of our institution between 2014 and April 2018 were reviewed retrospectively, following the technical guide for exposure to chronic intermittent hypobaria of the Chilean Ministry of Health [14]. Patients with hypobaria program alerts, requests for evaluation by the worker or their employer for detection of daytime sleepiness, incidents during work, findings in isolated surveys of daytime sleepiness, and/or night snoring were enrolled for the first evaluation.

Of these 1,039 patients, 312 underwent PSG at a miner camp at 3,200 masl. The inclusion criteria for PSG were altered from the sleep quality survey (Pittsburgh Scale) associated with altered night oximetry and/or abnormal respiratory polygraphy, i.e., Apnea Hypopnea Index (AHI) > 5 events per hour of sleep.

A subgroup of 51 patients with split-night PSG was analyzed after oxygen titration by nasal cannula using an oxygen concentrator (1–3 L/min), following the description in Annex 1.

Annex 1: Split-night protocol for the diagnosis and treatment of OSA at altitude.

First part of the night: 3 hours of registration trying two hours of sleep, including supine position.
CPAP therapy is initiated if: - IAH is > 15 ev/hra sleep, predominantly obstructive apnea, independent whether or not you have maintained oxygen desaturation > 50% of the basal sleep period. - Maintains respiratory events despite oxygen use up to 3lpm.
Oxygen titration is initiated if: - Patient rejects prior to the start of the CPAP degree study or the beginning of the degree. - Poor tolerance to CPAP. - IAH > 15 ev/hra sleep with predominance of central apneas. - Maintained oxygen desaturation > 50% of the time during basal registration with IAH < 15 ev/hra sleep. - Maintained oxygen desaturation > 50% of the time during the hour following the start of CPAP titration. - Appearance of central apneas during CPAP titration, in this case CPAP titration is suspended and maintained only with oxygen. **Oxygen titration is performed 1.5, 2, 2.5 and 3lpm, increasing every 20 minutes in case of persistence of respiratory events.**

Protocol created by Paula Contreras MD, from Simeds Center

All PSGs were performed by trained technicians using Alice 6 Philips Respironics equipment, and standard electrodes, sensors, and procedures were used in accordance with the guidelines of the American Academy of Sleep Medicine (AASM). Stages and sleep events were scored by two trained scorers following the recommendations of the AASM scoring manual (version 2.47) [15], with Philips Respironics Sleepware G3 software. The criterion for defining central predominance or obstructive predominance [16] was percentage of central apneas greater than or equal to 50% or less than 20%, respectively. Interexaminer reliability was determined by pairs of 30 examinations using Cohen's kappa coefficients for categorical variables, and intraclass correlation coefficients for continuous variables were applied with very good to acceptable results [17,18]. The data were tabulated using Microsoft Excel 365, and IBM SPSS Statistics 25™ was used for paired Student's t-tests. Adjustment of confounding variables was performed by separate group analyses, with establishment of 95% confidence intervals.

This study was approved by the scientific ethics committee of the Eastern Metropolitan Health Service (SSMO) of Chile.

Results

Fifty-one patients were enrolled in this study; 96.1% of the patients were men, and the mean age and body mass index were 44.4 years (range: 28–62 years, ds: 7.9) and 10.1 kg/m2 (range: 19.4–34.9 kg/m2, ds: 3.1; Table 1).
After baseline registration, all patients were administered oxygen therapy, and 24 patients underwent additional CPAP titration following indication in Annex 1. Of CPAP group, 20 had good tolerance to the procedure, whereas two showed intolerance.

The average baseline sleep architecture was slightly reduced (84.7%), with a larger distribution for the total group of different sleep stages, i.e., 67.1% surface sleep (N1–N2), 23.9% sleep N3, and 9% REM sleep, plus an arousal rate of 33.98 events/h (Table 2).

The average baseline AHI was 46.5/h (range: 0.6–154.6/h, ds: 36.4), with an average duration of respiratory events of 14.6 s (range: 10.4–28.9 s, ds: 3.8) and a minimum SpO2 of 76.4% (range: 58.0–88.0%, ds: 5.3; Table 2).

The average percentage of central apnea the entire group was 16.9% (range: 0.0–93.5%, ds: 22.4). Four patients (7.8%) had central predominance, 37 (72.5%) had obstructive predominance, and 10 (19.6%) had both components (Table 3).

Table 1: Demographic characteristics and basal polysomnographic parameters.

	Female (n = 2)		Male (n = 49)		Total (n = 51)			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Minimum	Maximum
AGE (YEARS)	49.5	0.7	44.2	8.0	44.4	7.9	28.0	62.0
BMI (KG/M²)	24.8	7.6	30.4	2.7	30.1	3.1	19.4	34.9
BASELINE AHI WITHOUT O_2 (EVENTS/H)	22.1	12.9	47.5	36.7	46.5	36.4	0.6	154.6
AVERAGE EVENTS DURATION (S)	16.6	7.1	14.6	3.7	14.6	3.8	10.4	28.9
MINIMUM SPO_2 WITHOUT O_2	73.5%	0.7%	76.6%	5.4%	76.5%	5.4%	58.0%	88.0%
AVERAGE SPO_2 WITHOUT O_2	84.5%	3.5%	85.9%	2.4%	85.8%	2.4%	80.0%	93.0%
CT-90 WITHOUT O_2	95.6%	5.8%	88.1%	19.8%	88.4%	19.5%	1.1%	99.9%
CENTRAL APNEA	1.4%	1.9%	17.6%	22.6%	16.9%	22.4%	0.0%	93.5%

Note: *A large proportion of men was observe, with a Body Mass Index (BMI) in the obesity range, with Apnea Hypopnea Index (AHI) in the severity range, over 30 ev/h of sleep. Average oxygen saturation (SPO2) in the baseline period (without the use of CPAP or oxygen) of 85.9% and sustained oxygen desaturation with an oxygen curve below 90% (CT-90) in the severe range on average 88.1%, most patients do not present a pattern of central apneas or a high number of central events despite an altitude above 3.000 masl.*

Table 2: Summary of electroencephalographic parameter means in basal stage and oxygen polysomnography studies.

	BASELINE SE	SE O_2	BASELINE AROUSAL	AROUSAL O_2	BASELINE N3	N3 O_2	BASELINE REM	REM O_2
TOTAL GROUP (51PSG)	84.7%	85.6 %	33.98	21.80	23.9%	11.5 %	9.0%	18.3%
CPAP GROUP	84.3%	81.9 %	29.32	20.72	29.8%	10.1 %	11.3%	19.4%
GROUP WITHOUT CPAP	83.6%	84.8 %	35.31	22.11	21.4%	10.7 %	7.9%	17.4%
INSUFFICIENT TECHNIQUE	92.9%	96.0 %	45.60	29.05	11.3%	14.5 %	9.2%	22.8%
BAD TOLERANCE	85.5%	86.6 %	30.70	15.30	0.0%	24.2 %	0.0%	9.4%

Note: The means for the basal sleep efficiency (SE) parameters, i.e., SE O2 (oxygen sleep efficiency), deep sleep stages N3, REM, and arousal, were analyzed for the entire group of oxygenated patients and were further divided accordingly those in which oxygen was used alone or with CPAP.

Table 3: Separate analysis of subgroups according to the use of CPAP and the type of predominant respiratory event.

				PAIRED SAMPLES TEST[A] PAIRED DIFFERENCES					
				MEAN	STD. DEVIATION	95% CONFIDENCE INTERVAL OF THE DIFFERENCE		T	SIG. (2-TAILED)
Event predominance	USO CPAP					LOWER	UPPER		
MIXED (N = 6)	**No (n = 6)**	**Pair 1**	**Baseline AHI without O_2 – Average AHI with O_2**	45.117	38.486	4.728	85.505	2.872	0.035
		Pair 2	**Baseline AHI without O_2 – Best AHI with O_2**	47.800	39.265	6.594	89.006	2.982	0.031
		Pair 3	**Average SpO_2 with O_2 – Average SpO_2 without O_2**	0.060	0.017	0.042	0.078	8.783	0.000
		Pair 4	**Minimum SpO_2 with O_2 – Minimum SpO_2 without O_2**	0.057	0.042	0.012	0.101	3.284	0.022
		Pair 5	**CT 90 without O_2 – CT 90 with O_2**	0.839	0.150	0.682	0.997	13.700	< 0.0005
	No (n = 18)	**Pair 1**	**Baseline AHI without O_2 - average AHI with O_2**	20.383	22.271	9.308	31.459	3.883	0.001
		Pair 2	**Baseline AHI without O_2 – best AHI with O_2**	21.994	23.329	10.393	33.596	4.000	0.001
		Pair 3	**Average SpO_2 with O_2 – average SpO_2 without O_2**	0.069	0.029	0.055	0.084	10.306	< 0.0005

OBSTRUCTIVE (N=34)	NO (N = 18)	Pair 4	Minimum SpO_2 with O_2 – minimum SpO_2 without O_2	0.095	0.060	0.065	0.125	6.770	< 0.0005
		Pair 5	CT-90 without O_2 – CT-90 with O_2	0.798	0.261	0.669	0.928	12.997	< 0.0005
	Yes (n = 16)	Pair 1	Baseline AHI without O_2 – average AHI with O_2	36.563	31.990	19.516	53.609	4.572	< 0.0005
		Pair 2	Baseline AHI without O_2 – best AHI with O_2	42.431	35.402	23.567	61.296	4.794	< 0.0005
		Pair 3	Average SpO_2 with O_2 – average SpO_2 without O_2	0.057	0.025	0.043	0.070	8.926	< 0.0005
		Pair 4	Minimum SpO_2 with O_2 – minimum SpO_2 without O_2	0.066	0.043	0.043	0.089	6.076	< 0.0005
		Pair 5	CT-90 without O_2 – CT-90 with O_2	0.590	0.240	0.462	0.718	9.819	< 0.0005

A. No statistics were computed for one or more split files: use of CPAP technically insufficient and poor tolerance, event type: central and mixed predominance with CPAP.

Analysis of neurophysiological parameters (Table 2) showed that for the total number of patients studied, sleep efficiency increased slightly with the use of oxygen from 84.7% to 85.6%. By contrast, when differentiating according to group, better sleep efficiency and increased sleep efficiency were observed in patients administered oxygen only compared with baseline sleep. The increase was slight, i.e., from 83.6% to 84.8%, compared with the group using CPAP plus oxygen, in which a reduction in sleep efficiency was observed when compared with baseline sleep (from 84.3% to 81.9%).

When analyzing the distributions of different stages of sleep, in the group given oxygen, independent of the use of CPAP, we observed a statistically significant increase in the percentage of REM sleep and a decrease in the percentage of N3 stage sleep compared with baseline sleep parameters (Table 4). A statistically significant reduction in arousal was also observed in the total group with oxygen administration (21.8 episodes/h) compared with baseline sleep (33.9/h), with a greater reduction in the group in which only oxygen was used versus the group in which oxygen was given with CPAP. Comparing baseline conditions with respect to oxygen therapy (Table 5), we noted a higher minimum SpO2 (76.4% versus 83.7%), a lower average AHI (46.5/h versus 7.8/h), an average SpO2 that was best at different oxygen levels (85.8% baseline versus 91.8%, 91.6%, 92.2%, and 94.3% with oxygen therapy at 1.5, 2.0, 2.5, and 3.0 L/min, respectively), and a lower average saturation time percentage of 90% (CT-90; 88.4% baseline versus 16.8%). These results were statistically significant and persisted even if confounding factors, such as the use of CPAP and predominant event type, were controlled (Table 4).

Table 4: Comparison of baseline and oxygen PSG parameters.

	AVERAGE	STANDARD DEVIATION	INFERIOR IC 95%	SUPERIOR IC 95%	T	SIG. (2-TAILED)
% BASELINE SLEEP EFFICIENCY - % O_2 SLEEP EFFICIENCY	-0.0094	0.1484	-0.0512	0.0323	-0.453	0.653
% BASELINE STAGE N1 - % O_2 STAGE N1	0.0055	0.1111	-0.0257	0.0368	0.355	0.724
% BASELINE STAGE N2 - % O_2 STAGE N2	-0.0245	0.2222	-0.0869	0.0379	-0.787	0.425
% BASELINE STAGE N3 - % O_2 STAGE N3	0.1232	0.1643	0.0770	0.1694	5.356	< 0.001
% BASELINE STAGE REM - % O_2 STAGE REM	-0.0926	0.1190	-0.1261	-0.0591	-5.555	< 0.001
BASELINE AROUSAL INDEX PER HOUR OF SLEEP - O_2 AROUSAL INDEX PER HOUR OF SLEEP	12.1803	24.5891	5.2646	19.096	3.538	< 0.001

BASELINE AHI WITHOUT O_2 – aVERAGE AHI WITH O_2	34.50	32.52	25.35	43.64	7.575	< 0.0005
BASELINE AHI WITHOUT O_2 – bEST AHI AT SOME OF THE O_2 LEVEL	38.69	34.20	29.07	48.31	8.078	< 0.0005
AVERAGE SPO_2 WITH O_2 – aVERAGE SPO_2 WITHOUT O_2	0.063	0.026	0.055	0.070	17.188	< 0.0005
MINIMUM SPO_2 WITH O_2 – MINIMUM SPO_2 WITHOUT O_2	0.073	0.057	0.057	0.089	9.172	< 0.0005
CT-90 WITHOUT O_2 – CT-90 WITH O_2	0.716	0.263	0.642	0.79	19.417	< 0.0005

Note: Sleep architecture analysis and comparison of sleep efficiency; sleep stages N1, N2, N3, REM, and arousal between AHI; SpO_2 and time spent with oxygen saturation ≤ 90% (CT-90) for baseline PSG and during oxygen use in all 51 patients.

Table 5: AHI, minimum SpO_2, average SpO_2, and CT-90 according to oxygen therapy and different oxygen levels.

CPAP USE	N° PATIENTS	BASELINE AHI WITHOUT O_2	AVERAGE AHI WITH O_2	BEST AHI WITH O_2	MINIMUM SPO_2 WITHOUT O_2	MINIMUM SPO_2 WITH O_2	AVERAGE SPO_2 WITHOUT O_2	AVERAGE SPO_2 WITH O_2	CT-90 WITHOUT O_2	CT-90 WITH O_2
POOR TOLERANCE	2	58.3	18.5	8.2	74.0%	81.0%	85.5%	91.0%	84.1%	23.6%
NO	27	38.6	5.3	3.6	77.6%	85.9%	86.1%	93.0%	89.2%	7.8%
YES	20	55.2	20.5	13.8	74.8%	81.4%	85.3%	90.9%	90.3%	29.4%
TECHNICALLY INSUFFICIENT	2	55.2	11.1	4.8	80.5%	81%	87.5%	93.5%	62.3%	6.5%
TOTAL	51	46.5	12.0	7.8	76.5%	83.7%	85.8%	92.1%	88.4%	16.8%

Average SpO_2 without O_2	SpO_2 with O_2 at 1.5 L/min	SpO_2 with O_2 at 2 L/min	SpO_2 with O_2 at 2.5 L/min	SpO_2 with O_2 at 3 L/min
85.8%	91.8%	91.6%	92.2%	94.3%

Hypnograms of two typical patients are shown in Figures 1 and 2.

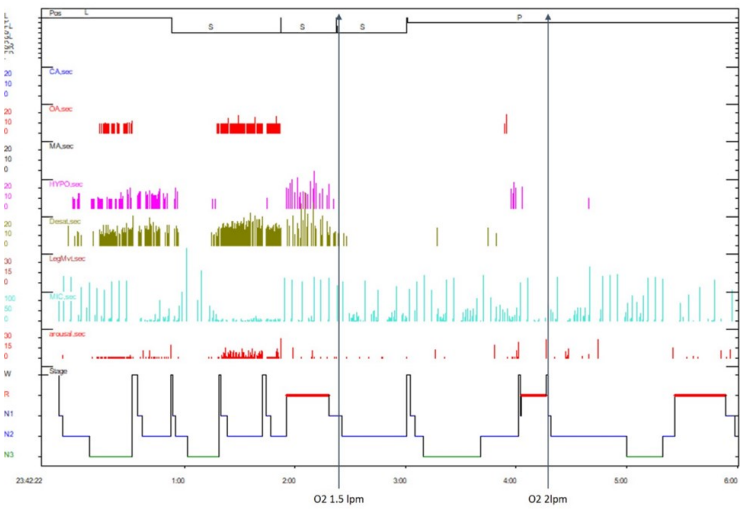

Figure 1: *Baseline hypnogram and titration with oxygen.*

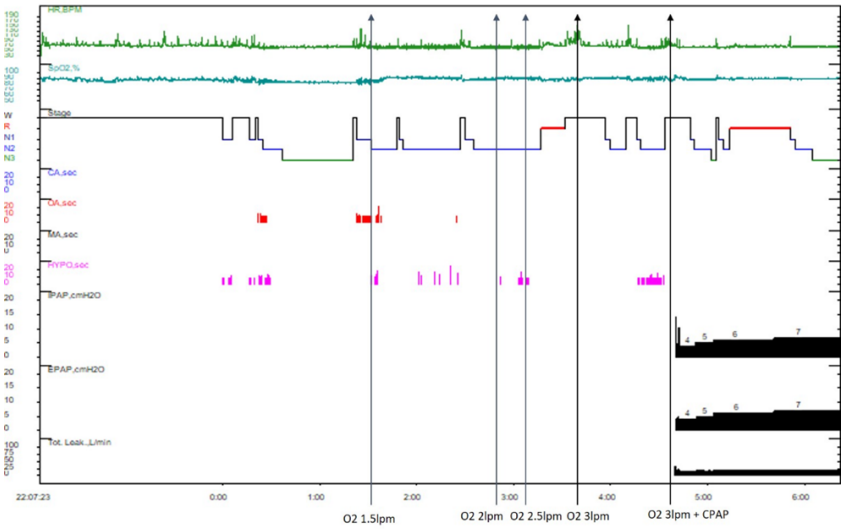

Figure 2: *Baseline hypnogram and titration with oxygen only and oxygen plus CPAP.*

Discussion

The use of supplemental oxygen in OSA therapy has been extensively studied; however, the effects of this therapy on the severity of OSA have been inconsistent, with some studies showing a 50% or more reduction in AHI with oxygen use and some showing little or no effect [19,20,21,22]. In our study, we observed a significant reduction in AHI by 74% when compared with the AHI found after average oxygen titration (throughout the segment with oxygen use, regardless of the amount administered); this reduction increased further when only the best AHI at any oxygen level (1.5, 2, 2.5, or 3 L/min) was considered reaching a reduction of up to 83.2%.

One possible approach for the use of oxygen in the treatment of OSA involves patients with ventilatory instability or high loop gain (HLG), as described by Edwards et al. [23]. Additionally, in a study by Wellman et al. (2008), a group of 12 patients was categorized according to loop gain (LG; a measure of ventilatory instability; n = 6 with HLG, showing greater ventilatory instability and n = 6 with low LG [LLG] showing lower ventilatory instability), and among those who responded to oxygen (initial oxygen doses of 3–5 L/min), patients with HLG tended to be responders to the use of oxygen versus whereas patients with LLG tended to be nonresponders; in addition, an increase in the length of the remaining apnea and hypopnea was observed with the use of oxygen [24]. Moreover, in theoretical studies by Longobardo et al. [25], researchers evaluated the roles of LG in the production of obstructive sleep apnea. The model contained equations describing the neurochemical control of breathing, changes in alertness, and collapse of the upper airway. The findings showed that HLG caused obstructive apnea when the upper airway was moderately collapsible and that lowering the LG with the use of oxygen eliminated this obstruction [25]. Although this study was theoretical, it was important that researchers considered the control of obstructive respiratory events with oxygen. In our study, we found that there was a higher proportion of patients with purely obstructive apnea and/or central and obstructive mixed patterns. Furthermore, even if we separated all types of respiratory events and focused only on obstructive events, we found that the use of oxygen significantly contributed to the control of respiratory events, as demonstrated by improvement of the mean saturation parameters and CT-90, independent of concomitant use of CPAP. These findings may suggest that the intermittent elevation at high altitude of those people, associated with variable airway collapse observed at baseline could be generating an increase in LG, which could be controlled with the use of oxygen.

In a meta-analysis evaluating the effects of CPAP and placebo CPAP versus oxygen in AHI and SpO2, researchers demonstrated a significant reduction in AHI with the use of CPAP compared with the use of oxygen alone; however, each of the studies included in the meta-analysis analyzed only a few patients, ranging from five to 21 [20]. By contrast, our current findings demonstrated an improvement in PSG parameters with oxygen therapy, independent of the use of CPAP, and our study included a larger number of patients. Additionally, we observed reductions in AHI, minimum O2 saturation, average O2 saturation, and CT-90 in patients with oxygen therapy who worked at high elevations, although varying oxygen requirements were observed in patients without a central apnea pattern.

Conclusion

Hypobaria affects the results of PSG performed at high altitudes. In this study, which was performed at 3200 masl, oxygen therapy was associated with a significant improvement in critical PSG parameters (arousal, REM sleep, AHI, minimum SpO2, average SpO2, and CT-90), as evaluated during a sleep study, independent of CPAP use and the predominant respiratory event type.

Under these conditions, night oxygen therapy may be an alternative to CPAP or acetazolamide therapy [26] and could be useful in patients with obstructive or central apnea because night oxygen therapy is likely to benefit both groups. The benefits observed in this group of patients could be related to the rotating shifts of patients in the study, with shifts in elevation occurring on a weekly basis. Moreover, the patients showed tremendous ventilatory instability, behaving similar to the HLG group, and thus showed better control of the AHI when using this type of therapy, requiring oxygen levels that were much lower than those used in other studies. Additional studies already in progress to confirm our results with longer follow-up times. Overall, our results are expected to provide insights into the management of sleep-disordered breathing in patients exposed to intermittent hypobaria.

Author Disclosure Statement

Paula Contreras, Pedro Moya, Javiera Hagn, Sonia Carlos, Katherine Vallejos, and María Belén Sobarzo declare that they have no conflicts of interest. The authors did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

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