REWARMING MILD HYPOTHERMIA AFTER AVALANCHE BURIAL

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ABSTRACT:
Purpose: To determine if mildly hypothermic avalanche burial victims can be rewarmed in the field we measured esophageal core body temperature (T_{es}) during snow burial and after extrication during passive rewarming in a hypothermia wrap.
Methods: 6 subjects were buried in compacted snow (mean density 39%) for up to 60 minutes at an altitude of 2450 m (barometric pressure 571 mm Hg) while breathing with an AvaLung (Black Diamond Equipment, Salt Lake City, Utah). Mean snow temperature was -3.5 ±1.0ºC and mean air temperature was 0 ±2ºC. Subjects wore a one-piece Gore-Tex™ suit over medium weight Capilene™ underwear with a hood, face mask, goggles, mittens, and boots. After extrication from snow burial subjects were placed in a sleeping bag wrapped in a blanket on an insulating pad. All layers were wrapped in heavy plastic. T_{es} was measured for an additional 60 minutes as subjects rewarmed by shivering.
Results: T_{es} cooling rate during snow burial was 0.8 ±0.3ºC/hr during a mean burial time of 58 ±4 minutes. T_{es} continued to decrease for 12 ±8 minutes after extrication from snow burial (afterdrop) at a cooling rate of 4.0 ±0.8ºC/hr ($p<0.001$ T_{es} cooling rate during snow burial versus afterdrop cooling rate). Rewarming occurred at a rate of 1.1 ±0.3ºC/hr over the subsequent 48 ±8 minutes ($p=0.05$ snow burial cooling versus passive rewarming rate).
Conclusion: Core body temperature cooling rate after extrication from snow burial increased about fourfold for a transient time period in subjects who were placed as quickly as possible into an insulating hypothermia wrap. Passive rewarming increased core body temperature at about the same rate that it decreased during snow burial. These findings suggest that field rewarming of avalanche burial victims with mild hypothermia who are shivering is possible, but they should be insulated quickly to limit the significant afterdrop that may occur.

KEYWORDS: avalanche burial, avalanche rescue, hypothermia, afterdrop

1. INTRODUCTION

Survivors of avalanche burial require treatment for hypothermia (Brugger and Durrer, 2002: Brugger et al, 1996: Brugger et al, 2001). Knowledge of the severity of hypothermia after avalanche burial would be useful for rescuers to triage and treat avalanche burial victims. Mildly hypothermic avalanche burial victims could potentially be rewarmed in the field, while those with moderate or severe hypothermia would require rapid evacuation to a hospital for rewarming.

In a previous study we measured core body temperature cooling rate in subjects buried in snow wearing a lightweight clothing insulation system and found that core body temperature cooling rate was 1.2 ° C/hr (Grissom et al, 2004a). In a subsequent study we measured core body temperature cooling that occurs after removal from snow burial, which is called afterdrop. In subjects extricated from 60 minutes of snow burial and who ambulated 30 meters to a warming shelter, we found that core temperature cooling rate during afterdrop was 2.2°C/hr, more than 50% greater than the cooling rate of 1.3°C/hr during snow burial (Grissom et al, 2004b). This suggests afterdrop may significantly worsen hypothermia in extricated avalanche burial victims and significantly impair rewarming attempts in the field or during transport. The high rate of core temperature cooling during afterdrop that we observed,

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however, may have been due to ambulation of the subjects from the study site to a rewarming area, because exercise is known to increase afterdrop in studies of immersion hypothermia (Giesbrecht et al, 1987). We therefore designed this current study to measure core temperature afterdrop in subjects who are immediately packaged for transport in an insulating hypothermia wrap after extrication from snow burial.

Our previous studies also suggest that avalanche burial victims buried for periods of up to one hour, and who are extricated alive, should only have mild hypothermia (32 to 36°C) if core body temperature was normal (37°C) at the time of burial. Mildly hypothermic avalanche burial victims extricated alive should exhibit vigorous shivering. Studies of immersion hypothermia show that it is possible for mildly hypothermic persons to rewarm by shivering alone if dry insulation is provided, a method known as passive rewarming (Giesbrecht et al, 1987). We also designed this study to determine whether passive rewarming could attenuate afterdrop and rewarm subjects after extrication from snow burial.

In this study we hypothesized that afterdrop can be limited and passive rewarming can occur in subjects extricated from 60 minutes of burial in dense snow. In order to test this hypothesis we measured core body temperature in subjects buried in dense snow for up to 60 minutes. We continued to measure core body temperature for an additional 60 minutes after extrication from snow burial as subjects were placed in an insulating hypothermia wrap at the study site and allowed to rewarm by shivering alone.

2. STUDY SITE

This study was performed at 2450 m elevation (average barometric pressure, 571 ±3 mm Hg) at The Canyons ski resort in the Wasatch Mountains, Utah, during the winter months of 2005. Average ambient air temperature was 0 ±2°C during the studies. The experimental set-up consisted of a large mound of snow compacted with body weight and allowed to age harden for approximately two hours. Snow density was determined in multiple sites using a 1000 cc wedge density cutter (Snowmetrics, Ft. Collins, CO) that measured the weight of water per cubic meter (kg/m^3). Snow density is reported as a percent (i.e. 300 kg/m^3 is 30% density snow). Mean snow density was 39 ±3%. Snow temperature was measured with a dual thermocouple thermometer (Model 600-1040, Barnant Company, Barrington, IL). Mean snow temperature was – 3.5 ±1°C. 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 would be approximately 50 cm under the top surface of the mound after burial. Figure 1 shows the experimental burial site with a subject during extrication at the end of a study burial.

Figure 1. The study site with a subject buried in a mound of dense compacted snow while breathing with an AvaLung as core body temperature is monitored. At the end of 60 minutes the subject is extricated from snow burial.

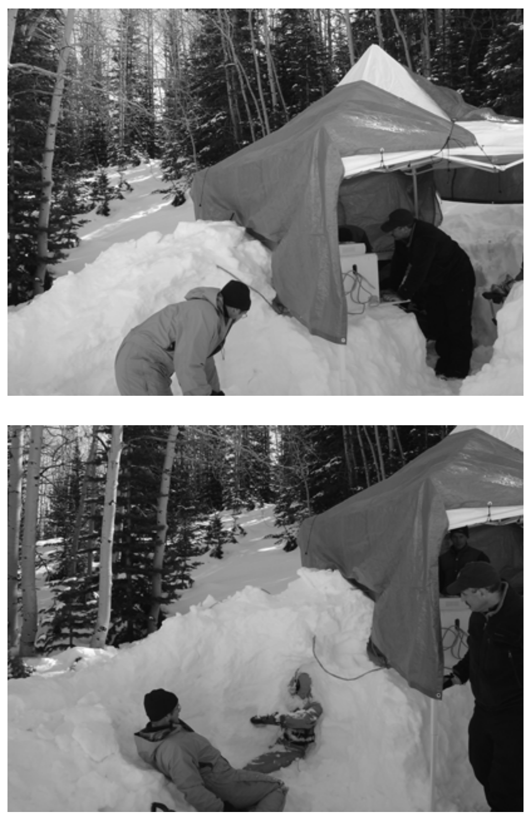

Figure 2. The breathing device used during the snow burial is shown (AvaLung 2™, Black Diamond Equipment, Ltd., Salt Lake City, UT). White arrows show flow of inspiratory air, and dark arrows show flow of expiratory air. The subject breathes in and out through the mouthpiece (A). An emergency oxygen back-up line (B) is attached directly into the mouthpiece apparatus and is used only if the subject becomes hypoxemic or requests to end the study. Monitoring lines (C, D) are connected to a device for measuring and recording inspired carbon dioxide ($PICO_2$), expired carbon dioxide ($ETCO_2$), and minute ventilation (respiratory rate times tidal volume of each breath V_E). Inhaled air enters from the snowpack through the 1-way inspiratory valve on the side of the housing inside the mesh-protected harness on the chest (E). Expired air leaves the lungs through the mouthpiece and travels down the respiratory tubing to the housing and then passes through an expiratory 1-way valve located at the bottom of the housing (E) and travels via respiratory tubing inside the harness around to the back (F).

Figure 3. Side view of a subject during extrication from burial at the end of a study.

Figure 4. Front view of a subject during extrication from burial showing the AvaLung breathing device.

3. METHODS

Subjects were fully buried in the snow for up to 60 minutes while breathing with an artificial device (AvaLung 2™, Black Diamond Equipment Ltd, Salt Lake City, Utah). After 60 minutes of snow burial subjects were extricated and immediately wrapped in insulating material and then allowed to rewarm by shivering for 60 minutes.

Subjects were healthy paid volunteers, 3 women and 3 men, mean age 27 $\pm$3 years, mean height 174 $\pm$5 cm, mean weight 66 $\pm$4 kg, mean BMI 22 $\pm$1. All subjects wore an identical lightweight clothing insulation system consisting of a one-piece Gore-tex™ suit (Patagonia, Ventura, CA) over medium weight Caplilene™ underwear (Patagonia), a hood and facemask with goggles, mittens and warm boots. The LDS Hospital Research and Human Rights Committee approved this study, and written informed consent was obtained from volunteers.

During snow burial subjects breathed through an artificial device that draws inspired air from the snowpack in front of the subject's chest and diverts expired air into the snowpack behind the subject (Figure 2-4). This device is used by some persons traveling in avalanche terrain and is intended to prolong survival during avalanche burial (AvaLung 2™, Black Diamond Equipment). In a previous study our group demonstrated that subjects breathing with this device during snow burial maintained adequate oxygenation for up to 60 minutes but gradually developed hypercapnia (high blood carbon dioxide) (Grissom et al, 2000).

Physiologic parameters were continuously monitored during the burial studies and were recorded every minute. These parameters included esophageal core body temperature (T_{es}) in °C obtained by a probe inserted through the nose and into the esophagus with the tip at the level of the heart. Core body temperature was also measured with a rectal probe (T_{re}) inserted to 15 cm. Esophageal and rectal temperature probes (model 401, YSI Incorporated, Yellow Springs, OH) were attached to a monitor (Propaq Encore, Protocol Systems Incorporated, Beaverton, OR) that also monitored surface three lead electrocardiogram (ECG). Ventilation parameters measured included partial pressure of end-tidal (expired) carbon dioxide ($ETCO_2$) and partial pressure of inspired carbon dioxide ($PICO_2$) in mm Hg, minute ventilation (V_E) in l/min (minute ventilation is respiratory rate multiplied by the volume of each breath) and percent saturation of hemoglobin with oxygen (SaO_2) (CO_2SMO Plus, model 8100, Novametrix, Wallingford, CT). Fraction of inspired carbon dioxide ($FICO_2$) was obtained by dividing $PICO_2$ by ambient barometric pressure. Arterial oxygen saturation (SaO_2) was measured by four different pulse oximeters (Propaq Encore, CO_2SMO Plus, and two Masimo SET Rad-5s, one with a finger and the other with a forehead probe, Masimo Corporation, Irvine, CA).

Immediately prior to burial subjects made a brisk uphill walk for 5 minutes and then returned to the study area where they were rapidly buried while sitting in the snow mound trench and breathing on the AvaLung. Snow was rapidly and densely compacted around their bodies until they were completely buried and immobile. Subjects were in communication with the surface team via intercom. Time –60 minutes of burial was noted when the subject's head was completely buried. During the burial subjects could communicate with the surface team via intercom if necessary. The study burial was terminated after 60 minutes, or when SaO_2 fell to $\leq$ 85%, or when core temperature dropped below 35°C, or at the subject's request. An emergency oxygen backup line was attached to the breathing device mouthpiece and could deliver 15 l/min of 100% oxygen.

After 60 minutes of burial subjects were extricated from the snow (time 0) and then immediately placed in a synthetic sleeping bag wrapped in a wool blanket on an foam pad (Figure 5). A heavy plastic vapor barrier was then wrapped around the wool blanket, sleeping bag, and foam pad. Core body temperature was monitored for an additional 60 minutes (to time 60).

Figure 5. At the end of the 60 minute snow burial the subject is immediately placed in a sleeping bag wrapped in a wool blanket on a foam pad and then wrapped in a heavy plastic vapor barrier. Core body temperature is monitored for 60 minutes as the subject passively rewarms by shivering.

Statistical Analysis

All data was compared using time 0 of extrication so that if a subject's snow burial portion of the study was less than 60 minutes, their data was adjusted so that end burial occurred at time 0 (extrication) and the start of burial occurred at minus the number of minutes of the duration of their study burial. Both T_{es} and T_{re} were recorded and are reported for comparison, but T_{es} is primarily used for data analysis due to the known lag of T_{re} during rewarming.

Cooling rate in °C/hr was calculated arithmetically using the T_{es} at extrication and T_{es} at the time of burial. Afterdrop cooling rate in °C/h was calculated arithmetically by using the nadir in afterdrop Tes and the Tes at extrication. Rewarming rate in °C/hr was calculated arithmetically by using the nadir in afterdrop T_{es} and the end study (60 minutes after extrication) T_{es}. Afterdrop cooling rate was compared to cooling rate during snow burial by a paired *t*-test. Cooling rate during snow burial and rewarming rate after the nadir of afterdrop were compared using a paired *t*-test. $P<0.05$ was considered statistically significant. Data are reported as mean ± standard deviation (SD).

4. RESULTS

T_{es} cooling rate during snow burial was 0.84 ±0.3 ºC/hr during a mean burial time of 58 ±4 minutes (Figure 6). T_{es} afterdrop occurred over 12 ±8 minutes after extrication from snow burial with a T_{es} cooling rate of 4.0 ±0.8 ºC/hr (p<0.001 snow burial as compared to afterdrop cooling rate). Even though cooling rate during afterdrop was 4.0 ±0.8 ºC/hr, the short duration (12 ±8 minutes) resulted in a mean afterdrop of 0.8 ±0.4ºC. Rewarming occurred after the nadir of the T_{es} afterdrop at a rate of 1.1 ±0.3 ºC/hr over the subsequent 48 ±8 minutes during passive rewarming (p=0.05 snow burial as compared to T_{es} passive rewarming rate).

T_{re} cooling rate during snow burial was similar to T_{es}. T_{re} afterdrop was 0.7 ±0.5ºC/hr (p=0.5 compared to T_{es} afterdrop), and the nadir of T_{re} afterdrop was at 26 +15 minutes (p=0.13 compared to T_{es} time to afterdrop nadir). T_{re} afterdrop cooling rate was 1.8 ±1.9ºC/hr (p=0.07 compared to T_{es} afterdrop cooling rate). T_{re} rewarming rate significantly lagged behind T_{es}.

During snow burial inspired CO_2 increased from 0.4±0.6% to 4.9 ±2.1% (p=0.005), end tidal CO_2 increased from 38 ±2 to 52 ±10 mm Hg (p=0.03), and minute ventilation increased from 14 ±2 to 33 ±9 liters/min (p=0.008). SaO2 decreased from 97 ±1 % to 91 ±5 % (p=0.02).

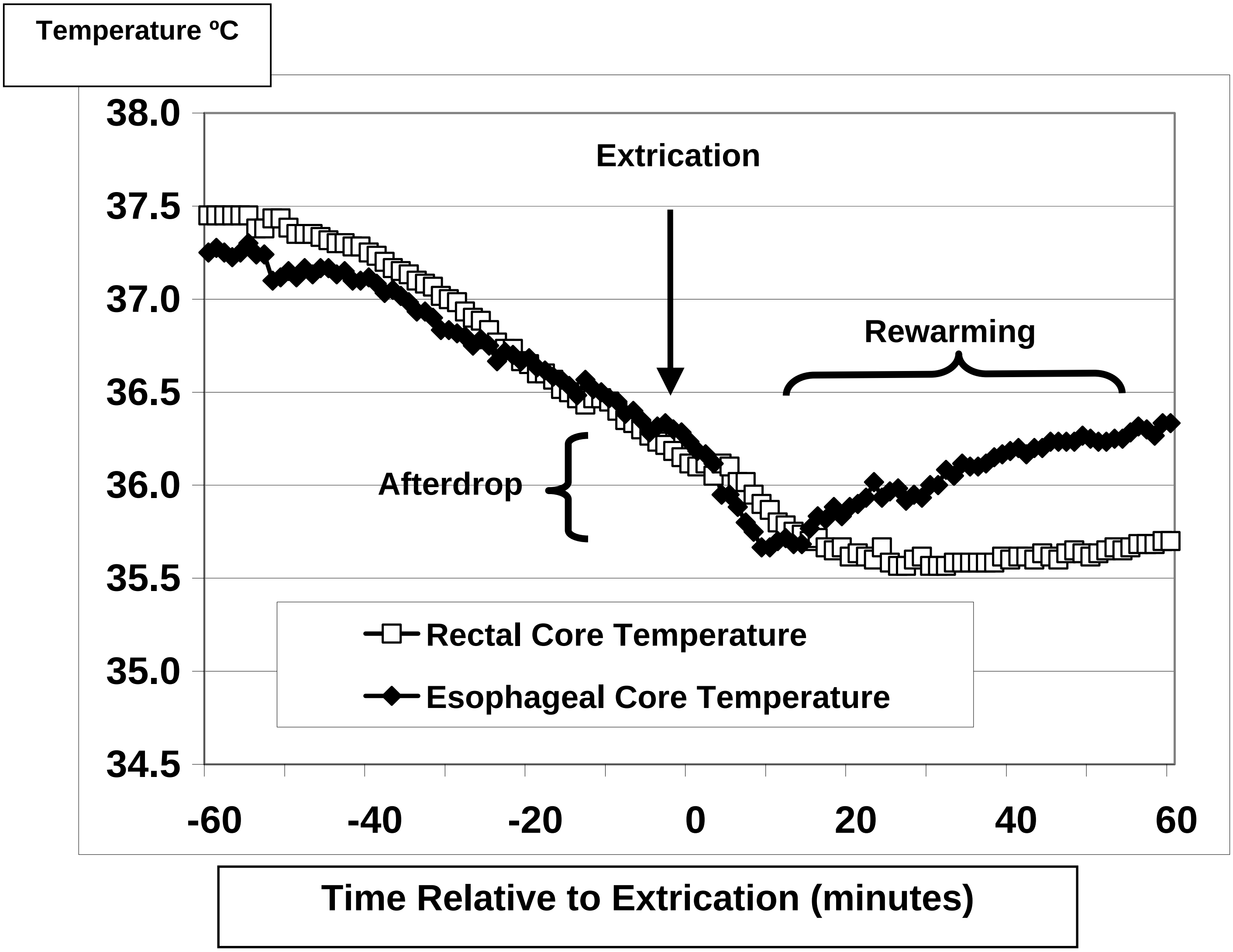

Figure 6. Esophageal (T_{es}) and rectal (T_{re}) core temperatures during snow burial and after extrication during passive rewarming. The T_{es} probe is at the level of the heart and most closely represents the "core" body temperature. T_{es} and T_{re} show about the same cooling rate during snow burial from minutes –60 to 0. Then at extrication from snow burial both T_{es} and T_{re} show an afterdrop, but the afterdrop of T_{es} is attenuated and the T_{es} shows rewarming of the core as insulation is provided to the shivering subject. T_{re} lags behind T_{es} during rewarming representing temperature gradients from the body core to the body shell as rewarming occurs. The findings suggest that core cooling rates during avalanche burial will cause only mild hypothermia during burials of up to about one hour in duration, significant afterdrop can occur in avalanche burial victims after they are extricated from snow burial and insulation should be provided as quickly as possible, and that avalanche burial victims who are awake and shivering after extrication from snow burial can be rewarmed in the field using passive rewarming methods (providing insulation and allowing shivering to rewarm the avalanche burial survivor).

5. DISCUSSION

We found that in subjects buried in dense snow for up to 60 minutes core body temperature cooling rate was 0.84 $\pm$0.3 ºC/hr. After extrication from snow burial afterdrop core cooling rate significantly increased to four times the cooling rate during snow burial (4.0 $\pm$0.8ºC/hr), but afterdrop was attenuated after just 12 $\pm$8 minute thus limiting afterdrop to 0.8 $\pm$0.4ºC. Passive rewarming increased core temperature at slightly faster rate than it decreased during snow burial (rewarming rate 1.1 $\pm$0.3ºC/hr, p=0.05 compared to cooling rate).

The findings in our study suggest that a mildly hypothermic and shivering avalanche burial survivor can be rewarmed in the filed if adequate insulation is provided. Our study also suggests that providing insulation as soon as possible to an avalanche burial victim is important to limit afterdrop. The possible mechanisms for the increased cooling rate during afterdrop in our study include conduction, convection, or increased activity by the subject upon extrication from snow burial. Exercise is known to cause increased afterdrop due to increased blood flow to cold peripheral tissues and cooling of the blood before returning to the heart (Giesbrecht et al, 1987). The abrupt increase in core cooling rate during afterdrop after extrication from snow burial suggests that increased activity and circulation of blood to cool extremities was the primary mechanism for afterdrop in our study (Mittleman and Mekjavic, 1988). This is consistent with the higher T_{es} afterdrop cooling rate that was accelerated by cold blood returning to the heart as compared to the T_{re} afterdrop cooling rate. Conductive cooling would have occurred at the same rate, or slower, as cooling during snow burial, and convective cooling would also be slower, especially in subjects wearing a one piece Gore-Tex suit.

The core temperature afterdrop in our study has important implications for medical care of avalanche burial victims. If possible, an avalanche burial victim should be insulated, kept supine, and placed in a rescue litter as quickly as possible after extrication from snow burial in order to limit afterdrop and potential complications from hypothermia. Although increased physical activity after extrication from avalanche burial should be avoided in order to limit afterdrop, this is not always possible for safety or logistical reasons, and extricated avalanche victims may need to ambulate in order to move to a location away from further avalanche danger or self evacuate from a backcountry location when a rescue litter and rescue team are not available. In a previous study (Grissom et al, 2004b) we simulated this situation and provided estimates of core temperature afterdrop that might occur in rescued avalanche burial victims who ambulate for short distances of 30 meters or less, and we found that T_{re} cooling rate during afterdrop was 2.2 $\pm$1.3ºC/hr, similar to the T_{re} afterdrop cooling rate in this study.

Hypothermia is the major medical problem requiring treatment in survivors of avalanche burial. Knowledge of core temperature cooling rate during avalanche burial would help rescue personnel estimate the severity of hypothermia and provide appropriate treatment for survivors. Few previous studies report core body temperature cooling rate during avalanche burial. Locher and Walpoth retrospectively studied 32 avalanche accidents where mean burial times and mean transport times to the hospital were over 60 minutes, and estimated that core body temperature cooling rate averaged 3°C/h from the time of burial in the avalanche to arrival at a hospital (Locher and Walpoth, 1996). Braun reported a similar average cooling rate over the time of burial and transport to a hospital in a retrospective analysis of five avalanche burial survivors (Braun, 1976). In the study that we report here, and in previous studies, we observed a lower core temperature cooling rate during snow burial of 0.8 to 1.3ºC/h (Grissom et al, 2004a: Grissom et al, 2004b). The difference in cooling rates between our studies and that of Locher and Walpoth might be explained by the rate of core temperature cooling after extrication from avalanche burial. The higher core temperature cooling rate reported by Locher and Walpoth included cooling during avalanche burial and after extrication during transport to a hospital. Cooling rate may have been higher after extrication due to core temperature afterdrop. Rapid core temperature afterdrop in extricated avalanche burial victims has been reported from clinical observations by Brugger and colleagues (Brugger et al, 1996), and is suggested by our observations of core temperature afterdrop in this study.

Lower cooling rates during avalanche burial have been reported when core body temperature is measured at the scene of avalanche accidents during extrication of a victim (Spiegel, 2002). A 25 year old male snowboarder survived avalanche burial for 20 hours with a large air pocket in front of his body and at the time of extrication had a core body temperature of 25.6°C (tympanic) in –5°C temperature snow and was spontaneously breathing with a Glasgow Coma Score of 8, heart rate 35, and a palpable pulse. Core body temperature cooling rate in this anecdotal report was about 0.6°C/hr, even lower than the cooling rates measured in our studies during snow burial.

In the controlled experimental set up in our study some factors that may occur in actual avalanche burial cannot be duplicated for safety reasons and core temperature cooling rate during actual avalanche burial may vary more than in our study. Avalanche burial victims may be unconscious or have traumatic injuries that could influence thermoregulation and increase core temperature cooling rate. Differences in clothing insulation may increase or decrease core temperature cooling rate. During prolonged burial core temperature cooling rate may not be linear and may plateau or accelerate below the core temperatures observed in our study. Persons buried in an avalanche may become more hypoxic than the subjects in our study, which may further accelerate core temperature cooling rate because hypoxia, independent of hypercapnia, can accelerate core temperature cooling rate (Johnston et al, 1996).

The artificial breathing device used in the hypercapnic burials in our study is worn by some persons traveling in high-risk avalanche terrain for use as an emergency breathing device if they are caught and buried in an avalanche. Survival after avalanche burial using this device has occurred (Radwin and Grissom, 2002). The results from our study may be applied by rescue personnel to estimate the severity of hypothermia in persons using this device for breathing after avalanche burial, or for persons buried in an avalanche breathing with an air pocket in the snow. Our study suggests that avalanche burial victims with an air pocket or an artificial breathing device who are extricated alive within an hour will only be mildly hypothermic and can be rewarmed in the field. In contrast, the results of our study may not be directly applicable to avalanche burial victims without an air pocket or an artificial breathing device.

6. CONCLUSIONS

Core body temperature cooling rate after extrication from snow burial increased about fourfold for a transient time period in subjects who were placed as quickly as possible into an insulating hypothermia wrap, but afterdrop was attenuated after a mean of only 12 minutes. Passive rewarming from shivering alone increased core body temperature at a slightly higher rate than it decreased during snow burial. This suggests that field rewarming of avalanche burial victims with mild hypothermia who are shivering is possible, but they should be insulated quickly to limit the significant afterdrop that can occur. An accelerated afterdrop cooling rate places avalanche burial survivors at greater risk of complications due to hypothermia. This is important information for rescue personnel who should keep the avalanche burial victim supine and provide insulation as quickly as possible in order to prevent further heat loss after extrication from the snow.

7. ACKNOWLEDGEMENTS

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