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ORIGINAL RESEARCH

Effect of Head and Face Insulation on Cooling Rate During Snow Burial

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Objectives.—Avalanche victims are subjected to a number of physiological stressors during burial. We simulated avalanche burial to monitor physiological data and determine whether wearing head and face insulation slows cooling rate during snow burial. In addition, we sought to compare 3 different types of temperature measurement methods.

Methods.—Nine subjects underwent 2 burials each, 1 with head and face insulation and 1 without. Burials consisted of a 60-minute burial phase followed by a 60-minute rewarming phase. Temperature was measured via 3 methods: esophageal probe, ingestible capsule, and rectal probe.

Results.—Cooling and rewarming rates were not statistically different between the 2 testing conditions when measured by the 3 measurement methods. All temperature measurement methods correlated significantly.

Conclusions.—Head and face insulation did not protect the simulated avalanche victim from faster cooling or rewarming. Because the 3 temperature measurement methods correlated, the ingestible capsule may provide an advantageous noninvasive method for snow burial and future hypothermia studies if interruptions in data transmission can be minimized.

Key words: avalanche, snow burial, hypothermia

Introduction

Avalanche burial can be a significant hazard for the backcountry traveler. Those who are buried face a high risk of mortality and morbidity. Most avalanche deaths result from asphyxiation, approximately 25% from trauma, and a minority from hypothermia.[1–6] In the avalanche victim, asphyxia begins immediately as rebreathing expired air in the enclosed space results in progressive hypoxia and hypercapnia if the victim is not unburied within 15 to 20 minutes. Cooling from the surrounding snow begins immediately as well. In snow burial, the body loses heat primarily via radiation and conduction. Hypothermia may be accelerated via heat loss from the head and face, as these body areas are extremely vascular areas. Core temperature drops approximately 1° to 3°C/h during snow burial.[2,7] The fastest documented drop in core body temperature is 9°C/h, described in a backcountry skier.[8]

An avalanche burial victim with an air pocket in front of his or her oral cavity may survive longer before death occurs from asphyxiation and may experience hypothermia. In addition, an emergency-breathing device that diverts expired air away from inspired air during avalanche burial—the AvaLung (Black Diamond Equipment, Salt Lake City, UT)—may delay asphyxiation during prolonged snow burial, increasing the potential to develop hypothermia.[9] Hypothermia is a common medical problem requiring treatment in avalanche victims who are extricated alive and especially those with extended burial times. The degree of cooling will be minimal in those extricated early, but becomes more significant as time elapses, if the victim has an air pocket, or is wearing an AvaLung.

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Helmets have been advocated for use during backcountry recreation to prevent head injury.[10] Although asphyxiation is usually the cause of death in an avalanche, many victims sustain head trauma that is thought to be the main cause of trauma-related fatalities.[6] Helmets may have the additional benefit of slowing the progression of hypothermia by providing insulation to the head. Although only limited data exist, more skiers and snowboarders are thought to be wearing helmets in resorts[11] and in the backcountry.

We evaluated the rate of temperature change (via 3 different methods) during snow burial simulating avalanche conditions and rewarming in participants wearing full head and face insulation and without. Our primary hypothesis was that core body temperature would drop slower when wearing the head and face insulation. Our secondary hypothesis was that the 3 temperature measurement methods would correlate. By conducting this study, we aimed to further describe physiology and heat exchange during avalanche burial and propose strategies for preventing heat loss and therefore improving hypothermia care during these events.

Methods

Based on a previous publication[7] by members of our group, 0.7°C/h represents a significant difference in mean cooling rate. The SD of core temperature in this prior study was 0.5°C. Eleven subjects would be needed for 80% power to detect a difference in cooling rate of 0.7°C/h. The recruiting goal of 11 participants was ultimately not achieved, and therefore 9 participants were recruited and gave written consent according to the approved University of Utah Institutional Review Board protocol. Volunteers were healthy adults, nonpregnant nonsmokers with no cardiac, pulmonary, renal, gastrointestinal, endocrine, or infectious disease history. Height and weight were measured, and body mass index (BMI) was calculated.

Burials were performed at 2600 m elevation at Alta Ski Resort in the Wasatch Mountains, Utah. Ambient and snow temperatures were recorded along with measurements of the snow density. Snow density was determined in multiple sites using a 1000-mL wedge density cutter (Snowmetrics, Ft. Collins, CO) that measured the weight of snow per cubic meter, reported as a percent (ie, 300 kg/m^3 is 30% density snow, or 70% air). Snow temperature was measured with a dual thermocouple thermometer (Model 600-1040, Barnant Company, Barrington, IL).

Study burial protocols paralleled those used by Grissom et al.[7,9] The experimental setup consisted of creating a large mound of snow, approximately 8 by 8 by 8 feet, compacted with body weight and allowed to age-harden for 1 hour. A shoulder-width trench was dug into 1 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. Subjects were then quickly buried by shoveling snow into the trench while study personnel packed the snow around the subject and AvaLung pack. A new site was constructed each day.

Each participant underwent 2 burials on 2 different days, 1 with face and head insulation (FHI, intervention) and 1 with no face and head insulation (NFHI, control). Each was randomly assigned to receive 1 experimental condition first, such that half of the participants started with intervention and half started with control conditions. During each burial, participants wore medium-weight synthetic material underwear (Capilene 1 or equivalent, Patagonia, Ventura, CA), warm boots and mittens, and a one-piece Gore-Tex suit (Patagonia). For the FHI burial, the participant wore an insulated helmet, ski goggles, and balaclava. In the NFHI burial, each volunteer wore the above-mentioned gear without the insulated helmet and facemask; only swim goggles and Gore-Tex hood covered the head.

Patients breathed with a device that diverts expired from inspired air during snow burial (AvaPack, Black Diamond Ltd, Salt Lake City, UT). This allowed for oxygen to be inhaled from the snow pack via mesh-protected respiratory tubing. A 1-way valve expelled exhaled air behind the back of the participant. A diagram of this setup is shown in Figure 1.

Time zero began once the head was buried. Body temperature was measured by 3 methods placed or swallowed before burial: 1) rectal probe (Tre) inserted to 15 cm (model 401, YSI Incorporated, Yellow Springs, OH), 2) esophageal probe (Tes) inserted to the level of the mediastinum (measured before placement from the nose along its anticipated course in the esophagus to half the distance between the sternal notch and xiphoid process, then the probe was inserted this distance), and 3) remotely transmitting swallowed capsule (Tcap; VitalSense Philips Respironics, Bend, OR; Figure 2).

Heart rate and rhythm, end-tidal CO_2, and 2 independent pulse oximetry sites were also monitored throughout. Measured ventilation parameters included partial pressure of end-tidal CO_2 (P_{ETCO_2}) and partial pressure of inspiratory CO_2 (P_{ICO_2}) in mm Hg, minute ventilation ($\dot{V}_E$) in L/min, and arterial oxygen saturation (Sa_{O_2}; CO_2SMO Plus, model 8100, Novametrix, Wallingford, CT). Sa_{O_2} was measured by 3 different pulse oximeters (CO_2SMO Plus; Propaq Encore, Protocol Systems Inc, Beaverton, OR; Nellcor N-395, Mallinckrodt, St. Louis, MO). Temperature probes were attached to a monitor (Propaq Encore, Protocol Systems) that also monitored a 3-lead electrocardiogram (ECG). An emergency oxygen backup line was attached to the breathing