HYPOTHERMIA DURING SNOW BURIAL

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Abstract: The development of hypothermia during avalanche burial has never been prospectively studied. Previous retrospective reports of core body temperature in avalanche burial victims after extrication estimate an average decrease in core body temperature of – 3 ° C per hour. The objective of this study was to measure decrease in core body temperature during snow burial under conditions of normal blood carbon dioxide (CO2), or normocapnic conditions, as compared to conditions of elevated blood carbon dioxide, hypercapnic conditions. An elevated blood carbon dioxide is expected to occur during avalanche burial as persons rebreathed expired CO2. Eight subjects were buried breathing with a device that diverts expired air to the snow surface and maintains normocapnia. Three of the 8 subjects were also buried breathing with a device that diverts expired air around to the back of the subject (Avalung ™, Black Diamond Equipment, Ltd., Salt Lake City, Utah), which results in the gradual development of hypercapnia.

Physiologic measurements made at baseline and followed throughout the study burials included core body temperature, arterial oxygen saturation % (SpO2), partial pressure of end-tidal CO2 (ETCO2) in mmHg and partial pressure of inspired CO2 (PiCO2) in mmHg. The study set up consisted of a large mound of compacted snow of similar density to avalanche debris (mean density 35%, range 28% - 39%). Subjects sat in a trench dug into one end of the mound. While breathing on either the modified device that maintained normocapnia, or the AvaLung device that resulted in hypercapnia, subjects were completely buried in densely compacted snow with the head 50 cm under the surface. Study burial endpoints were after a time period of 90 minutes, when SpO2 % <84, core body temperature < 35 ° C or at the subjects request. Subjects were in constant communication with the surface crew via intercom.

During normocapnic burials breathing with the modified device where expired air was diverted to the snow surface, core body temperature decreased at a mean rate of - 0.7 ° C per hour (range - 0.33 to – 1.73 ° C per hour). End study respiratory parameters remained unchanged from mean baseline values of SpO2 96%, ETCO2 40 mm Hg and PiCO2 5 mm Hg. During the hypercapnic burials breathing with the AvaLung, core body temperature decreased at a rate of –1.2 ° C per hour in all three subjects. Respiratory parameters changed from baseline with the ETCO2 increasing to an end study mean of 59 mm Hg, PiCO2 increasing to 43 mm Hg and SpO2 decreasing to 90%. Core body temperature decreased at a rate of 1.5 to 3 times faster in the hypercapnic group as compared to the normocapnic group.

These preliminary data suggest the rate of decrease in core body temperature during snow burial is less than the previously reported 3 ° C per hour. As a result of rebreathing CO2 during snow burial, hypercapnia develops and appears to accelerate the rate of decrease in core body temperature. These findings may have important implications for triage and resuscitation of avalanche burial victims.

Keywords: Avalanche accidents, Avalanche rescue, Hypothermia, Hypercapnia

1. INTRODUCTION

Approximately 75% of avalanche deaths are due to asphyxiation, up to 25% to trauma and very few to hypothermia. Probability of survival is 92% for persons extricated within 15 minutes, but only 30% at 35 minutes, representing death from acute asphyxiation. Survival after 35 minutes is dependent on an air pocket for breathing, and is 27% at 90 minutes, but only 3% at 130 minutes, representing avalanche burial victims with an air pocket succumbing to late asphyxiation. Asphyxiation occurs during avalanche burial because carbon dioxide (CO_2) in expired air is rebreathed, resulting in an elevated blood CO_2 (a condition called hypercapnia) and a decreased blood oxygen level.

An artificial air pocket breathing device that diverts expired air away from an inspiratory air pocket (Avalung ™, Black Diamond Equipment, Ltd., Salt Lake City, Utah) may allow survival of avalanche burial victims by delaying development of hypercapnia. By diverting expired CO_2 away from the inspiratory air pocket, the AvaLung allows a buried person to breathe the air contained in the snow. In a prior study we demonstrated that breathing with this device during avalanche burial maintained adequate oxygenation for up to 60 minutes and delayed development of hypercapnia as compared to a control burial without the device. This device may prolong survival during snow burial and make the development of hypothermia a more important factor in survival.

Severe hypothermia and clinical death as a result of asphyxia can be difficult to differentiate when extricating avalanche burial victims. This is because severe hypothermia causes apparent asystole. Current international triage recommendations assume the average rate of decrease in core body temperature is $-3\,^\circ C$ per hour. This is based on retrospective data and has never been studied in a prospective fashion. Additionally, the influence of hypercapnia on the rate of decrease in core body temperature during snow burial is unknown. The development of hypercapnia is of significant concern in avalanche victims due to the closed air space from which an avalanche victim breathes and his limited capacity to dispose of expired carbon dioxide.

The objective of this study was to measure core body temperature during snow burial while subjects breathed using two different artificial air pocket devices. One device resulted in hypercapnia over time while the second maintained a normal blood CO_2, a condition called normocapnia. We hypothesized that the rate of cooling during snow burial was less than the reported - 0 3 ° C per hour and that hypercapnia would accelerate the rate of core body temperature cooling during avalanche burial.

2. METHODS

2.1 Subjects.

Subjects were healthy volunteers between the ages of 18 and 55. By reason of their place of residence or their recreational activities, subjects were adapted to the approximate altitude of the mountainous outdoor test site. Persons with lung, heart, liver, kidney, or neurologic disease were excluded from the study. Persons with psychiatric disorders such as psychosis, panic attacks, or phobias about enclosed spaces or immobility were also excluded. Other groups excluded from the study include pregnant women, mentally disabled persons, and cigarette smokers. A total of 8 subjects (Table 1) underwent burial under normocapnic conditions. Three of the 8 subjects also underwent burial under hypercapnic conditions. The LDS Hospital Research and Human Rights Committee approved this study, and written consent was obtained from the volunteers.

2.2 Experimental Setup

The burials for the study took place at Snowbird, Utah (2385m elevation, average barometric pressure 573 mm Hg) during the months of February and March 2000. Snow temperature was -1.5 to $-2\,^\circ C$ and mean snow density was 35% (range 28-39%) .The experimental set-up was designed to simulate avalanche debris with a large mound of snow compacted with body weight. Snow density was determined in multiple sites using a 250 cc wedge density cutter (Snowmetrics, Ft. Collins, CO) that measures the weight of water per cubic meter (kg/m^3). A shoulder width trench was dug into one end of the snow mound and a sitting platform created for the subject so that the head was 50 cm under the surface.

Two devices were used for breathing while buried in the snow. The device that maintained normocapnia has a one- way inhalation valve through which the subject breathes directly from the snow pack, without an air pocket. The subject expires through another one-way exhalation valve which diverts all the expired air, and hence CO_2, through tubing to the snow surface. The Avalung ™(Black Diamond Equipment, Ltd., Salt Lake City, Utah) is the second device used (Figure 1). With this device, the subjects inhale through a one-way valve from the snow pack via a 500cc air pocket. Expired air is diverted around the back through tubing connected to a second one-way valve, and hence, away from the inspiratory air pocket. In burials using this device, hypercapnia eventually develops.

2.3 Safety Arrangements

Amongst the surface team were two physicians trained in critical care and airway management who were present throughout all studies. Emergency resuscitation equipment was available.

A two-way intercom system was buried with the subject during each burial and continuous communication was maintained between the subject and the surface team at all times. Subjects were informed of the time every 5-10 minutes and updated on their physiologic parameters.

An oxygen back-up line capable of delivering 100% oxygen at 15 liters per minute flow was attached to the mouthpiece of the breathing device in case of emergency. The surface team had the ability to dig out and clear the head and airway of snow in less than a minute in the case of emergency and full body extrication could be accomplished in approximately five minutes.

Study burials were terminated at the subject's request, when SpO2 was less than 84%, core body temperature less than 35 ° C or after 90 minutes in the normocapnic burials and 60 minutes in the hypercapnic burials.

2.4 Physiologic Parameters

Physiologic parameters were measured at baseline while the subject breathed ambient air and throughout the course of the burial. These clinical measurements included core body temperature in ° C obtained by rectal probe, arterial oxygen saturation (SpO2) %, partial pressure of end-tidal CO2 (ETCO2) in mmHg, partial pressure of inspired CO2 (PiCO2) in mm Hg, respiratory rate (RR), heart rate (HR), and surface three lead electrocardiogram (ECG). ETCO2, PICO2, RR were monitored using a capnometer (CO_2SMO Plus Model 8100, Novametrix). Another capnometer was employed for ETCO2 measurements as well (NPB-75, Mallinckrodt). ECG, HR, SpO2 and core body temperature were measured using a portable patient monitor (NPB-4000, Mallinckrodt). A second digital pulse oximeter to measure SpO2 was used as well for backup (N-395, Mallinckrodt). These physiologic parameters were observed continuously and recorded every minute by the surface team.

2.5 Clothing

All subjects wore an identical lightweight insulation system consisting of a one-piece Gore-tex ™ suit over medium weight Capilene™ underwear, a hood and facemask with goggles, mittens and warm boots.

3 RESULTS

3.1 Normocapnic Burials

A total of 8 subjects underwent burial with the breathing device that maintained normocapnia. Table 2 summarizes the burials under these conditions. End study respiratory parameters remained unchanged from mean baseline values of SpO2 96%, PETCO2 40 mm Hg and PiCO2 5 mm Hg. Most subjects remained buried for a total of 90 minutes. One burial was terminated at 75 minutes due to the subject's rapid decrease in core body temperature. Core body temperature decreased at a mean rate of -0.7 °C per hour (range -0.33 to -1.73 °C per hour).

3.2 Hypercapnic Burials

Three of the subjects underwent burial with the Avalung and developed hypercapnia during their burials. This is consistent with the results of previous burials using this device, with hypercapnia developing by 60 minutes. Table 3 illustrates these burials. Respiratory parameters changed from baseline with the ETCO2 increasing to an end study mean of 59 mm Hg, PiCO2 increasing to 43 mm Hg and SpO2 decreasing to 90%. During the hypercapnic burials, core body temperature decreased at a rate of –1.2 °C per hour in all three subjects.

Table 4 and Figure 2 provide a direct comparison of the three subjects who underwent both burials.

4 DISCUSSION

4.1 Summary of the Findings

Our data show that, during snow burial, while breathing on a device that maintains normocapnia and wearing a lightweight clothing insulation system, decrease in core body temperature averages -0.7 °C per hour. Under similar conditions, wearing a device that results in the gradual development of hypercapnia, decrease in core body temperature is –1.2 ° C per hour. Hypercapnia appears to accelerate the development of hypothermia.

4.2 Influence of hypercapnia on the development of hypothermia

Hypercapnia is an important consideration in avalanche burial victims because it always occurs, with and without an artificial air pocket breathing device. The effect of hypercapnia on decrease in core body temperature during snow burial has not previously been studied. Two previous studies on humans in cold-water immersion reported that hypercapnia lowers the shivering threshold, but only one study found an increased cooling rate. Possible mechanisms of this observed acceleration in decrease in core body temperature include the onset of shivering at a lower core body temperature, increased respiratory heat loss secondary to hyperventilation and increased convective and conductive heat loss due to the vasodilatory effects of hypercapnia.

4.3 Influence of body fat percentage on the development of hypothermia

We found no correlation with rate of core body temperature decrease and body fat percentage or body mass index (BMI). Lower body fat percentage leading to the more rapid development of hypothermia is well documented in immersion hypothermia studies. The reason we did not obtain similar findings may be related to the nature of snow burial, the fact that the subjects wear insulating clothing that protects them from direct contact to the snow, or it may simply reflect an insufficient number of study burials to find a significant correlation.

4.4 Rate of core body temperature decrease during snow burial

Our findings demonstrate a significantly less rapid rate of decrease in core body temperature than previously the previously reported rate of 3 ° C per hour. This difference may be accounted for by the nature of the studies done to obtain this data. Much of the previous data was gathered retrospectively from avalanche burial victims and many of the victims were dead upon their recovery. It is unclear what the rate of core body temperature change is once the victim has expired, but our data suggest that a live person will cool much more slowly than an avalanche victim who has expired. Our study is the first prospective data gathered on live subjects and it may be different than previous retrospective data from dead as well as live extricated avalanche burial victims.

One potential limitation of this study is the snow temperatures at which our study burials were done. All our burials were done in –1.5 ° C to –2 ° C snows. Perhaps, with colder snow temperatures during some of the burials, we would have found a more rapid decline in core body temperature. Future studies should include burials at colder snow temperatures.

An international recommendation for triage of avalanche burial victims includes criteria based on body temperature measured in the field and the duration of burial. Under the current recommendations, a victim found with a core body temperature of 32 ° C (criteria for severe hypothermia) would be thought to be buried for a relatively shorter period of time and possibly not to have succumbed to death by asphyxiation. As such, resuscitation attempts would be pursued. If our findings were considered, the victim found at 32 ° C would have either died early or been buried for a long period of time to reach this degree of hypothermia. In this long period of time, the victim would likely have asphyxiated and resuscitation attempts may not be successful. In the presence of an artificial air pocket such as the Avalung, these same criteria would not be applicable, as asphyxia may have been averted.

We acknowledge that our study consists of a small number of subjects and further studies may be necessary to confirm our findings. However, hypothermia may be an important factor to consider in avalanche burial victims breathing with an Avalung as they are likely to have prolonged survival. This preliminary data could ultimately have important implications for avalanche burial victims.

5. REFERENCES

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FIGURES AND TABLES

BURIAL SUBJECTS CHARACTERISTICS					
SUBJECT NUMBER	AGE	SEX	BODY FAT %	SNOW DENSITY	SNOW TEMP (deg C)
1	36	M	18	32%	-1.5
2	39	M	22	32%	-1.5
3	29	M	6	32%	-1.5
4	44	M	26	39%	-1.5
5	29	M	13	39%	-1.5
6	29	M	18	28%	-1.5
7	19	F	13	28%	-1.5
8	35	F		38%	-2
mean	**33**		**17**	**34%**	**-1.6**

TABLE 1 - SUBJECTS

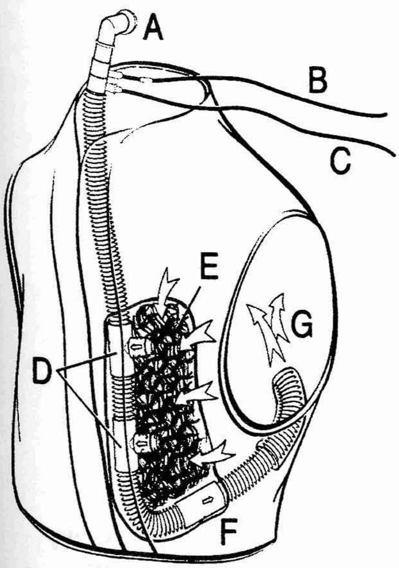

Figure 1 - Mechanism of the AvaLung "A" is the mouthpiece of the AvaLung which is connected by respiratory tubing to a plastic mesh air-pocket by two one-way inspiratory valves. During inspiration, air enters the respiratory tubing from the plastic mesh air-pocket via these two one-way valves. Air travels up the respiratory tubing to the mouthpiece. During expiration, air bypasses the one-way inspiratory valves and exits through the one-way expiratory valve around to the back. "B" and "C" are not required for function of the AvaLung, but were part of our experimental set-up. "B" is an End-Tidal carbon dioxide ($ETCO_2$) monitor and "C" is the emergency oxygen backup line.

CORE BODY TEMPERATURE DURING NORMOCAPNIC BURIALS									
SUBJECT NUMBER	BURIAL TIME (min)	SNOW TEMP (deg C)	ETCO2 (mm Hg)		PICO2 (mm Hg)		CORE BODY TEMPERATURE (DEG C)		
BURIAL			baseline	end	baseline	end	baseline	end	rate (°C/hr)
1	100	-1.5	40	47			37.5	36.5	-0.60
2	90	-1.5	32	35	3	4	37.1	36.2	-0.60
3	73	-1.5	38	38			37	34.9	-1.73
4	90	-1.5	36	37	5	3	37.6	36.8	-0.53
5	90	-1.5	39	40	8	10	37.5	37	-0.33
6	90	-1.5	45	39	5	5	37.6	36.4	-0.80
7	90	-1.5	38	28	4	9	36.7	36.1	-0.40
8	90	-2	31	28	4	4	37.5	36.8	-0.47
mean	**89**	**-1.6**	**37**	**37**	**5**	**6**	**37.3**	**36.3**	**-0.68**

TABLE 2 – PHYSIOLOGIC MEASUREMENTS OF THE EIGHT SUBJECTS UNDERGOING BURIAL WITH A TABLE MODIFIED BREATHING DEVICE WHICH MAINTAINS NORMOCAPNIA

CORE BODY TEMPERATURE DURING HYPERCAPNIC BURIALS									
SUBJECT NUMBER	BURIAL TIME (min)	SNOW TEMP (deg C)	ETCO2 (mm Hg)		PICO2 (mm Hg)		CORE BODY TEMPERATURE (DEG C)		
AVALUNG BURIAL			baseline	end	baseline	end	baseline	end	rate (deg C/hr)
6	60	-1.5	39	49	0	29	37.5	36.3	-1.20
7	35	-1.5	35	62	0	53	37.3	36.6	-1.20
8	60	-2	34	65	2	47	37.3	36.1	-1.20
mean	**52**	**-1.7**	**36**	**59**	**1**	**43**	**37.4**	**36.3**	**-1.20**

TABLE 3 – PHYSIOLOGIC MEASUREMENTS OF THE THREE SUBJECTS UNDERGOING BURIAL WITH A BREATHING DEVICE WITH WHICH HYPERCAPNIA DEVELOPS

	AvaLung Burial Change in Core Body Temperature (degrees C/hour)	Normocapnic Burial Change in Core Body Temperature (degrees C/hour)
Subject 6	-1.2	-0.8
Subject 7	-1.2	-0.4
Subject 8	-1.2	-0.5
Mean	-1.2	-0.6

TABLE 4- COMPARISON OF CORE BODY TEMPERATURE CHANGES DURING SNOW BURIAL IN THE SAME SUBJECTS UNDER NORMOCAPNIC AND HYPERCAPNIC CONDITIONS

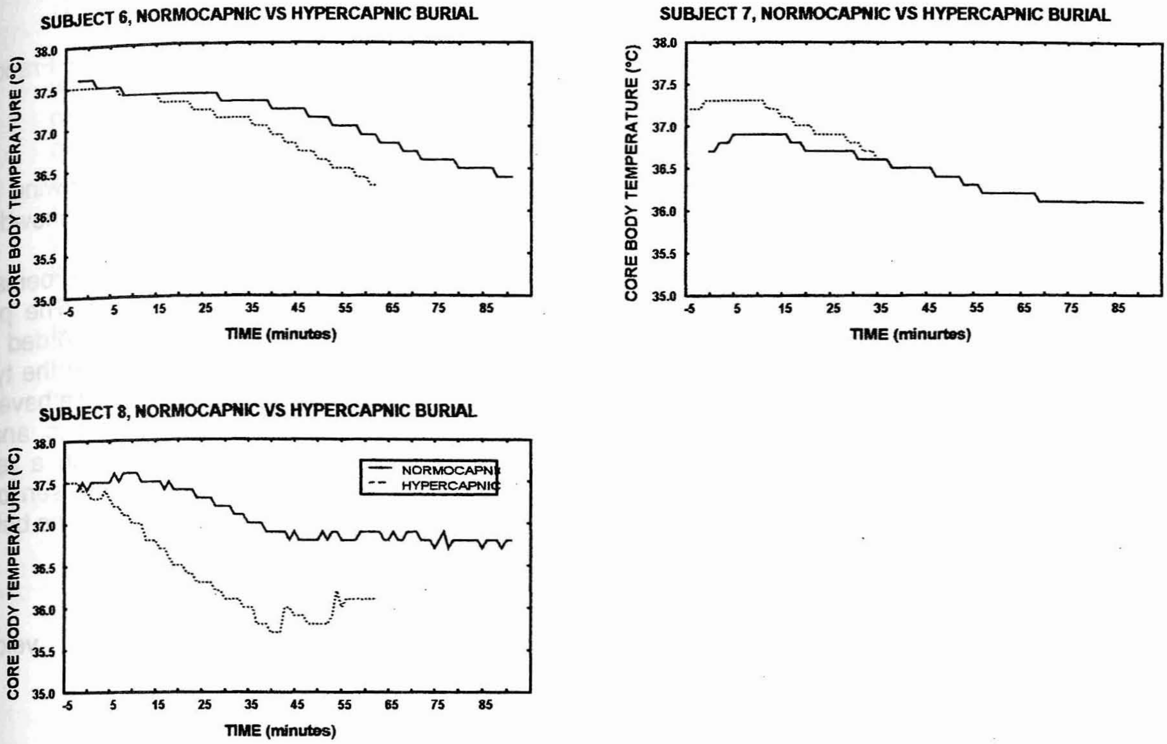

FIGURE 2 – GRAPHICAL REPRESENTATION OF CORE BODY TEMPERATURE CHANGE IN SUBJECTS DURING NORMOCAPNIC AND HYPERCAPNIC BURIALS