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ORIGINAL ARTICLE

Treatment of moderate acute mountain sickness with pressurization in a portable hyperbaric (Gamow^{TM}) Bag

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The Gamow Bag^{TM} has recently been introduced as a treatment modality for acute mountain sickness (AMS), but clinical experience with its use is limited. We report our use of this modality during one season at the Himalayan Rescue Association Aid Post in Manang, Nepal (altitude 3550 m). Ten subjects with symptoms of moderate AMS were offered acetazolamide 250 mg every 12 or pressurization to 104 Torr above ambient pressure for 1 h. Four subjects were treated with acetazolamide; six underwent pressurization. Subjects undergoing pressurization experienced significant and rapid improvement in AMS symptom scores, whereas those taking acetazolamide did not. The unimproved subjects in the acetazolamide group elected to cross over to treatment with pressurization, and then improved to the same degree as did subjects initially choosing pressurization. All subjects remained at altitude and subsequently crossed a 5380 m pass. This study suggests that the Gamow Bag^{TM} may be used to rapidly alleviate the symptoms of moderate acute mountain sickness. It also suggests that a relatively short treatment period appears to offer prolonged benefit. Confirmation awaits further trials.

Key words: acute mountain sickness, Gamow Bag, pressurization

Introduction

The Gamow (hyperbaric) Bag^{TM} has recently been introduced as a modality for the treatment of acute mountain sickness (AMS). Anecdotal reports have been published supporting its efficacy, and pressurization as a treatment modality utilizes logical principles [1]. However, clinical trials have been limited [2]. No comparisons have been reported between pressurization and acetazolamide for the treatment of moderate AMS.

The Gamow Bag^{TM} is constructed of coated nylon and fitted with a high-pressure tolerant zipper. Inflated, it becomes a cylinder measuring 0.6 m in diameter by 2.5 m in length and easily accommodates a patient, sleeping bag, and small oxygen cylinder. A window allows visual access, and conversation with the occupant can take place using a normal voice. Inflation and pressurization are accomplished with an inflatable raft-style foot pump. Two pressure-relief valves automatically open after an internal pressure of 104 Torr (2 pounds per square inch) above ambient atmospheric pressure is achieved. The apparatus weighs 6.6 kg including the pump, and folds to fit in a small rucksack.

Pressurization as a treatment modality for AMS has previously been reported [3]. The

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original pressure chamber, used at the Himalayan Rescue Association Aid Post in Pheriche (4250 m), consisted of a metal tank that was also pressurized to 104 Torr above ambient pressure by a foot pump. It was reported to alleviate symptoms "almost immediately". The major advances represented by the development of the Gamow Bag™ are portability and ease of use. Another bag currently in commercial release achieves the same level of pressurization, and would be expected to yield similar results.

The amount of simulated descent achieved by increasing ambient pressure by 104 Torr is determined by the altitude at which pressurization is begun. At 3550 m (P_B 490 Torr), increasing the pressure within the Bag by 104 Torr is equivalent to descending to an altitude of 2050 m (P_B 594 Torr).

The Himalayan Rescue Association Aid Post in Manang, Nepal (altitude 3550 m) is the main source of urgent medical care for trekkers attempting the 5380 m Thorung Pass. Located at the base of the pass, Manang is on a plateau several kilometers long; thus, further descent is not easily accomplished. Victims of moderate AMS who have not improved upon descent to Manang, or who have become ill while ascending to Manang, have traditionally required medical intervention and assisted evacuation, often terminating their trek. We report on our experience with the Gamow Bag™ during its first season of use in Manang.

Materials and methods

From March to May 1989, the Aid Post in Manang was manned by two volunteer physicians, who evaluated, scored, and treated all subjects. Ten subjects developed symptoms of moderate AMS on ascent to Manang and were felt to need medical therapy beyond rest and analgesics. They were offered the choice of acetazolamide 250 mg orally every 12 h or pressurization to 104 Torr above ambient pressure for 1 h in the Gamow Bag™. Four chose acetazolamide, while six elected pressurization. Since neither the Gamow Bag™ nor acetazolamide is an established modality of treatment for AMS, and the trekkers involved were on an expensive and perhaps once-in-a-lifetime adventure, the choice of treatment was left to them. As it is not possible to perform 'sham' pressurization, a control group was not included.

Using an eighteen point scale developed by Hackett *et al.* (Table 1), participants' symptoms were scored at 0, 1, and 12 h [4]. At 12 h, each subject was offered the choice of no further therapy, repetition of the previously used modality, or crossing over to the other modality. Subjects repeating a treatment or crossing over to the other modality were followed for an additional 12 h.

Statistical significance between mean scores was determined with the paired *t*-test for changes over time in the same subjects, and with the unpaired *t*-test for differences between groups.

Results

Twenty-seven patients who presented to the Aid Post were diagnosed with AMS. Fifteen of these had mild to moderate symptoms, and were treated with rest, fluids, oral analgesics, and in some cases, pressurization or acetazolamide. Since these patients had either already descended from higher elevation or had taken acetazolamide or dexamethasone prior to presentation, they were not enrolled in the study. Two other persons had

Table 1. AMS symptom questionnaire.

Symptom	*Remarks*	*Score*
Headache	transient, relieved with analgesic	1
	severe, or not relieved with analgesic	2
Insomnia	difficulty falling asleep, frequent waking	1
Dizziness		1
Ataxia	difficulty maintaining balance	1
	steps off line on walking maneuvre	2
	falls to ground, cannot finish test	3
Severe lassitude	requires assistance for tasks of daily living	3
Anorexia/nausea	true anorexia, not just distaste for diet	1
Vomiting		2
Dyspnea on exertion	dyspnea forces frequent halts, slow to recover	2
at rest	marked dyspnea after 10 minutes of rest	3
Global function	no symptoms	0
	symptoms, but able to continue	1
	symptoms, stopping ascent	2
	intensive treatment and/or evacuation required	3

descended from higher elevation with symptoms severe AMS, and were treated aggressively with dexamethasone, oxygen, and pressurization. The ten enrolled subjects all acquired symptoms during ascent to Manang; none had descended from higher elevation. All had ascended from Besisahar (820 m) over a period of 5–7 days. No subject had taken acetazolamide or dexamethasone prior to enrollment in the study. Seven of the 10 had taken non-narcotic analgesics (aspirin, acetaminophen, or ibuprofen) within the preceeding 24 h, but no analgesic or other medication was used by any participant within 6 h of starting the study period. The subjects who chose acetazolamide were 3 women and one man, ages 21–40. The six subjects who chose pressurization were all women, ages 22–37. The acetazolamide group had initial AMS scores of 5–7 (mean 6.0), and the pressurization group had initial AMS scores of 5–8 (mean 6.8). The difference between these groups was not significant ($p > 0.1$).

The results are shown in Table 2. The group which initially chose pressurization had significantly better scores than did the acetazolamide group at both 1 and 12 ($p < 0.02$ and $p < 0.05$, respectively).

Three patients within the acetazolamide group demonstrated AMS scores of 5,5, and 8 at 12 h, and elected to cross over to pressurization at that point, rather than they take the next does of acetazolamide. Their subsequent improvement (Table 2) was equal to the improvement noted in the persons who had initially selected pressurization. Subjects crossing over to pressurization did not have their symptoms return during our observation. Two subjects initially treated with pressurization in the Bag had satisfactory improvement at 1 and 12 h, but their symptom scores relapsed to 7 and 9, respectively, after 12–24 h. Symptoms were once again relieved with pressurization for 1 h and subsequently did not return. No subject initially choosing pressurization elected to cross over to acetazolamide. Four of the six subjects undergoing pressurization and one of the four

Table 2. Mean altitude illness (AMS) scores (Table 1) and standard deviations in selected treatment groups at 0, 1 and 12 h.

Treatment group (n)	*0 h*	*1 h*	*12 h*
Acetazolamide (4)	6.0 ± 0.5	5.5 ± 1.0	4.5 ± 2.3
Gamow Bag (6)	6.8 ± 0.9	2.7 ± 1.2	1.0 ± 1.3
Acet/Gamow (3)[a]	6.0 ± 1.3	2.7 ± 1.8	1.7 ± 1.1
Repeat Gamow (2)[b]	8.0 ± 1.0	4.0 ± 4.0	1.0 ± 1.0

[a]Initially treated with acetazolamide, then treated in Gamow Bag™ 12 h later.
[b]Initially treated in the Gamow Bag™, then re-pressurized 24 h later.

choosing acetazolamide felt sufficiently well (symptom score 0) to continue their ascent to the Thorung Pass on their scheduled itinerary (all itineraries include a planned rest day in Manang). The remaining subjects, all of whom underwent either crossover or repeat pressurization at 12 h, remained in Manang for an additional day. All treated subjects in both groups successfully crossed the Thorung Pass.

Discussion

Acute mountain sickness can be categorized as mild, moderate, or severe. Although these categories are somewhat subjective, accurate diagnosis directs the degree of effort that must be expended in treatment and evacuation. Descent continues to be the definitive treatment for all forms of altitude illness. The dilemma of moderate mountain sickness is whether to treat at altitude or to descend with the victim. Our study addresses the use of pressurization for treatment of moderate AMS.

Definitions of mild, moderate, and severe AMS are not standardized. We regard mild AMS as an illness characterized by headache, nausea, anorexia, and lethargy. Subjects with these symptoms would score 2–4 on the AMS symptom questionaire by our examiners. Treatment with oral analgesics and rest usually results in gradual allevation of mild symptoms, and ascent may be continued after the victim feels well. Descent or aggressive medical therapy is usually not warranted.

Severe AMS is a potentially fatal syndrome heralded by severe headache, vomiting, ataxia, dyspnea at rest, and lassitude. The victim needs assistance for simple activities of daily living and ambulation. Such symptoms correspond to AMS symptom scores of 12–18, and indicate the presence of life-threatening high altitude pulmonary or cerebral edema (HAPE or HACE). Immediate descent is required. Medical therapy, including dexamethasone, acetazolamide, nifedipine, and/or oxygen may be initiated as adjuncts to, but not as substitutes for, descent. It is not yet known if treatment with pressurization mimics descent sufficiently to obviate the need for it.

Symptoms of moderate AMS are milder than those of severe AMS and correspond to scores of 5–11 on the symptom questionnaire. Although uncomfortable, victims of moderate AMS may not require immediate evacuation; resting at the same elevation may result in gradual improvement. However, clinical criteria have not been established to aid in deciding which persons can safely be held at altitude to recover, and which persons need immediate descent. On an organized group trek, this can create an obvious logis-

tical problem. Descent of an ill trekker is usually not included in the itinerary, and so the group must then be divided. Unaffected members may be reluctant to sacrifice their journey to accompany the victim. These emotions may influence a group leader into down-playing the severity of an afflicted member's symptoms.

The ideal treatment for moderate AMS is one which provides rapid relief with long lasting benefit. It should be practical, free of adverse effects, and not disqualify continued ascent. Oxygen is widely used as a treatment for AMS and HAPE. However, metal tanks are awkward and heavy to carry; the few trekking groups that carry oxygen usually transport only a single bottle. Any group carrying this precious commodity would be hesitant to use it to relieve the symptoms of moderate AMS, when it could prove life-saving later in the trek for someone who might develop HACE or HAPE. While oxygen administration provides rapid relief and is free of adverse effects, its benefit is severely limited by the supply.

Acetazolamide has not been shown to be effective in treating AMS in controlled studies, although it has been well established as efficacious for prophylaxis [5–7]. Side effects from acetazolamide are frequent, but minor, and there is no danger of rebound illness after abrupt discontinuation. However, it has a significantly delayed onset of action. In our study, three of four subjects taking acetazolamide had no significant relief from symptoms of moderate AMS 12 h after taking it; one person felt worse. The dose of acetazolamide effective for treatment of AMS has not been established; 250 mg every 12 h is the dose commonly used for prophylaxis. In our study, no subject was willing to endure the prospects of an additional 12 h of mountain sickness to determine if the drug would eventually prove effective, given that an apparently more beneficial treatment was available.

Dexamethasone is the only proven pharmacological treatment for moderate AMS [8,9]. Administration has been shown to provide significant improvement in AMS symptom scores at 6–12 h [4]. However, it has also been shown that symptomatic improvement with its use does not correlate with reversal of pathophysiologic parameters, nor does the drug aid in acclimatization [9]. Furthermore, a rebound effect has been observed following discontinuation of the drug [4]. Thus, it has been recommended that dexamethasone be reserved for emergency treatment of acute mountain sickness to facilitate safe descent to a lower altitude [8]. Once dexamethasone treatment has been started, further ascent should be delayed until the victim remains symptom-free after the drug has been discontinued. Our study did not compare treatment with pressurization to that with dexamethasone.

Pressurization appears to circumvent many limitations. It is well tolerated; no study subject complained of adverse effects. Hyperbaric pressure on the middle ear during 'descent' was easily equalized by all subjects. Relief of AMS symptoms was dramatic, with most patients reporting nearly complete relief of symptoms within 10–15 min of pressurization. Its use did not disqualify further ascent. The current limitations of this modality are the cost and limited availability of the apparatus. One bag may ultimately be used to treat many victims, so a large initial expense may be spread out over many users. It should be noted that our experience in field use at the Aid Posts over the past four climbing seasons has revealed problems with clogging of the pressure-relief valves after as few as 15 treatments. The functional life of the Gamow™ Bag in the field remains to be determined.

Hypobaria and hypoxia have been implicated in the etiology of acute mountain

sickness [10,11]. Pressurization reverses both, as inspired PO_2 within the bag is effectively increased as the pressure increases. In our study, arterial blood oxygen saturation measurements were not available and could not be included in the participants' evaluations. Oximetry measurements on other subjects have shown that increases in arterial oxygen saturation inside the bag are equivalent to those attained by breathing oxygen at a rate of 2 liters per minute outside the bag [12]. The manufacturer claims that maintaining air circulation through the pressure-relief valves with continuous foot pumping at a rate of 10–15 strokes per minute will prevent the accumulation of carbon dioxide. This has not been measured in the field.

In this study, we noted prolonged or complete recovery in subjects treated for relatively short periods of time. In four of six subjects, a 1 h treatment provided complete recovery, such that the subjects were able to cross the Thorung Pass (5380 m) in the ensuing days without further therapy. In two other subjects, relief lasted less than 24 h and a repeat treatment period was required for persistent improvement. The mechanism of prolonged beneficial effect is not understood, nor has the effect been previously described. This observation should be evaluated in further trials.

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