

ORIGINAL RESEARCH

Carbon Monoxide Exposure on Denali: Comparing the 2004 and 2005 Climbing Seasons

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Objective.—This study assessed a potential relationship between elevated carboxyhemoglobin (COHb) levels and the presence of acute mountain sickness (AMS) at 4300 m on Denali and evaluated the relationship between COHb levels, AMS, and climber characteristics and behaviors. Building on our research done in 2004, in this article we report further data gathered during the 2005 climbing season and evaluate the combined results.

Methods.—Participants were screened for AMS using the Lake Louise Self-Report Questionnaire and answered questions focusing on AMS symptoms, AMS prevention, and previous history of altitude illness. Carboxyhemoglobin levels were measured by serum co-oximetry. Additional questions assessed stove practices, climbing practices, and climber behaviors. Nonparametric statistical analyses were performed to examine potential relationships between COHb levels, AMS symptoms, and climber behaviors across the 2 years and with years combined.

Results.—Overall, 317 climbers participated in the 2-year study. As in 2004, the combined data demonstrated no relationship between positive carbon monoxide (CO) exposure and positive criteria for AMS ($P = .276$). Climbers in 2005 were 1.92 times more likely to meet positive criteria for AMS, compared to climbers in 2004 ($P = .028$). On the contrary, climbers in 2004 were 3.93 times more likely to be CO exposed than climbers in 2005 ($P = .003$). Overall, climbers descending the mountain were more likely to be positive for CO exposure (5.56 times more likely than ascending climbers, $P = .002$) and to have higher overall mean COHb levels (2.26% descending vs 0.93% ascending, $P = .006$). The previous association between increased stove use and climbers who met positive criteria for AMS was not observed in the 2005 or in the combined data ($P = .715$). A relationship was observed between increased hours of operating stoves and increased COHb levels ($P = .002$). Female climbers were 2.041 times more likely to meet criteria for AMS ($P = .043$).

Conclusions.—No relationship between AMS symptoms and CO exposure was observed. As found in our initial study, descending climbers had higher overall COHb levels and an increased risk of CO exposure (COHb of $>3\%$ in nonsmokers and $>10\%$ in smokers). Also, increased hours of stove operation was linked to climbers who had elevated COHb levels.

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

Introduction

Anecdotal reports of carbon monoxide (CO) poisoning in mountaineers have been documented by the National Park Service (NPS) on Denali (Mt McKinley) for at least

20 years.¹ And from 1985 to present, up to 32% of all climbers on Denali have been treated annually for symptoms of acute mountain sickness (AMS).² Our research team investigated CO exposure and the potential relationship between CO toxicity and AMS in 146 climbers during the 2004 Denali climbing season and found no clear correlation between CO exposure and AMS.³ However, 4 findings related to CO exposure were described

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by the 2004 research: 1) increased overall carboxyhemoglobin (COHb) levels were observed in descending climbers; 2) there was increased risk of CO exposure (COHb levels of >3% in nonsmokers or of >10% in smokers) while descending; 3) there was a relationship between positive criteria for AMS and increased stove use; and 4) there was a relationship between medication use and elevated COHb levels.³ Additional data were gathered the following season in 2005, with an additional 171 climbers participating in the same study protocol.

We again hypothesized that elevated COHb is an identifiable risk factor for AMS. With a larger sample size and increased statistical power, we assessed 4 of the 5 significant findings described by the original research and examined the data for variables related to CO exposure and AMS, between years and with the 2 years combined.

Methods

This research project was reviewed and approved by the Human Subjects Review Committee of the Human Subjects Division of the University of Washington. Recruitment, consenting, and testing of climbers occurred per our 2004 research methods.³ Participation was anonymous and voluntary. As in 2004, individuals were asked to participate in the study when they presented to the first-aid tent complaining of symptoms of AMS, or they were recruited into the study by researchers and were screened for AMS. The Lake Louise Acute Self-Report (LLSR) Questionnaire was used to evaluate participants for AMS (Appendix 1—available at <http://www.wem.org>). The LLSR has been found to be sensitive and specific enough to reliably detect high-altitude illness.^{4,5}

Participants were also 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—available at <http://www.wem.org>). 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. Although the same protocol was followed, including using exactly the same climber demographic and behavior questions, answers to questions focusing on medication use unfortunately were not recorded in 2005 as a result of a misunderstanding by the field researchers that this question was to be excluded from the survey.

Participant COHb levels were again measured using the GEM OPL Oxygenation Portable Laboratory co-oximeter (Instrumentation Laboratory, Lexington, MA), analyzing approximately 0.3 mL of blood collected by venipuncture. Carboxyhemoglobin levels were recorded

as a percent range of 0.1% to 75.0%. The operation of the co-oximeter took place inside the relatively stable environment of the NPS first-aid shelter at the 4300-m-high base camp. Optical quality control cuvettes were utilized before analysis of every blood sample to calibrate the instrument, maintaining a constant result reliability for samples analyzed.

Carboxyhemoglobin levels of >3% (nonsmoker) or >10% (smoker) were considered positive for CO exposure (values below these cutoffs were considered negative). Carboxyhemoglobin levels of >10% for nonsmokers and >20% for smokers were considered positive for CO intoxication.⁶⁻¹¹

Data analysis

Using SPSS (Version 14, SPSS Inc, Chicago, IL), the same analytic strategy was employed as was detailed in our previous study.³ With the exception of medication use, the same variables were used in both studies. The data from 2004 and 2005 were combined in order to test the study hypotheses and to increase the power of the statistical tests. Crosstabs, tests of differences between means, Spearman correlation analyses, and logistic regression models were performed for the AMS and CO exposure classification variables with all other study variables that could potentially contribute to positive CO exposure and/or AMS (climbing year, age, days ascending, hours operating stove, gender, smoking status, use of a heater, and ascending/descending status).

Results

A total of 171 climbers were consented and enrolled and tested during May 2005. The total number of climbers participating over the 2 years was 317. Again in 2005, most participants were ascending the mountain. The median time to reach the 4300-m-high base camp was 6.9 days (compared to 7.1 days in 2004). All categorical and quantitative climber characteristics were similar between years, except for age (Table 1).

Using the combined data, with their increased statistical power, 4 of the 5 associations observed in 2004 were again tested (medication use was not tested because it was not recorded in 2005). For the combined data, the findings are as follows.

NO RELATIONSHIP BETWEEN CO EXPOSURE AND POSITIVE CRITERIA FOR AMS

Combined data upheld the null hypothesis, and no relationship was observed between positive CO exposure and positive criteria for AMS (Fisher exact test, $P =$

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