HYPOTHERMIA DURING AVALANCHE BURIAL

Colin K. Grissom MD, Chris H. Harmston MSE, Martin I. Radwin MD, Mary Beth Scholand MD, John C. McAlpine MD, J. Scott Morgan BA, Tim J. Bywater RN, Abigail W. Grissom JD.
LDS Hospital and the University of Utah, Salt Lake City, Utah.

ABSTRACT: Core body temperature cooling during avalanche burial results in hypothermia, and further core temperature cooling during extrication and evacuation of an avalanche burial victim may result in more severe hypothermia. We performed two studies measuring the rate of core body temperature cooling during snow burial and after extrication from snow burial. Subjects were completely buried in a large mound of age hardened snow (mean density 47%) while core body temperature was monitored with a rectal probe ($T_{re}$). All subjects dressed in a lightweight clothing insulation system consisting of a one piece gore-tex suit worn over medium weight capilene underwear with a hood, face mask, goggles, mittens, and boots. Inspired and expired carbon dioxide ($CO_2$) levels and arterial oxygen saturation ($SaO_2$) were also monitored.

In our first study avalanche burial was simulated by having 12 subjects breathe with a device (Avalung 2™, Black Diamond Equipment Ltd.) that resulted in hypercapnia (high $CO_2$) over 30 to 60 minutes. Mean snow temperature was $-2.6 \pm 2.1 ^{\circ}C$. Burial time was 49 $\pm 14$ minutes. Rate of decrease in $T_{re}$ was $1.3 \pm 0.5 ^{\circ}C$ / hr. The fraction of inspired carbon dioxide ($FICO_2$) increased from 1.4 $\pm 1.0$ % to 7.0 $\pm 1.4$ % and $SaO_2$ decreased from 97 $\pm 1$ % to 90 $\pm 6$ % ($P<0.01$).

In a second separate study 11 subjects were buried for 60 minutes breathing an inspired gas mixture containing 5% $CO_2$ and 21% oxygen ($O_2$). $T_{re}$ cooling rate was $1.3 \pm 0.4 ^{\circ}C$/hr. $SaO_2$ remained $> 90$% for all subjects. In this study we also measured core body temperature for 30 minutes after extrication from the snow during passive rewarming. Maximum $T_{re}$ cooling rate during passive rewarming increased to $2.2 \pm 1.3 ^{\circ}C$/hr at 20 $\pm 8$ minutes after extrication.

$T_{re}$ cooling rate during snow burial was $1.3 ^{\circ}C$/hr. This suggests that survivors of prolonged avalanche burial may not become as rapidly hypothermic as previously thought. The greatest $T_{re}$ cooling rate occurred just after extrication from snow burial. This suggests that core body temperature cooling during extrication and evacuation significantly contributes to hypothermia in avalanche burial victims. Medical care of avalanche burial victims should include measures to insulate and rewarm as soon as possible after extrication.

1. INTRODUCTION

The development of hypothermia in avalanche burial victims is determined by core body temperature cooling during snow burial and after extrication from snow burial during patient packaging and evacuation. Previous studies suggest the average core body temperature cooling rate from the time of initial burial in an avalanche until arrival at the hospital is about 3 $^{\circ}C$/hr (Braun 1976, Locher 1996), and this cooling rate is used in international triage and treatment recommendations for avalanche burial victims (Brugger 1996, 2001, 2002).

No study has prospectively measured core body temperature cooling rate during avalanche burial or during extrication and evacuation.

Although hypothermia is a major medical problem requiring treatment in survivors of avalanche burial (Brugger 1996, 2001, 2002), asphyxiation is the major cause of death during avalanche burial (Falk 1994, Grossman 1989). Asphyxiation during avalanche burial occurs because increased carbon dioxide ($CO_2$) and decreased oxygen ($O_2$) in expired air are rebreathed, which results in hypercapnia (elevated blood $CO_2$) followed by hypoxemia (low blood $O_2$) (Grissom 2000, Brugger 2003). Inspired air contains about 0.03 % $CO_2$ and 21 % $O_2$. Expired air contains about 4 % $CO_2$ and 16 % $O_2$, thus rebreathing expired air causes increasing $CO_2$ (hypercapnia) and decreasing $O_2$ (hypoxemia) in the blood.
Previous studies have shown that development of hypercapnia and hypoxemia during avalanche burial are delayed by the presence of an air pocket in the snow for breathing (Brugger 2003) or by use of an artificial breathing device that diverts expired air away from inspired air drawn from the snowpack (Avalung, Black Diamond Equipment, Ltd., Salt Lake City, Utah) (Grissom 2000). If an air pocket or an artificial breathing device allow prolonged survival during avalanche burial by delaying development of severe hypercapnia and hypoxemia sufficient to cause death from asphyxiation, then more severe hypothermia may develop and require treatment after extrication.

In this paper we report two different studies investigating the development of hypothermia during simulated avalanche burial. In the first study we report the first prospective measurement of core body temperature cooling rate during snow burial under hypercapnic and normocapnic (normal blood CO2) conditions (Grissom 2004). We show that core body temperature cooling rate during snow burial is increased by hypercapnia but is less than the previously reported 3 °C/hr. In the second study we report the first measurement of core body temperature cooling rate during and after extrication from snow burial under hypercapnic and normocapnic conditions (Grissom 2004). We show that core temperature cooling rate accelerates immediately after extrication from snow burial.

2. STUDY SITE
The first study was performed at 2400 m elevation (average barometric pressure, 569 mm Hg) at The Canyons and Snowbird ski resorts in the Wasatch Mountains, Utah, during the winter months of 2000 and 2001. The second study was performed at 2500 m elevation (average barometric pressure, 563 mm Hg) at Deer Valley ski resort in the Wasatch Mountains, Utah, during the winter months of 2003.

3. METHODS
Study 1
In the first study we measured rectal core body temperature (Tmr) in 12 subjects wearing a lightweight clothing insulation system during two different snow burials. In one burial subjects became hypercapnic while breathing with an artificial device designed to prolong survival during avalanche burial (AvaLung 2™, Black Diamond Equipment). In a separate control burial subjects remained normocapnic while breathing with a modified device that draws inspired air from the snowpack but diverts all expired air out of the snowpack.

Subjects were healthy paid volunteers, 2 women and 10 men, mean age 32 ±7 years, mean height 178 ±5 cm, mean weight 76 ±9 kg, mean BMI 24 ± 3, and mean body fat percentage 15 ±7%. Tmr was measured in subjects during a hypercapnic study burial and during a separate normocapnic control study burial. The two study burials were separated by at least two hour rest and indoor rewarming period. All subjects wore an identical lightweight clothing insulation system for both study burials consisting of a one-piece Gore-tex™ suit (Patagonia, Ventura, CA) over medium weight Capilene™ underwear (Patagonia), a hood and facemask with goggles, mittens and warm boots. The LDS Hospital Research and Human Rights Committee approved this study and the protocol for study 2, and written informed consent was obtained from the volunteers.

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/m³). Snow density is reported as a percent (i.e. 300 kg/m³ is 30% density snow, or 70% air). Mean snow density for the hypercapnic burials was 48 ±6 % and for the normocapnic burials 46 ±9 % (P=0.45). Snow temperature was measured with a dual thermocouple thermometer (Model 600-1040, Barnant Company, Barrington, IL). Mean snow temperature during the hypercapnic burials was –2.6 ±2.1 °C, and during the normocapnic burials was –2.5 °C ±2.0 °C (P=0.37). 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
Two different devices were used for breathing while buried in the snow. During the hypercapnic study burials 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). 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 (Grissom 2000).

A second breathing device was used during the normocapnic study burials. It was similar to the device used in the hypercapnic study burials except that all expired air was diverted out of the snowpack (Figure 3). Inspiratory air was inhaled directly from the snowpack, similar to the breathing device used in the hypercapnic study burials. In a previous study (Radwin 2001) we showed that the device used in the normocapnic study burials maintained normal oxygenation and ventilation for up to 90 minutes in subjects fully buried in compacted snow.

Physiologic parameters were continuously monitored during the burial studies and were recorded every minute. These parameters included $T_{re}$ in °C obtained by a rectal probe inserted to 15 cm (model 401, YSI Incorporated, Yellow Springs, OH) 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 CO$_2$ (ETCO$_2$) and partial pressure of inspiratory CO$_2$ (PICO$_2$) in mm Hg, minute ventilation ($V_e$) in l/min and $SaO_2$ (CO$_2$SMO Plus, model 8100, Novametrix, Wallingford, CT). Fraction of inspired CO$_2$ (FICO$_2$) was obtained by dividing PICO$_2$ by ambient barometric pressure. Arterial oxygen saturation ($SaO_2$) was measured by three different pulse oximeters (Propaq Encore, CO$_2$SMO Plus, and an N-395, Mallinckrodt, St. Louis, MO).

The protocol for both study burials was identical except for the breathing device used. Subjects sat in the snow mound trench as snow was rapidly and densely compacted around their bodies until they were completely buried. Subjects were in communication with the surface team via intercom. Time 0 of burial was noted when the subject’s head was completely buried. During the burial the subject reported subjective onset of shivering to the surface team via intercom. The study burial was terminated after 60 minutes, or when $SaO_2$ fell to < 85%, or when $T_{re}$ dropped below 35 °C, or at the subject’s request. An emergency O$_2$ backup line was attached to the breathing device mouthpiece and could deliver 15 l/min of 100% O$_2$.
Figure 2. Study 1 Hypercapnic Burial. The breathing device used during the hypercapnic study burial in study 1 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 capnometer and record PICO2, ETCO2, and V̇E. 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. Study 1 Normocapnic Burial. The breathing device used during the normocapnic study burial in study 1 is shown. 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 capnometer and record PICO2, ETCO2, and V̇E. Inhaled air enters from the snowpack through the mesh-protected respiratory tubing (E) and passes through a 1-way inspiratory valve and then travels to the mouthpiece and into the lungs. Expired air leaves the lungs through the mouthpiece and travels down the respiratory tubing and then passes through a series of 1-way expiratory valves (F) that divert exhaled air through a separate extended respiratory tubing circuit out of the snowpack (G).
Study 2

Similar to study 1, $T_{re}$ was measured in subjects during a hypercapnic study burial and during a separate normocapnic control study burial. In this study, however, a fixed inhaled gas concentration of 5% CO$_2$ was used in the hypercapnic study. The subject breathed a 5% CO$_2$ and 21% O$_2$ inhaled gas mixture through a two-way non-rebreathing valve (model 1410BB, Hans Rudolph, Kansas City, MO) (Figure 4). In the normocapnic study ambient air was inhaled through the same two-way non-rebreathing valve. Expired air was diverted out of the snowpack via respiratory tubing to a metabolic analyzer (Parvo Medics TrueMax 2400, Salt Lake City, UT) for measurement of oxygen consumption ($V_O2$), carbon dioxide production ($VCO2$), and $V_E$. The inflection point of $V_O2$ versus time of burial was used to indicate an objective measure of onset of shivering as indicated by increased metabolic rate.

Subjects were healthy paid volunteers, 2 women and 9 men, mean age 33 ±8 years, mean height 177 ±6 cm, mean weight 75 ±10 kg, mean BMI 24 ± 2, and mean body fat percentage 14 ±4%. All subjects wore the same identical lightweight clothing insulation as used in Study 1.

The experimental set-up consisted of a large mound of snow constructed as described for Study 1. Snow density was determined as described for study 1. Mean snow density for the hypercapnic burials was 46 ±4 % and for the normocapnic burials 45 ±2 % ($P=0.72$). Snow temperature was measured as described for Study 1. Mean snow temperature during the hypercapnic burials was $-3.1 ±2.8$ °C, and during the normocapnic burials was $-3.4 ±2.7$ °C ($P=0.78$).

All subjects underwent two different study burials on different days. The order of burials, hypercapnic or normocapnic first, was alternated between subjects. During one burial the subject breathing the 5% CO$_2$ inhaled gas mixture and during the other burial the subject breathed ambient air. The protocol for both study burials was identical except for the inhaled gas mixture. Subjects were prepared in a heated shelter (15 °C) and then walked to the study site. 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 breathing the inhaled gas mixture. The protocol for study burial including safety parameters was identical to that for study 1. After 60 minutes of burial subjects breathed ambient air as they were extricated from the snow over about 10 minutes and then walked back to the heated shelter (15 °C) for passive rewarming. $T_{re}$ was monitored for an additional 30 minutes after completion of the 60 minute burial as the subject was extricated from the snow and rewarmed indoors.
Statistical Analysis

Core body temperature change from baseline $T_{re}$ ($\Delta T_{re}$) was calculated minute by minute for each subject by subtracting $T_{re}$ data every minute throughout the study from $T_{re}$ at time 0. Cooling rate in °C/hr with 95% confidence limits (CL) was determined by multiple regression analysis of $\Delta T_{re}$ data for all subjects from time 0 of burial to the end of the study. Cooling rate in °C/hr was also calculated arithmetically by subtracting the end study $T_{re}$ from time 0 $T_{re}$ and then dividing by the burial time in hours for the study. Cooling rate determined by arithmetic calculation in the hypercapnic and normocapnic groups was compared by a paired $t$-test. Correlation between $T_{re}$ cooling rate and end study value for ETCO2 and correlation between $\Delta T_{re}$ and ETCO2 were determined using multiple regression analysis. $T_{re}$, SaO2, ETCO2, FICO2, and $V_E$ at time 0 and at the end of the study in the hypercapnic and normocapnic studies were compared by a paired $t$-test. $\Delta T_{re}$ at which onset of shivering occurred was compared between the hypercapnic and normocapnic studies using a paired $t$-test. $\Delta T_{re}$, SaO2, ETCO2, FICO2, and $V_E$ data for each subject every minute from time 0 to the end of the study in the hypercapnic group was compared to the same data for each subject in the normocapnic group using a one-way ANOVA. Statistica (StatSoft, 1999 edition, Tulsa, OK) software was used for all statistical analysis. $P<0.05$ was considered statistically significant. Data are reported as mean ± standard deviation (SD).

4. RESULTS

Study 1

The $T_{re}$ cooling rate during the hypercapnic burial was 1.2 °C/hr by multiple regression analysis (95% CL 1.1 to 1.3 °C/hr) and was 1.3 ±0.5 °C/hr by arithmetic calculation. The $T_{re}$ cooling rate during the normocapnic burial was 0.7 °C/hr by multiple regression analysis (95% CL 0.6 to 0.8 °C/hr) and was 0.6 ±0.6 °C/hr by arithmetic calculation ($P=0.001$, hypercapnic versus normocapnic cooling rate) (Figure 5). Shivering onset occurred at a lower $\Delta T_{re}$ in the hypercapnic study (−0.5 ±0.5 °C) than in the normocapnic study (0.1 ±0.4 °C) ($P<0.05$).

Mean burial time in the hypercapnic burial of 49 ±14 minutes was less than the normocapnic burial time of 60 minutes for all subjects ($P=0.02$). 5 of the 12 subjects in the hypercapnic burial requested termination prior to 60 minutes at times of 26, 30, 35, 38, and 42 minutes. The reason for terminating the study prior to 60 minutes was subjective dyspnea in all 5 subjects, associated with hypoxemia (SaO2 < 85%) in 3 subjects. Mean FICO2, $V_E$, and $\Delta T_{re}$ for the hypercapnic and normocapnic burials are shown in Figure 5.

Figure 5. Study 1 Data: Mean fraction of inspired carbon dioxide (FICO2; A), minute ventilation ($V_E$; B), and rectal core body temperature ($T_{re}$; C) during burial in dense snow for up to 60 minutes during the hypercapnic and normocapnic studies ($n=12$). 5 of the subjects in the hypercapnic study did not complete the full 60 minutes of burial (studies terminated at 26, 30, 35, 38, and 42 minutes). $T_{re}$ data are presented as difference from values at time 0 of burial ($\Delta T_{re}$). Bars, SD. *Significant difference between the hypercapnic and the normocapnic study, $P<0.05$. 

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FICO₂ increased significantly during the hypercapnic study from 1.4 ±1.0 % to 7.0 ±1.4 % at the end of the hypercapnic study (P<0.001). This increase in FICO₂ resulted in an increase in ETCO₂ during the hypercapnic study from a baseline of 39 ±7 mm Hg to an end study value of 58 ±9 mm Hg (P<0.001). ETCO₂ in the hypercapnic study significantly correlated with ΔTₑₑₑₑ(ₚ <0.001). End study values for ETCO₂ from all 24 study burials (hypercapnic and normocapnic) also significantly correlated with Tₑₑₑₑ cooling rate data (P=0.02). The increased FICO₂ and hypercapnia resulted in an increased Vₑ during the hypercapnic burial from a baseline of 15 ±7 l/min to an end study value of 40 ±12 l/min (P<0.001). SaO₂ decreased during the hypercapnic burial from 96 +3 % to 90 +6 % (P=0.003). End study values of ETCO₂, FICO₂, and Vₑ were all significantly greater in the hypercapnic than in the normocapnic burial (P<0.001), and the end study value of SaO₂ was less in the hypercapnic than in the normocapnic burial (P=0.01). ETCO₂, FICO₂, Vₑ, and SaO₂ were unchanged during the normocapnic study.

**Study 2**

The Tₑₑₑₑ cooling rate during the hypercapnic burial was 1.33 °C/hr by multiple regression analysis (95 % CL 1.28 to 1.38 °C/hr) and was 1.3 ±0.4 °C/hr by arithmetic calculation. The Tₑₑₑₑ cooling rate during the normocapnic burial was 0.98 °C/hr by multiple regression analysis (95% CL 0.93 to 1.02 °C/hr) and was 1.0 ±0.4 °C/hr by arithmetic calculation (P<0.05, hypercapnic versus normocapnic cooling rate)(Figure 6). Shivering onset occurred at a lower ΔTₑₑₑₑ in the hypercapnic study (−0.5 ±0.5 ° C) than in the normocapnic study (0.1 ±0.4 °C) (P<0.05). SaO₂ % as measured by a pulse oximeter remained > 90% for all subjects during both study burials. Maximum Tₑₑₑₑ afterdrop in the hypercapnic study was 0.7 ±0.4 ° C at 20 ±8 minutes, and maximum Tₑₑₑₑ afterdrop in the normocapnic study was 0.9 ±0.3 ° C at 23 ±5 minutes (P=0.11). Maximum cooling rate in the hypercapnic group increased to 2.2 ±1.3 ° C/hr over the first 20 ±8 minutes after extrication, and maximum cooling rate in the normocapnic group increased to 2.5 ±1.4 ° C/hr over the first 23 ±5 minutes after extrication (P=0.60 hypercapnic versus normocapnic).

**Figure 6. Study 2 Data:** Rectal core body temperature (Tₑₑₑₑ) during burial in dense snow for 60 minutes during the hypercapnic and normocapnic studies (n = 11). Tₑₑₑₑ data are presented as difference from values at time 0 of burial (Change in Tₑₑₑₑ) on the y-axis, and time relative to start of full burial in minutes is on the x-axis. Subjects were extricated from the snow after 60 minutes, and data at 70, 75, 80, 85, and 90 minutes represents Tₑₑₑₑ cooling rate (afterdrop) as subjects were extricated from snow and rewarmed in a heated (15 °C) shelter.

**5. DISCUSSION**

We found that hypercapnia increased core temperature cooling rate during snow burial. Subjects had a Tₑₑₑₑ cooling rate of 1.3 °C/hr with hypercapnia, as compared to 0.6 to 1.0 °C/hr while normocapnic. Hypercapnia may have increased Tₑₑₑₑ cooling rate by reducing the core temperature threshold for shivering or by increasing respiratory heat loss due to evaporation and gas warming during hypercapnia induced hyperventilation. Onset of shivering occurred at a lower core temperature from baseline with hypercapnia using a subjective measure of shivering onset in study 1, and using an objective measurement of shivering onset in study 2. These findings indicate that hypercapnia reduces the core body temperature at which shivering starts, and therefore delays rewarmin and accelerates development of hypothermia. Increased respiratory heat loss likely also occurred in the hypercapnic study burials because the end study value of Vₑ with hypercapnia was twice that with normocapnia in both studies. Similar results have been reported during cold water
immersion by other investigators who found that hypercapnia increased core temperature cooling rate due to depression of shivering threshold and increased minute ventilation (Johnston 1996).

The artificial breathing device used in the hypercapnic burials in study 1 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 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, defined as a core body temperature of about 32 to 36 °C and characterized by an increased metabolic rate with tachypnea, tachycardia, shivering, and altered judgment. Moderate or severe hypothermia, with an associated depression of metabolism and consciousness, would not be expected to occur until after prolonged avalanche burial of more than several hours when core body temperature reached less than 32 °C.

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 1996).

The results from our study suggest that average core temperature cooling rate during snow burial may be less than previously reported by other investigators in retrospective studies of hypothermia in avalanche burial victims. A core temperature cooling rate of 3 °C/hr during avalanche burial is frequently stated in the medical literature based on two retrospective studies (Braun 1976, Locher 1996). Both studies calculated an average core temperature cooling rate from the time of initial burial in the avalanche to the time of arrival at the hospital using measured core body temperature at hospital arrival. Both studies assumed that initial core body temperature was 36.5 °C at the time of initial burial in the avalanche. Neither study reported core body temperature measurements at the avalanche accident site.

The largest previous study to report a core temperature cooling rate of 3 °C/hr during avalanche burial is by Locher and Walpoth (1996) who reported a retrospective analysis of core body temperature measured at hospital arrival in 16 survivors and 16 non-survivors of avalanche burial. Trauma was not identified as a cause of death in any of the non-survivors. All 16 non-survivors and 1 survivor were found in cardiac arrest upon extrication from avalanche burial. The survivor who was in cardiac arrest upon extrication had a short burial time of 10 minutes and was successfully resuscitated at the avalanche accident site. Two other survivors suffered cardiac arrest after extrication and were successfully resuscitated after extracorporeal rewarming at the hospital (core temperature upon hospital arrival 22 and 25 °C). Mean core body temperature cooling rate from the time of initial burial in the avalanche to arrival at the hospital for survivors was 2.88 °C/hr (range 0.75 to 4.75 °C/hr), and for non-survivors was 3.07 °C/hr (range 1.34 to 5.83 °C/hr). Mean time buried in the avalanche for survivors was 76 minutes (range 10 to 150 minutes) and for non-survivors was 80 minutes (range 10 to 165 minutes). Mean time from avalanche burial extrication to arrival at the hospital for survivors was 71 minutes and for non-survivors was 78 minutes.

There are important differences between the results of our study and the data reported by Braun, and by Locher and...
Walpoth. These previous studies report an average core temperature cooling rate from initial burial in the avalanche to arrival at the hospital, while our studies continuously measured cooling rate during the period of snow burial and for 30 minutes after extrication. Locher and Walpoth argued that core temperature cooling rate was greater during snow burial than during transport to the hospital, while Braun argued that cooling rate was greater during extrication and transport to the hospital.

The results from our study show that core body temperature cooling rate increases transiently during and after extrication from snow burial. Core body temperature cooling rate accelerated by 50% for about 20 minutes during and after extrication after both hypercapnic and normocapnic burials. An accelerated cooling rate during and after extrication places avalanche burial victims at greater risk of complications due to hypothermia. Every effort should be made by rescue personnel to prevent further heat loss in avalanche burial victims starting as soon as possible during extrication from the snow. Rapid core temperature cooling during and after extrication in avalanche burial victims has been recognized clinically by Brugger and colleagues (1996).

Death from acute asphyxiation in avalanche burial victims without an air pocket occurs within 35 minutes of burial (Brugger 2001, Falk 1994). Prolonged survival beyond 35 minutes requires an open airway and an air pocket for breathing, or use of an artificial breathing device (Grissom 2000, Radwin 2002). If an air pocket is present and death from asphyxiation is delayed, then core body temperature cooling rate becomes a major determinant of survival. Published protocols for medical care of avalanche burial victims use a core body temperature of less than 32 °C to indicate a critical degree of hypothermia where cardiac arrest may occur due to hypothermia (Brugger 1996, 2001). The distinction between cardiac arrest due to hypothermia rather than asphyxiation is important for triage decisions. Resuscitation efforts are more likely to be successful and result in survival when cardiac arrest is due to hypothermia rather than asphyxiation (Brugger 2001, Locher 1991). Our study suggests that a burial time of greater than 180 minutes is required to reach a core temperature less than 32 °C where hypothermic cardiac arrest may occur. This means that most avalanche victims found in cardiac arrest after prolonged burial have probably died from asphyxiation rather than hypothermia, and resuscitation efforts are unlikely to be successful. In the study by Locher and Walpoth there were no survivors among the 13 avalanche victims who were found in cardiac arrest after burials of 30 to 165 minutes duration, suggesting that cardiac arrest was due to asphyxiation rather than hypothermia (Locher 1996).

The core temperature cooling rate during snow burial in our study is supported by a recent report of prolonged survival during avalanche burial for 20 hours in a 25 year old male snowboarder with a large air pocket in front of his body (Spiegel 2002). At the time of extrication he 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. The large air pocket likely allowed adequate diffusion of expired air away from inspired air and prevented asphyxiation. In that same rescue the survivor’s companion was found dead from asphyxiation after 20 hours of burial with a core body temperature of 6 °C (tympanic) which is an average core body temperature cooling rate of about 1.5 °C/hr. This anecdotal report demonstrates that core body temperature cooling rate during avalanche burial may vary significantly depending on adequacy of ventilation as determined by the size of an air pocket.

Our study is the first to prospectively measure core temperature cooling rate during snow burial in a controlled experimental protocol with the objective to better understand the development of hypothermia during avalanche burial. In subjects buried in snow wearing a lightweight clothing insulation system and breathing with a device that results in hypercapnia, we found that core temperature cooling rate was about 1.3 °C/hr. In a second study we confirmed that hypercapnia increases core temperature cooling rate during snow burial, and we again measured a cooling rate of 1.3 °C/hr using the same clothing insulation system.
Importantly, in the second study we also showed that core temperature cooling rate increases by about 50% for about 20 minutes during the period of extrication from the avalanche and initial rewarming. These results are important for medical care of rescued avalanche burial victims. Avalanche burial victims who survive burials of approximately one hour will only be mildly hypothermic and upon extrication should be quickly insulated and protected from further heat loss during packaging and evacuation.

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7. REFERENCES


