BRIEF REPORT

The Snow Snorkel: A Proof of Concept Study

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Objective.—To demonstrate that the Snow Snorkel can be used safely by healthy volunteers buried in snow for up to 1 hour.

Methods.—Nine healthy male volunteers were placed in a shoulder-width trench and buried with snow to a depth of 30 to 40 cm. The study was divided into 2 stages. The first stage (Stage 1) was performed with the Snow Snorkel in operation (60-minute duration) and was then followed by a second stage (Stage 2) (15-minute duration) when the device was removed. Arterial oxygen saturation (SaO₂), heart rate (HR), respiratory rate (RR), axillary temperature (T), and 3-lead electrocardiography (ECG) were monitored throughout the study.

Results.—Of the 9 volunteers who were enrolled, 7 were able to complete Stage 1, while only 3 were able to complete Stage 2. In those who completed Stage 1, the mean HR fell by 14.1 beats/min ($P = .002$), while RR ($P = .5$) and SaO₂ ($P = .7$) remained unchanged compared to baseline measurements. There were no changes in T or ECG.

Conclusions.—Simple systems such as the Snow Snorkel are effective during snow burial and warrant further investigation.

Key words: avalanche, snow burial, asphyxia, carbon dioxide

Introduction

Each year avalanches claim the lives of significant numbers of skiers, snowboarders, and mountaineers across the world. Although many of these deaths are due to trauma, the majority survive the initial impact of the avalanche and eventually die from suffocation.¹ A group from the University of Utah^{2,3} has shown that following snow burial in a simulated avalanche, adequate oxygenation and clearance of waste gases is possible for up to 60 minutes in healthy human volunteers, provided there is some means of diverting expired gas away from the face. One device that is capable of this is the AvaLung (Black Diamond Equipment Ltd, Salt Lake City, UT). According to information published on the AvaLung

Web site, this device may have been responsible for saving the lives of at least 5 skiers and snowboarders.⁴ Despite this, it is the opinion of the authors that the AvaLung and other commercially available devices are not in widespread use. While the reasons for this are uncertain, the cost, weight, and difficulty in using these devices may be mitigating factors. The intention of this “proof of concept” study is to take the first steps in determining whether a new, cheap, lightweight, and simple-to-use alternative (Figure 1) can be used comfortably for long periods of time by those buried under snow.

Methods

This study was completed with ethical approval from University College London, and all volunteers provided written informed consent.

SUBJECTS

Nine healthy male volunteers were enrolled in the study. Two volunteers were unable to tolerate the study and

E.H. is the inventor of the Snow Snorkel and is involved in the production and marketing of the product for commercial use. J.S.W., M.P.G., M.J.O'D., and J.S.M. have no financial interests in the Snow Snorkel.

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Figure 1. The Snow Snorkel.

withdrew after 2 and 6 minutes, respectively, during Stage 1. The age, mass, and height of the remaining 7 volunteers are summarized in Table 1.

PROCEDURE

The trial was conducted in a ski resort in the French Alps at an altitude of 2330 m and closely followed previous methods.^{2,3} A snow mound of approximately 3 m in height was created by a mechanical snow plough and a shoulder-width trench was excavated. A tent was erected on a platform cut close to the subject's head in order to house the observers and monitoring equipment. After monitoring probes were attached, each volunteer sat in the trench and was buried to a minimum depth of 30 to 40 cm, with his head, trunk, and limbs fully covered (Figure 2). This not only made it possible for each volunteer to communicate with observers by voice, but it also allowed the volunteer an opportunity to break out by simply punching through the snow without assistance.

The study was divided into 2 stages separated by a short period of rest. The first stage (Stage 1) was performed with the Snow Snorkel in operation (60-minute duration) and was followed by a second stage (Stage 2)

Table 1. The age, weight, and height of the 7 male volunteers who completed Stage 1

Subject	Age	Weight (kg)	Height(m)
1	46	75	1.80
2	26	75	1.90
3	23	80	1.80
4	35	82	1.80
5	19	75	1.80
6	22	75	1.82
7	49	72	1.72
Mean	31.4	76.3	1.81

(15-minute duration), during which the device was removed. The study was abandoned when the following conditions were met: 1) There was a fall in arterial oxygen saturations (SaO_2) below 85%; 2) There was a fall in axillary temperature below 35°C; 3) There was a respiratory rate above 20 breaths per minute for 3 consecutive minutes; or 4) The subject was too uncomfortable to continue.

The 2 stages were separated by a period of rest lasting a minimum of 5 minutes. During this time the snow surrounding the head of the volunteer was cleared and the Snow Snorkel was removed from the mouth. This allowed the volunteer an opportunity to breathe ambient air and permitted physiological measurements to return to normal prior to reburial.

INSTRUMENTATION

The following monitoring was completed (Dash 4000 Monitor, GE Healthcare, Chalfont St Giles, UK): 1) SaO_2 ; 2) heart rate (HR); 3) respiratory rate (RR); 4) axillary temperature (T); 5) 3-lead electrocardiography (ECG).

During Stage 1 each measurement was recorded at an interval of 1 minute for the first 30 minutes. Since a steady state was reached by this point in all volunteers, recordings were then made every 2 minutes for the remaining 30 minutes. In Stage 2, measurements were obtained at intervals of 1 minute throughout the stage.

EQUIPMENT

Over normal cold-weather ski clothing each subject wore a large down parka into which the Snow Snorkel was attached (Figure 1). The Snow Snorkel consisted of a simple mushroom mouthpiece attached to a rigid plastic tube of length 45 cm (18 inches) and internal diameter 1 cm. The mouthpiece was spring-loaded so that on

Figure 2. The snow burial of a volunteer.

pulling a ring-pull it stood out about 5 cm (2 inches) and comfortably fitted into the mouth. The lower end of the tube was positioned near the subject's waist or hip. Prior to burial, the subject was instructed to place his gloved hands over his face and insert the mouthpiece. Throughout Stage 1 the volunteer inspired through the nose or around the tube and exhaled directly into the Snow Snorkel.

The snow density covering each subject was measured by weighing a 2-L plastic container filled with a sample of packed snow. This was found to vary between 350 and 533 g·L⁻¹ (typical density of avalanche snow is 300–600 g·L⁻¹).¹

DATA ANALYSIS

Statistical analysis was performed using JMP Version 5.1 (SAS Institute Inc., Cary, NC) software. Normality was assessed using a Shapiro-Wilk *W* test. Changes in variables over time were assessed using a paired *t* test. A *P* value of <.05 was deemed significant.

Results

Although 9 volunteers were initially enrolled into the study, 2 found the experience too uncomfortable and

aborted the trial after 2 and 6 minutes, respectively, of Stage 1. This was attributed to shortness of breath and difficulties exhaling through the Snow Snorkel. The remaining 7 subjects were all able to complete Stage 1 (Table 2). Of those 7 subjects only 3 were able to finish Stage 2. The remaining 4 volunteers completed 4, 5, 6, and 11 minutes (mean 6.75 minutes), respectively, of Stage 2 (Table 3).

In the 7 volunteers who completed Stage 1, the mean HR fell by 14.1 beats/min (*P* = .002) from baseline. SaO₂ (*P* = .7) and RR (*P* = .5) measurements were unchanged compared to baseline measurements.

SaO₂, RR, and HR measurements during Stages 1 and 2 are presented in Tables 2 and 3.

No changes in axillary T and ECG pattern were observed during the study.

Discussion

The intention of our “proof of concept” study was to demonstrate that the Snow Snorkel could be safely used by subjects buried in snow for up to 1 hour. Although 2 of our volunteers were unable to use the device for the entire duration of Stage 1, 7 did so and reported that they would have been able to use it for considerably

Table 2. The SaO₂, heart rate, and respiratory rate of those volunteers who completed Stage 1

<i>Subject*</i>	<i>Initial SaO₂ (%)</i>	<i>Final SaO₂ (%)</i>	<i>Initial heart rate (bpm)</i>	<i>Final heart rate (bpm)</i>	<i>Initial respiratory rate (brpm)</i>	<i>Final respiratory rate (brpm)</i>
1	94	99	89	72	9	11
2	96	95	77	72	13	8
3	98	96	74	67	17	12
4	97	95	105	86	8	13
5	99	94	80	60	...	...
6	95	96	82	69	14	16
7	97	94	91	73	...	...
Mean	96.6	95.6	85.4	71.3	12.2	12

*As a result of technical difficulties with the monitoring equipment it was not possible to measure respiratory rate in volunteers 5 and 7.
bpm = beats per minute, brpm = breaths per minute.

longer. This is reflected by the unremarkable SaO₂, HR, and RR measurements recorded while the Snow Snorkel was in use.

In sharp contrast, only 3 volunteers were able to complete Stage 2. All 7 subjects reported symptoms of dyspnea, headache, agitation, and light-headedness during snow burial once the Snow Snorkel was removed. As a safety feature, the design of this study allowed volunteers to withdraw as soon as they began to feel uncomfortable. Consequently, most terminated Stage 2 prior to demonstrating the profound physiological changes that would be needed for statistical confirmation of the Snow Snorkel's superiority. As 4 of the 7 subjects were unable to complete the 15 minutes assigned to Stage 2, it was felt by the authors that a statistical comparison between baseline and endpoint values would be statistically misleading. Nevertheless, the clear differences in SaO₂, HR, and RR underline the physiological changes to which

the subjects were exposed during the second stage of the study.

While our study shows that volunteers are able to breathe comfortably during snow burial with a simple valveless tube, the risk of inspiring exhaled gases remains high. In contrast, the AvaLung system contains inspiratory and expiratory valves that allow air from the snowpack to be inspired and waste gases to be vented away from the face. The valves in the AvaLung are housed in either a bandolier or a rucksack, some distance away from the user's mouth. While this is comfortable to wear, during snow burial access may prove to be difficult. By inserting a single 1-way valve near the Snow Snorkel's mouthpiece, it may be possible to not only avoid the inspiration of waste gases but also to allow users to relieve any obstruction by either blowing forcefully down the tube or squeezing the valve with their teeth.

Table 3. The SaO₂, heart rate, and respiratory rate of those who completed either all or part of Stage 2

<i>Subject*</i>	<i>Duration of Stage 2 completed (min)</i>	<i>Initial SaO₂ (%)</i>	<i>Final SaO₂ (%)</i>	<i>Initial heart rate (bpm)</i>	<i>Final heart rate (bpm)</i>	<i>Initial respiratory rate (brpm)</i>	<i>Final respiratory rate (brpm)</i>
1	15	94	89	63	100	12	19
2	6	96	91	73	89	17	22
3	15	96	96	70	78	16	18
4	4	96	94	95	84	13	25
5	6	98	97	65	80	...	...
6	11	93	95	78	81	20	32
7	15	97	91	73	75	...	...
Mean	10.3	95.7	92	68.7	84.3	14	18.5

*As a result of technical difficulties with the monitoring equipment it was not possible to measure respiratory rate in volunteers 5 and 7.
bpm = beats per minute, brpm = breaths per minute.

The 2 volunteers who were unable to complete Stage 1 complained of breathlessness and difficulties exhaling through the tube. While breathlessness may have been due to the inspiration of exhaled CO₂, the difficulty in exhaling, especially while breathless, may have been the result of significant amounts of expiratory resistance. According to the Hagen-Poiseuille equation, laminar flow is limited by the radius and, to a lesser extent, the length of the cylinder through which it passes.⁵ By increasing the internal radius from 0.5 to 0.7 cm (the smallest internal radius of the AvaLung system currently available), the rate of laminar flow in the Snow Snorkel would rise by a factor of more than 4 and result in a considerable reduction in expiratory resistance. Expiratory resistance can be reduced to a lesser extent by shortening the length of the tube. Our study has demonstrated that a tube measuring 45 cm is sufficient to vent exhaled gases. This is considerably shorter than the tubing currently used in the AvaLung system (67.5–118 cm). Shorter tubing not only reduces expiratory resistance but it also makes devices like the Snow Snorkel easier to incorporate into ski clothing or equipment.

We believe that this study has demonstrated that a simple valveless system is capable of maintaining comfortable levels of ventilation during snow burial. Nev-

ertheless, it is clear that a number of issues still need to be addressed. Further investigation is clearly warranted.

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