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ORIGINAL RESEARCH

Investigating Carbon Monoxide Exposure on Denali

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Objective.—This exploratory study assessed a potential relationship between elevated carboxyhemoglobin (COHb) levels and acute mountain sickness (AMS) at 4300 m on Denali. Additional analysis assessed the relationship among COHb levels, AMS, and climber characteristics and behaviors.

Methods.—Participants were screened for AMS with the Lake Louise Self-Report questionnaire and answered questions focusing on AMS symptoms, prevention, and previous altitude illness. Levels of COHb were measured by serum cooximetry. Additional questions assessed stove practices, climbing practices, and climber behaviors. Nonparametric statistical analyses were performed to examine potential relationships among COHb levels, AMS symptoms, and climber behaviors.

Results.—A total of 146 climbers participated in the study. Eighteen climbers (12.5%) were positive for carbon monoxide (CO) exposure and 20 (13.7%) met criteria for AMS. No significant relationship was observed between positive CO exposure and positive criteria for AMS. Climbers descending the mountain were 3.6 times more likely to meet the study criteria for positive CO exposure compared with those ascending the mountain ($P = .42$). In addition, COHb levels were significantly higher for those descending the mountain ($P = .012$) and for those taking prophylactic medications ($P = .010$). Climbers meeting positive criteria for AMS operated their stoves significantly longer ($P = .047$).

Conclusions.—No significant relationship between AMS symptoms and CO exposure was observed. This may have been affected by the low percentage of climbers reporting AMS symptoms, as well as limited power. Descending climbers had a 3.6 times increased risk of CO exposure compared with ascending climbers and had significantly higher COHb scores. Increased hours of stove operation was significantly linked to climbers who also met criteria for AMS.

Key words: carbon monoxide, stove, high altitude, poisoning, acute mountain sickness, mountaineering

Introduction

Since the advent of polar exploration in the past century, portable stoves have been used on high-altitude expeditions. Although invaluable, stove use increases the risk of carbon monoxide (CO) exposure and toxicity for individuals exposed to exhaust fumes.[1–4] Interestingly, initial symptoms of CO poisoning are similar to symptoms of acute mountain sickness (AMS), and determining whether a climber has AMS, CO poisoning, or both poses a challenge to health care providers in the high-altitude setting.[4–7]

Anecdotal reports of CO poisoning in mountaineers have been documented by the National Park Service (NPS) on Denali (Mt McKinley) for at least 20 years.[8] In 1985, 2 American climbers were found severely impaired after cooking inside their tent at the high camp (5200 m).[9] In 1986, a fatal incident was reported involving 2 Swiss climbers cooking inside a sealed tent at advanced base camp (4300 m).[10] There are numerous anecdotal reports of climbers perishing from CO poisoning while climbing in the Himalayas.[11,12] Descriptions of fatal CO poisonings also include exposures while cooking inside tents on camping trips in temperate climates and during military expeditions in subzero temperatures.[1,5,13]

Carbon monoxide has a binding affinity with hemoglobin 200 to 250 times greater than oxygen and a half-life of 4 to 6 hours at sea level. Normal basal levels of carboxyhemoglobin (COHb) range from <1.0% to 3.0% in nonsmokers and up to 10.0% in moderate smok-

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ers.[6,14]. Levels of COHb ≥3.0% but <10.0% in asymptomatic nonsmokers are abnormal and constitute CO exposure.[2,6,14,15] At approximately 10.0% COHb in nonsmokers, mild to moderate CO intoxication occurs, causing severe headache, nausea, dizziness, and insomnia.[6,14–16]

From 1985 to present, 5% to 32% of all climbers on Denali were treated annually for symptoms of AMS.[14,17] The number of climbers experiencing CO exposure or intoxication on Denali, however, is unknown and diagnosis is difficult considering a climber may have either AMS, CO toxicity, or both.[18] Additionally, the effects of CO toxicity (acute or chronic) and altitude hypoxia are possibly additive, as CO bound to hemoglobin increases hypoxic stress and renders a person at a ''physiologically higher'' altitude, which may precipitate AMS.[4,5,19–22] For this study, it was hypothesized that a significant number of climbers with symptoms of AMS would also have elevated COHb levels.

Materials and methods

The Human Subjects Review Committee of the Human Subjects Division of the University of Washington reviewed and approved this research project.

All climbers reviewed a general information card explaining the research during the mandatory climber orientation meeting at the NPS headquarters in Talkeetna, AK, before flying to Kahiltna Base Camp (2200 m). Individuals interested in participating in the study signed a consent form, which the NPS headquarters held until completion of the study. The consent form required the participant's signature only and no personal identifying information.

At the 4300-m high base camp on Denali, research team members recruited subjects after confirming that they had signed a consent form. Individuals who did not sign a consent form in Talkeetna were not recruited into the study.

All participants were screened for AMS with the Lake Louise Self-Report (LLSR) questionnaire (Appendix 1). The LLSR score was developed at consensus meetings in Lake Louise, Canada, in 1991 and 1993. Primarily developed for research use, the short and simple format, which is easy to complete in difficult situations, has led to its adoption by trekkers and mountaineers. The LLSR is sensitive enough to detect AMS, with sufficient specificity to prevent overdiagnosis.[23]

Subjects and controls were asked 11 questions focusing on basic demographic data and climber behaviors that focused on potential CO exposure risk and individual risk for developing AMS (Appendix 2). Demographic, LLSR, and climber-behavior data were recorded by a research investigator and did not interfere with any assessment and treatment performed by the NPS medical staff.

Subjects' COHb levels were measured with the GEM OPL Oxygenation Portable Laboratory cooximeter (Instrumentation Laboratory Inc, Lexington, MA). Approximately 0.3 mL of blood was collected by venipuncture from a peripheral vein on the hand or wrist by using a sterile technique and a 1-mL heparinzed tuberculin syringe. A 50-μL sample was injected into a disposable cuvette and analyzed with the cooximeter. Levels of COHb were recorded as a percent with a range of 0.1% to 75.0%. On Denali, the operation of the cooximeter took place inside the NPS first-aid shelter located at high base camp, which is heated and provided a relatively stable environment for operation. Optical quality control cuvettes were used before analysis of every blood sample to calibrate the instrument and maintain constant result reliability of blood samples analyzed.

Each participant's LLSR score, demographic data, and COHb level was assigned a unique identifying number. All data were anonymous and without link to participant name, consent form, or other personal identifying information.

Levels of COHb >3% (nonsmokers) or >10% (smokers) were considered positive for CO exposure. Levels below these cutoffs were classified as negative for COHb exposure. For this study, COHb levels >10% for nonsmokers and >20% for smokers were considered positive for CO intoxication.[5,6,12–14,16]

DATA ANALYSIS

By using SPSS software (version 12, SPSS Inc, Chicago, IL), analysis of frequency distributions and quantitative variables showed that nonparametric statistical techniques were indicated. Spearman rank order correlations were calculated for the quantitative variables in the study. Crosstabulations were produced for the AMS and CO exposure classification variables with all other categorical study variables that could potentially contribute to positive CO exposure or AMS (eg, age, days ascending, hours operating stove, gender, smoking status, history of AMS, use of medications, and ascending or descending the mountain). Mann-Whitney and Kruskal-Wallis tests were used to test for differences in the mean ranks of the quantitative variables. Logistic regression was used to explore models and identify predictive variables for both AMS and CO exposure classifications by using combinations of study variables.

Results

A total of 146 consented climbers (median age 33 years, men 84.8%, nonsmokers 86.2%) were enrolled in the