Continuous Positive Airway Pressure Treatment for Acute Mountain Sickness at 4240 m in the Nepal Himalaya

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Abstract

Johnson, Pamela L., Claire C. Johnson, Prasanta Poudyal, Nirajan N. Regmi, Megan A. Walmsley, and Buddha Basnyat. Continuous positive airway pressure treatment for acute mountain sickness at 4240 m in the Nepal Himalaya. *High Alt Med Biol* 14:230–233, 2013.—Acute mountain sickness (AMS) is very common at altitudes above 2500 m. There are few treatment options in the field where electricity availability is limited, and medical assistance or oxygen is unavailable or difficult to access. Positive airway pressure has been used to treat AMS at 3800 m. We hypothesized that continuous positive airway pressure (CPAP) could be used under field conditions powered by small rechargeable batteries. *Methods Part 1.* 5 subjects trekked to 3500 m from 2800 m in one day and slept there for one night, ascending in the late afternoon to 3840 m, where they slept using CPAP 6–7 cm via mask. The next morning they descended to 3500 m, spent the day there, ascended in late afternoon to 3840 m, and slept the night without CPAP. Continuous overnight oximetry was recorded and the Lake Louise questionnaire for AMS administered both mornings. *Methods Part 2.* 14 trekkers with symptoms of AMS were recruited at 4240 m. All took acetazolamide. The Lake Louise questionnaire was administered, oximetry recorded, and CPAP 6–7 cm was applied for 10–15 min. CPAP was used overnight and oximetry recorded continuously. In the morning the Lake Louise questionnaire was administered, and oximetry recorded for 10–15 min. The equipment used in both parts was heated, humidified Respironics RemStar® machines powered by Novuscell™ rechargeable lithium ion batteries. Oximetry was recorded using Embletta™ PDS. *Results Part 1.* CPAP improved overnight Sao_2 and eliminated AMS symptoms in the one subject who developed AMS. CPAP was used for 7–9 h and the machines operated for >8 h using the battery. *Results Part 2.* CPAP use improved Sao_2 when used for 10–15 min at the time of recruitment and overnight CPAP use resulted in significantly reduced AMS symptoms. *Conclusion.* CPAP with rechargeable battery may be a useful treatment option for trekkers and climbers who develop AMS.

Key Words: acute mountain sickness; arterial oxygen saturation; expeditions to high altitude; pressure support ventilation.

Introduction

ASCENT TO HIGH ALTITUDE RESULTS in hypobaric hypoxia, and some individuals will develop acute mountain sickness (AMS) from altitudes of 2500 m or even lower in some individuals (Hackett and Rennie, 1976; Maggiorini et al., 1990; Basnyat and Lemaster, 1999; Roach et al., 1993).

Hypoxia is believed to be the cause of AMS, although the pathophysiological mechanisms are not understood (Ward

et al., 2000; Bartsch et al, 2004). Furthermore, AMS is known to be associated with lower overnight sleeping oxyhemoglobin saturation (Burgess et al., 2004; Erba et al, 2004). Rate of ascent and hydration significantly affect the incidence of AMS.

In previous research, noninvasive positive pressure ventilation (NIPPV), used during sleep at 3800 m, was found to increase the sleeping oxyhemoglobin saturation (Spo_2) and eliminate symptoms of AMS (Johnson et al., 2010). NIPPV was more beneficial in increasing sleeping Spo_2 in subjects

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who developed AMS compared with subjects who did not develop AMS. In fact, the subjects with AMS symptoms, when sleeping at 3800 m with NIPPV, had similar SpO_2 as the subjects who did not develop AMS when they were sleeping *without* NIPPV. This may reinforce previous findings that sleeping oxygen saturation is strongly associated with AMS (Burgess et al., 2004; Erba et al., 2004).

Other investigations into positive airway pressure at high altitude have found that, in awake subjects, positive end expiratory pressure (PEEP) applied via face mask increased SpO_2 and decreased AMS symptoms (Schoene et al., 1985) or decreased AMS but did not significantly improve SpO_2 (Savoirey et al., 1998; Launay et al., 2004). Continuous positive airway pressure (CPAP) was used after ascent to 3205 m on Mount Cook in New Zealand; it improved SpO_2 and reduced symptoms of high altitude pulmonary edema (Davis et al., 1999). A recent study used continuous positive airway pressure (CPAP) 7 cm after acute exposure to 4559 m and after prolonged exposure to 5350 m (Agostoni et al., 2010) and found that CPAP used after acute high altitude exposure increased oxygen saturation, reduced the heart rate and systolic pulmonary pressure, but after 9–10 days at 5350 m, CPAP had no effect on any parameter. Additionally, pursed lip breathing was used in one individual at 4330 m and resulted in markedly improved SpO_2 (Tannheimer et al., 2009).

Positive pressure has been used to increase altitude tolerance since the 1940s (Gagge et al., 1945; Barach et al., 1947; Taylor et al., 1948) under simulated altitudes, but it has not been possible to date to employ PAP in the field to treat high altitude illnesses due to the limitations of electricity availability and lack of suitable, portable batteries.

AMS can be prevented by slow ascent, acclimatization, rest until symptoms improve, and descent to lower altitude if improvement does not occur. The efficacy of acetazolamide for prevention of AMS has been demonstrated, and is widely used as a preventative in trekking areas of the Nepal Himalaya (Basnyat et al., 2006). Despite effective preventative measures being available, AMS continues to be a common illness during trekking, climbing, and working at altitudes above 2000 m. There is a risk of AMS progressing to the more serious, and sometimes fatal, illnesses high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE).

This research, therefore tested the utility, under field conditions, of a heated, humidified CPAP machine operating from a small, rechargeable, lithium-ion battery.

Methods

This research consists of two parts:

Part 1 investigated whether CPAP used with a rechargeable battery could be used overnight during sleep in high altitude conditions in Khunde (3840 m) in Nepal.

Five healthy subjects (one male) aged 27–59 years participated in the study. Each subject gave informed consent and the protocol was approved by the Nepal Health Research Council. None had traveled to high altitudes in the previous 12 months. The subjects flew from 1400 m to 2800 m and slept for 1 night at that altitude after a 5-hour trek. The following day they trekked for 7 hours to 3500 m and slept there for 1 night before ascending to 3840 m in the late afternoon of the following day.

On the first night at 3840 m, the subjects used heated, humidified CPAP (Respironics® RemStar®) at pressures of 6–

7 cm H_2O via nasal or full face mask, which was powered directly by a rechargeable lithium-ion battery (Novuscell Freedom Air 250™ battery pack). Continuous oximetry was recorded using the Embletta™ PDS system via finger probe.

The Lake Louise questionnaire (Roach et al., 1993) for AMS was administered in the morning to obtain a Lake Louise score (LLS); $\text{LLS} \geq 3$, in the presence of headache, was considered positive for AMS.

The subjects descended to 3500 m and spent the day at that altitude before once again ascending to 3840 m in the late afternoon. The second night at 3840 m was spent with continuous oximetry but no CPAP. The Lake Louise questionnaire was again administered in the morning within 30 min of waking.

The CPAP machines (Respironics Remstar™) had built-in heated humidifiers set to maximum. The CPAP machines automatically detected altitude and adjusted the pressure accordingly. The batteries were fully charged in Kathmandu before departure to high altitude, and all equipment was carried by porter from Lukla airport to the high altitude location at which the research was performed.

Comparisons were made between overnight SpO_2 on and off CPAP and the LLS in the mornings after CPAP use and without CPAP, using paired *t* tests.

Part 2 investigated the usefulness of CPAP for AMS at high altitude location in Nepal.

This research was carried out at 4240 m near the Himalayan Rescue Association (HRA) Aid Station in Pheriche. Notices were put up at the Aid Station and lodges to recruit trekkers with symptoms of AMS. Trekkers visiting the Aid Station for treatment of AMS were informed about the research by the volunteer doctors. Fourteen subjects were recruited; each subject gave informed consent. The protocol was approved for both parts of the study by the Nepal Health Research Council.

Fourteen subjects (6 female) aged 39 ± 13 years (range 21–62) with AMS were recruited. The subjects were trekkers who had reached 4240 m after trekking over 4–5 days from 2800 m, in a similar pattern as the subjects in Part 1, and had either attended the HRA Aid Station due to AMS or had sought out the researchers after reading notices describing the project. All were taking acetazolamide 125–250 mg bd either preventatively since the first day of their trek or in the previous 24–48 h as treatment for symptoms of AMS. All subjects had moderate to severe headache and at least one other symptom of AMS.

At the time of recruitment, oximetry measurements were recorded for 10–15 min, the mean SpO_2 derived, and the Lake Louise questionnaire was administered. Continuous positive airway pressure (CPAP) via nasal or full face mask was applied for 10–15 min, and oximetry recorded during this time. CPAP was used overnight and oximetry recorded continuously. The Lake Louise questionnaire was administered the next morning and oximetry recorded for 10–15 min.

Comparisons were made between the LLS at time of recruitment and in the morning after CPAP use and daytime recordings of SpO_2 on and off CPAP, while awake, using paired *t* tests.

The equipment used for this part of the research was the same as used in Part 1 [i.e., CPAP machines (Respironics Remstar), rechargeable lithium ion batteries (Novuscell™), oximeters (Embletta™)], and was transported in the same manner. Additionally a roll-up solar panel was used at times to recharge the batteries.

Results

Part 1. In the preliminary study at 3840 m, the CPAP machine operated for >8 h via battery on pressures of 6–7 cm H₂O. Each subject tolerated CPAP during sleep for 7–9 h.

Only one of the five subjects developed AMS, with LLS score of 5 in the morning after sleeping at 3840 m without CPAP. The LLS in this subject after CPAP use was 0. The mean LLS for the five subjects off CPAP was 1.6 ± 2 and on CPAP, 0 ± 0 ($p=0.14$) (Table 1).

The mean overnight SpO₂ off CPAP was $79 \pm 6\%$ and on CPAP, $82 \pm 4\%$ ($p=0.07$). The minimum overnight SpO₂ off CPAP was $63 \pm 10\%$ and on CPAP, $68 \pm 7\%$ ($p=0.02$) (Table 1).

Part 2. In the larger study at 4240 m, oxygen saturation improved during 10–15 min of CPAP use at the time of recruitment (awake in the evening whilst sitting): before CPAP use the mean SpO₂ of the 14 subjects was $85 \pm 5\%$ and after CPAP use was $88 \pm 3\%$ ($p=0.005$) (Table 2). The mean LLS at the time of recruitment was 6.5 ± 2.8 and in the morning after sleeping with CPAP at 6–7 cm H₂O, mean LLS was 1.8 ± 1.2 ($p<0.001$) (Table 2). Overnight mean SpO₂ during CPAP use in the 14 subjects was $82 \pm 4\%$.

Twelve of the subjects continued to ascend after 1 night on CPAP at 4240 m, and each reached altitudes above 5400 m without return of AMS symptoms. Two subjects remained at 4200 m to await the return of their trekking groups and then descended to 2800 m for return flights to Kathmandu.

Discussion

This research has demonstrated the usefulness of CPAP at high altitude to treat AMS and for raising the oxyhemoglobin saturation. The findings from this research are in agreement with previous findings that CPAP, PEEP, Auto-PEEP/pursed lip breathing, and EPAP used at high altitude, rapidly increases the oxygen saturation (Schoene et al., 1985; Savourey et al., 1998; Davis et al., 1999; Launay et al., 2004; Tannheimer et al., 2009; Agostoni et al., 2010). The low number of subjects limits the robustness of the findings but it is clear that CPAP provides potential for treating this common disorder in an area where treatment availability is limited.

The CPAP pressures used were 6–7 cm, which is known to have a very low risk of barotrauma (Schoene et al., 1985).

The mechanisms for improvement in oxyhemoglobin saturation and improvement in AMS symptoms are most likely due to several factors: increased end-expiratory volume resulting in increased alveolar gas exchange with improved oxygen saturation/reduced hypoxia, recruitment of microatelectatic alveoli, and prevention of upper airway collapse during sleep, as well as fluid shift from the alveolar-capillary membrane caused by CPAP, thus improving gas exchange. The finding that subclinical pulmonary edema is present in

TABLE 2. PART 2 RESULTS DEMONSTRATED IMPROVED SAO₂ AFTER CPAP USE WHEN AWAKE AND SIGNIFICANTLY REDUCED SYMPTOMS OF AMS AFTER USING CPAP DURING SLEEP

Measurement during wakefulness	At recruitment	Morning after CPAP	P value
SaO ₂ %	85 ± 5	88 ± 3	0.001
LLS	6.5 ± 2.80	1.8 ± 1.2	<0.0001

many recreational climbers at 4559 m (Cremona et al., 2002) supports this fluid shifting hypothesis.

Previous research found an improvement in SpO₂ with the use of expiratory positive airway pressure (EPAP) 5–10 cm during exercise at 4400 m (Schoene et al., 1985). Positive end expiratory pressure (PEEP) 5 cm via a face mask utilizing a bi-directional valve, was used in eight men during ascent of Mont Blanc (4810 m) to prevent AMS (Launay et al., 2004) and in a hypobaric chamber (Savourey et al., 1998) simulating 4500 m altitude in 22 subjects. AMS was reduced in all subjects in these two studies. There were no changes to SpO₂ between PEEP and no-PEEP in the hypobaric chamber (Savourey et al., 1998), but an increase with PEEP on Mont Blanc (Launay et al., 2004).

A case study reporting “Auto-PEEP” (i.e., pursed lips breathing in one subject at 4330 m, Tannheimer et al., 2009) found remarkable improvement in SpO₂ from 62% to 85% after 5 min, and to 95% after 30 min. The authors hypothesized that the increased intrathoracic pressure improved the alveolar–capillary pressure gradient, re-opened collapsed alveoli, making them available once again for gas exchange. This enlarged gas exchange surface improved pulmonary circulation and SpO₂.

The availability of solar power has enabled the use of oxygen concentrators at the Aid Station in Pheriche (4240 m) but the power required to run the concentrators drains the stored electricity, and while concentrators are in use, other devices that run on stored electricity cannot be operated. The size and weight of concentrators and batteries prohibits the portability of this treatment method. The advantage of CPAP operating from a rechargeable lithium ion battery is that the CPAP machine plugs directly into the battery and will run the machine for over 8 h on a single charge. The battery recharges either from the roll-up solar panel or from battery stored solar power in 4–5 hours. The CPAP machine and battery are small and lightweight ($25 \times 12 \times 12$ cm and 1 kg for the CPAP, and $22 \times 5 \times 14$ cm and 2 kg for the battery). The feasibility of walking whilst using CPAP may allow trekkers and climbers who have developed AMS during the first few days at high altitude, to make their way to lower altitudes for treatment and recovery. CPAP has been found not to be effective in improving SpO₂ after prolonged altitude exposure (Agostoni et al., 2010), therefore its usefulness may be in those developing hypoxia-related illness in the first few days at high altitude.

There are limited treatment options in many areas of high altitude trekking and climbing. The introduction of solar electricity has somewhat increased treatment options and has made the use of oxygen concentrators available to several aid stations and medical facilities in the Khumbu area of Nepal. However, most people become ill in areas that are still underserved by medical assistance or oxygen availability. The

TABLE 1. Part 1. RESULTS DEMONSTRATED IMPROVED SAO₂ DURING SLEEP WHEN CPAP WAS USED

Overnight measurement	Off CPAP	On CPAP	P value
Mean SaO ₂ %	79 ± 6	82 ± 4	0.07
Min. SaO ₂ %	63 ± 10	68 ± 7	0.02
LLS	1.6 ± 2	0 ± 0	0.14

Only one subject developed AMS, with LLS of 5 in morning after sleeping without CPAP; but the LLS was 0 after CPAP use.

Aid Station at Pheriche is staffed by volunteer doctors and provides medical treatment, lectures, and other support services to trekkers and climbers passing the village on their way to higher altitudes. The incidence of AMS in trekkers at Pheriche is 29%–53% (Hackett and Rennie, 1976; Maggioni et al., 1990; Kayser, 1991; Basnyat and Lemaster, 1999) and most of these will stay at Pheriche until symptoms subside and further ascent is possible. Many will seek medical advice and treatment from the Aid Station. Most trekkers and climbers will have been taking acetazolamide 125–250 mg 1–2/day. If AMS symptoms return at higher altitudes, there is little or no access to medical treatment or advice and descent is the recommended option if symptoms persist after rest for 1–2 days. The risk of being too ill to walk to lower altitudes is all too common, and transportation options are limited to being carried by a porter to lower altitudes. Evacuation by helicopter is reliant on weather conditions. It would therefore be useful to have a light and portable system for treating people suffering AMS when other treatment or transportation is unavailable. The CPAP machine and battery weigh less than 3 kg and could be easily carried to the sick person, treatment instigated, and even carried by a porter as the patient walks to lower altitudes, if recovery is sufficient to enable walking.

Further work is now needed to investigate the usefulness of CPAP with rechargeable batteries in field conditions for the treatment of AMS.

Acknowledgments

The authors would like to thank Joanna Scott and Phillips Respirionics, Australia for lending the Remstar CPAP machines, masks, and tubing for this research; Karen Taylor and Embla for lending the Embletta devices for monitoring and recording oxygen saturation, and The Battery Geeks, Austin, Texas, USA for the loan of Novuscell batteries. Without the assistance and generosity of these people, the research would not have been possible.

Author Disclosure Statement

No competing financial interests exist.

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Received February 1, 2013;
 accepted in final form March 7, 2013.