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Hypercapnia increases core temperature cooling rate during snow burial

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Grissom, Colin K., Martin I. Radwin, Mary Beth Scholand, Chris H. Harmston, Mark C. Muetterties, and Tim J. Bywater. Hypercapnia increases core temperature cooling rate during snow burial. *J Appl Physiol* 96: 1365–1370, 2004. First published December 5, 2003; 10.1152/japplphysiol.00531.2003.—Previous retrospective studies report a core body temperature cooling rate of 3°C/h during avalanche burial. Hypercapnia occurs during avalanche burial secondary to rebreathing expired air, and the effect of hypercapnia on hypothermia during avalanche burial is unknown. The objective of this study was to determine the core temperature cooling rate during snow burial under normocapnic and hypercapnic conditions. We measured rectal core body temperature (T_{re}) in 12 subjects buried in compacted snow dressed in a lightweight clothing insulation system during two different study burials. In one burial, subjects breathed with a device (AvaLung 2, Black Diamond Equipment) that resulted in hypercapnia over 30–60 min. In a control burial, subjects were buried under identical conditions with a modified breathing device that maintained normocapnia. Mean snow temperature was -2.5 ± 2.0°C. Burial time was 49 ± 14 min in the hypercapnic study and 60 min in the normocapnic study ($P = 0.02$). Rate of decrease in T_{re} was greater with hypercapnia (1.2°C/h by multiple regression analysis, 95% confidence limits of 1.1–1.3°C/h) than with normocapnia (0.7°C/h, 95% confidence limit of 0.6–0.8°C/h). In the hypercapnic study, the fraction of inspired carbon dioxide increased from 1.4 ± 1.0 to 7.0 ± 1.4%, minute ventilation increased from 15 ± 7 to 40 ± 12 l/min, and oxygen saturation decreased from 97 ± 1 to 90 ± 6% ($P < 0.01$). During the normocapnic study, these parameters remained unchanged. In this study, T_{re} cooling rate during snow burial was less than previously reported and was increased by hypercapnia. This may have important implications for prehospital treatment of avalanche burial victims.

hypothermia; avalanche burial; avalanche survival

INTERNATIONAL TRIAGE AND TREATMENT recommendations for avalanche burial victims (2–4) assume an average core body temperature cooling rate of 3°C/h during avalanche burial based on previous retrospective studies (1, 14). Although hypothermia is a major medical problem requiring treatment in survivors of avalanche burial (2–4), asphyxiation is the major cause of death during avalanche burial (4, 7, 10, 20). 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 followed by hypoxemia (5, 9). Previous studies have shown that development of hypercapnia and hypoxemia during avalanche burial is delayed by the presence of an air pocket in the snow for breathing (5, 9) or by use of an artificial breathing device that diverts expired air away from inspired air drawn from the snowpack (9). If an air pocket or an artificial breathing device allows prolonged survival during avalanche burial, then more severe hypothermia may develop and require treatment after extrication.

The effect of hypercapnia on core body temperature cooling rate during snow burial is unknown. Previous studies evaluating the effect of hypercapnia on hypothermia during cold water immersion and cold air exposure suggest that hypercapnia may increase core body temperature cooling rate by increasing respiratory heat loss from hyperventilation or by reducing the threshold temperature for shivering (6, 11, 19). We report the first prospective measurement of core body temperature cooling rate during snow burial under hypercapnic and normocapnic conditions. We hypothesized that core body temperature cooling rate during snow burial is increased by hypercapnia and is less than the previously reported 3°C/h. To test this hypothesis, we measured rectal core body temperature (T_{re}) 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. 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.

METHODS

This study was performed at an elevation of 2,400 m (average barometric pressure, 569 mmHg) in the Wasatch Mountains, Utah, during the winter months of 2000 and 2001. Subjects were healthy, paid volunteers (2 women and 10 men) with a mean age of 32 ± 7 yr, mean height of 178 ± 5 cm, mean weight of 76 ± 9 kg, mean body mass index (BMI) of 24 ± 3 kg/m^2, and mean body fat percentage of 15 ± 7%. All subjects lived at an elevation of 1,500–2,000 m and were acclimated to the winter environment of the Wasatch Mountains through outdoor activities, which included skiing and climbing. No subjects smoked cigarettes. T_{re} was measured in subjects during a hypercapnic study burial and during a separate normocapnic control study burial. For both study burials, 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 face mask with goggles, mittens, and warm boots. The LDS Hospital Research and Human Rights Committee approved this study, and written, informed consent was obtained from the volunteers.

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The experimental setup consisted of a large mound of snow compacted with body weight and allowed to age harden for ~2 h. Snow density was determined in multiple sites by using a 1,000-ml 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 percentage (i.e., 300 kg/m^3 is 30% density snow or 70% air). Mean snow density for the hypercapnic burials was 48 $\pm$ 6% and for the normocapnic burials was 46 $\pm$ 9% ($P = 0.45$). Reported density of avalanche debris ranges from 30% for a midwinter dry snow avalanche to 60% or higher for a springtime wet snow avalanche (15). Snow temperature was measured with a dual thermocouple thermometer (model 600-1040, Barnant, Barrington, IL). Mean snow temperature during the hypercapnic burials was -2.6 ± 2.1°C and during the normocapnic burials was was -2.5 ± 2.0°C ($P = 0.37$). A shoulder-width trench was dug into one end of the snow mound, and a sitting platform was created for the subject so that the head would be ~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.

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 (Fig. 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, Salt Lake City, UT). In a previous study (9), our group demonstrated that subjects breathing with this device during snow burial maintained adequate oxygenation for up to 60 min but gradually developed hypercapnia.

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 (Fig. 3). Inspiratory air was inhaled directly from the snowpack, similar to the breathing device used in the hypercapnic study burials. Resistance to airflow and respiratory tubing dead space were similar in both devices. In a previous study (17), we showed that the device used in the normocapnic study burials maintained normal oxygenation and ventilation for up to 90 min in subjects fully buried in compacted snow.

Fig. 1. The compacted snow mound with a subject in the sitting position partially extricated after a completed burial.

Fig. 2. Breathing device used during the hypercapnic study burial (AvaLung 2, Black Diamond Equipment, Salt Lake City, UT). Open arrow shows flow of inspiratory air, and shaded arrows show flow of expiratory air. The subject breathes in and out through the mouthpiece (*A*). An emergency oxygen backup 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* and *D*) are connected to a capnometer and record inspiratory P_{CO_2}, end-tidal P_{CO_2}, and minute ventilation ($\dot{V}_E$). 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*).

Physiological parameters were continuously monitored during the burial studies. These parameters included T_{re} (°C) obtained by a rectal probe inserted to 15 cm (model 401, Yellow Springs Instruments, Yellow Springs, OH), partial pressure of end-tidal CO_2 ($P_{ET_{CO_2}}$) and inspiratory P_{CO_2} (in Torr), minute ventilation ($\dot{V}_E$; in l/min), arterial O_2 saturation (Sa_{O_2}) as measured by pulse oximetry, and surface three-lead electrocardiogram. The fraction of inspired CO_2 (FI_{CO_2}) was obtained by dividing inspiratory P_{CO_2} by ambient barometric pressure. $P_{ET_{CO_2}}$, inspiratory P_{CO_2}, $\dot{V}_E$, and Sa_{O_2} were measured by using a capnometer (CO_2SMO Plus, model 8100, Novametrix, Wallingford, CT). Data from the capnometer was simultaneously downloaded to a computer (CO_2SMO Plus software, Novametrix). Electrocardiogram, Sa_{O_2}, and T_{re} were monitored by using a portable patient monitor (Propaq Encore, Protocol Systems, Beaverton, OR). A third pulse oximeter also measured Sa_{O_2} (N-395, Mallinckrodt, St. Louis, MO). Three pulse oximeters were used on different fingers to ensure that at least one reliable reading was obtained when a subject's hands became cold. All physiological parameters were observed continuously and recorded every minute.

In nine subjects, the hypercapnic burial was done first followed by at least a 2-h rewarming period in a heated indoor environment before

Fig. 3. Breathing device used during the normocapnic study burials. Open arrows show flow of inspiratory air, and shaded arrows show flow of expiratory air. The subject breathes in and out through the mouthpiece (*A*). An emergency oxygen backup 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* and *D*) are connected to a capnometer and record inspiratory P_{CO_2}, end-tidal P_{CO_2}, and $\dot{V}_E$. Inhaled air enters from the snowpack through the mesh-protected respiratory tubing (*E*), 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*).

the second normocapnic burial on the same day (*subjects 4–12*). Three subjects underwent the normocapnic and hypercapnic burials on different days (2 of these subjects underwent the normocapnic burial first). 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 either after 60 min, when Sa_{O_2} fell to ≤85%, 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 to increase inspired partial pressure of O_2 and flush CO_2.

Core body temperature change from baseline T_{re} (ΔT_{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/h) with 95% confidence limits (CL) was determined by multiple-regression analysis of ΔT_{re} data for all subjects from *time 0* of burial to the end of the study. Cooling rate (in°C/h) 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 the end-study value for $P_{ET_{CO_2}}$ and correlation between ΔT_{re} and $P_{ET_{CO_2}}$ were determined by using multiple-regression analysis. T_{re}, Sa_{O_2}, $P_{ET_{CO_2}}$, $F_{I_{CO_2}}$, and $\dot{V}_E$ at *time 0* and at the end of the study in the hypercapnic and normocapnic studies were compared by a paired *t*-test. ΔT_{re} at which onset of shivering occurred was compared between the hypercapnic and normocapnic studies by using a paired *t*-test. ΔT_{re}, Sa_{O_2}, $P_{ET_{CO_2}}$, $F_{I_{CO_2}}$, and $\dot{V}_E$ data for each subject every minute from *time 0* to the end of the study in the hypercapnic group were compared with the same data for each subject in the normocapnic group by 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 means ± SD.

RESULTS

T_{re} cooling rate during the hypercapnic burial was 1.2°C/h by multiple-regression analysis (95% CL: 1.1–1.3°C/h) and was 1.3 ± 0.5°C/h by arithmetic calculation. The T_{re} cooling rate during the normocapnic burial was 0.7°C/h by multiple-regression analysis (95% CL: 0.6–0.8°C/h) and was 0.6 ± 0.6°C/h by arithmetic calculation ($P = 0.001$, hypercapnic vs. normocapnic cooling rate) (Fig. 4). Shivering onset occurred at

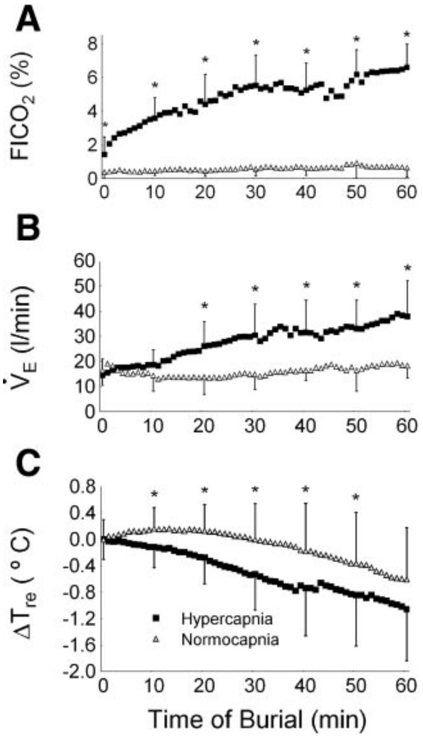

Fig. 4. Mean fraction of inspired carbon dioxide ($F_{I_{CO_2}}$; *A*), $\dot{V}_E$ (*B*), and rectal core body temperature (T_{re}; *C*) during burial in dense snow for up to 60 min during the hypercapnic and normocapnic studies ($n = 12$). Five of the subjects in the hypercapnic study did not complete the full 60 min of burial (studies terminated at 26, 30, 35, 38, and 42 min). T_{re} data are presented as difference from values at *time 0* of burial (ΔT_{re}). Values are means ± SD. *Significant difference between the hypercapnic and the normocapnic study ($P < 0.05$).

a lower ΔT_{re} in the hypercapnic study ($-0.5 \pm 0.5°C$) than in the normocapnic study ($0.1 \pm 0.4°C$) ($P < 0.05$).

Mean T_{re} cooling rate for all 24 study burials (hypercapnic and normocapnic) was 0.83°C/h by multiple-regression analysis (95% CL: 0.76–0.90°C/h) and was $0.9 \pm 0.7°C/h$ by arithmetic calculation. T_{re} cooling rate data from all 24 study burials (hypercapnic and normocapnic) significantly correlated with end-study values for $P_{ET_{CO_2}}$ ($P = 0.02$).

Mean burial time in the hypercapnic burial of 49 ± 14 min was less than the normocapnic burial time of 60 min for all subjects ($P = 0.02$). Five of the 12 subjects in the hypercapnic burial requested termination before 60 min at times of 26, 30, 35, 38, and 42 min. The reason for terminating the study before 60 min in all five subjects was subjective dyspnea, which was associated with hypoxemia ($Sa_{O_2} \leq 85\%$) in three subjects. Mean $F_{I_{CO_2}}$, $\dot{V}_E$, and ΔT_{re} for the hypercapnic and normocapnic burials are shown in Fig. 4.

$F_{I_{CO_2}}$ 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 $F_{I_{CO_2}}$ resulted in an increase in $P_{ET_{CO_2}}$ during the hypercapnic study from a baseline of 39 ± 7 Torr to an end-study value of 58 ± 9 Torr ($P < 0.001$). $P_{ET_{CO_2}}$ in the hypercapnic study significantly correlated with ΔT_{re} ($P < 0.001$). The increased $F_{I_{CO_2}}$ and hypercapnia resulted in an increased $\dot{V}_E$ during the hypercapnic burial from a baseline of 15 ± 7 l/min to an end-study value of 40 ± 12 l/min ($P < 0.001$). Sa_{O_2} decreased during the hypercapnic burial from 96 ± 3 to 90 ± 6% ($P = 0.003$). End-study values of $P_{ET_{CO_2}}$, $F_{I_{CO_2}}$, and $\dot{V}_E$ were all significantly greater in the hypercapnic than in the normocapnic burial ($P < 0.001$), and the end-study value of Sa_{O_2} was less in the hypercapnic than in the normocapnic burial ($P = 0.01$).

$P_{ET_{CO_2}}$, $F_{I_{CO_2}}$, $\dot{V}_E$, and Sa_{O_2} were unchanged during the normocapnic study. Normocapnic baseline $P_{ET_{CO_2}}$ was 37 ± 7 Torr, and the normocapnic end-study value of $P_{ET_{CO_2}}$ was 36 ± 5 Torr ($P = 0.63$). Normocapnic baseline $F_{I_{CO_2}}$ was 0.4 ± 0.4%, and the normocapnic end-study value of $F_{I_{CO_2}}$ was 0.7 ± 0.6% ($P = 0.08$). Normocapnic baseline $\dot{V}_E$ was 16 ± 6 l/min, and the normocapnic end-study value of $\dot{V}_E$ was 18 ± 5 l/min ($P = 0.38$). Normocapnic baseline Sa_{O_2} was 95 ± 2%, and the normocapnic end-study value of Sa_{O_2} was 96 ± 2% ($P = 0.42$).

DISCUSSION

Our study found that hypercapnia increased core temperature cooling rate during snow burial. Subjects had a T_{re} cooling rate of 1.2 to 1.3°C/h as they became progressively hypercapnic, compared with 0.6 to 0.7°C/h while normocapnic. Hypercapnia may have increased T_{re} 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. Although we did not objectively measure onset of shivering, subjective onset of shivering occurred at a lower core temperature from baseline during the hypercapnic study burial. Increased respiratory heat loss likely occurred in the hypercapnic study burials because the end-study value of $\dot{V}_E$ in the hypercapnic group was twice that in the normocapnic group.

Other investigators have found similar influences of hypercapnia on core temperature cooling rate during cold water immersion and cold air exposure. Wagner et al. (19) exposed subjects to 5 and 29°C air while breathing 4% CO_2 and found that hypercapnia increased core body temperature cooling rate due to greater respiratory heat loss because of hypercapnia-induced hyperventilation. Johnston and colleagues (11) found that hypercapnia increased core temperature cooling rate when they studied subjects after exercise during immersion in 28°C water while breathing 4% CO_2. Core temperature cooling rate was 1.74°C/h with hypercapnia, which was significantly greater than 1.39°C/h with normocapnia, which the authors attributed to both a reduced core temperature threshold for shivering and greater respiratory heat loss. These findings are similar to our study and suggest similar causes of increased core temperature cooling rate with hypercapnia during snow burial. Further studies on core temperature cooling rate during snow burial with objective measurements of core temperature shivering threshold and inspiratory gas temperature are needed to confirm this.

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 with the use of this device has occurred (16). 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 who breathe 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. 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.

In the controlled experimental setup 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 (12).

Our study has other limitations, which may have influenced the results. The order of hypercapnic and normocapnic study burials was not randomly allocated among subjects. Only two subjects underwent the normocapnic burial before the hypercapnic burial. This may influence comparison of results from the normocapnic and hypercapnic burials. The two subjects who underwent the normocapnic burial first, however, had higher cooling rates during the hypercapnic burial than during the normocapnic burial, consistent with the results of 9 of the 10 subjects who underwent the hypercapnic burial first.

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/h during avalanche burial is frequently stated in the medical literature (4, 3, 7, 13) based on two studies, one by Braun (1) and another by Locher and Walpoth (14). 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 by 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.

Braun (1) reported core T_{re} measurements in five hypothermic avalanche burial survivors at hospital arrival who did not suffer cardiac arrest. The mean core temperature cooling rate from the time of initial burial in the avalanche to arrival at the hospital was 3.0°C/h. Mean burial time was ~90 min, and mean transport time was ~90 min.

Locher and Walpoth (14) reported a retrospective analysis of core body temperature measured at hospital arrival in 16 survivors and 16 nonsurvivors of avalanche burial. Trauma was not identified as a cause of death in any of the nonsurvivors. All 16 nonsurvivors and 1 survivor were found in cardiac arrest on extrication from avalanche burial. The survivor who was in cardiac arrest on extrication had a short burial time of 10 min 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 on hospital arrival was 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/h (range: 0.75–4.75°C/h) and for nonsurvivors was 3.07°C/h (range: 1.34–5.83°C/h). Mean time buried in the avalanche for survivors was 76 min (range: 10–150 min) and for nonsurvivors was 80 min (range: 10–165 min). Mean time from avalanche burial extrication to arrival at the hospital for survivors was 71 min and for nonsurvivors was 78 min.

There are important differences between the results of our study and the data reported by Braun (1) and Locher and Walpoth (14). These previous studies report an average core temperature cooling rate from initial burial in the avalanche to arrival at the hospital, whereas our study measured cooling rate just during the period of snow burial. Locher and Walpoth argued that core temperature cooling rate was greater during snow burial than during transport to the hospital, whereas Braun argued that cooling rate was greater during extrication and transport to the hospital. Rapid core temperature cooling during and after extrication in avalanche burial victims has been recognized clinically by Brugger and colleagues (3). Preliminary data from our group also 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 25 min during and after extrication in subjects buried in snow for 60 min (8). 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. Further studies measuring core body temperature at the time of extrication from avalanche burial and at hospital arrival are needed to better understand core temperature cooling during the periods of snow burial, extrication, and transport to the hospital.

Death from acute asphyxiation in avalanche burial victims without an air pocket occurs within 35 min of burial (4, 7, 20). Prolonged survival beyond 35 min requires an open airway and an air pocket for breathing (4, 7) or use of an artificial breathing device (9, 16). 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 <32°C to indicate a critical degree of hypothermia where cardiac arrest may occur due to hypothermia (3, 4). With the use of a mean core temperature cooling rate of 3°C/h, protocols estimate that an average burial time of 90 min is required to reach this critical degree of hypothermia (3, 4). The distinction between cardiac arrest due to hypothermia rather than to asphyxiation is important for triage decisions. Resuscitation efforts are more likely to be successful and to result in survival when cardiac arrest is due to hypothermia rather than asphyxiation (4, 13). Our study suggests that a burial time of >180 min is required to reach a core temperature of <32°C where hypothermic cardiac arrest may occur. In the study by Locher and Walpoth (14), there were no survivors among the 13 avalanche victims who were found in cardiac arrest after burials of a duration of 30–165 min, suggesting that cardiac arrest was due to asphyxiation rather than hypothermia.

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 h in a 25-yr-old male snowboarder with a large air pocket in front of his body (18). 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 of 35 beats/min, and a palpable pulse. Core body temperature cooling rate in this anecdotal report was ~0.6°C/h. 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 h 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/h. 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 1.2–1.3°C/h, higher than the 0.6–0.7°C/h cooling rate under normocapnic conditions. These results may be important for medical care of rescued avalanche burial victims, especially persons buried in an avalanche who are wearing the breathing device used in this study or who have an air pocket in the snow for breathing. Core temperature cooling rate during avalanche burial cannot be assumed to occur at a certain rate but rather depends on a variety of factors, including clothing insulation, traumatic injuries, snow temperature, and adequacy of ventilation and oxygenation as determined by the size of an air pocket. More studies are required to answer the questions of how these different variables may influence core temperature cooling rate in avalanche burial victims.

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