Carbon monoxide (CO) is formed wherever incomplete combustion of carbonaceous products occurs. CO is the leading cause of poisoning in the United States, and common sources of CO poisoning include housefires, automobile exhaust, water heaters, kerosene space heaters, and furnaces.2 Stoves used for cooking and heating during outdoor activities also produce significant amounts of CO. Mountain climbers have been reported to succumb to fumes generated by small cook stoves.2 The aim of this study was to investigate if burning a cooking stove inside a tent is a potential health hazard. Seven healthy male volunteers used a cooking stove inside a small tent for 120 minutes. CO levels in the ambient tent air were measured in addition to heart rate (HR) and pulse oximetry (SpO2). Venous blood samples were obtained every 15 minutes for measurement of carboxyhemoglobin (COHb). After 2 hours, all the subjects had significant CO levels in their blood (mean COHb = 21.5%). Mean SpO2, also fell from 98% to 95.3% (P < .05), whereas mean HR increased from 63 to 90 beats/min (P < .05). Kerosene camping stoves do produce CO when burned in a small tent. The concentration is high enough to cause significant COHb levels in venous blood after 120 minutes’ stay in the tent. (Am J Emerg Med 2004;22:204-206. © 2004 Elsevier Inc. All rights reserved.)

Carbon monoxide (CO) is a tasteless, odorless, colorless, and nonirritating gas produced by incomplete combustion of organic materials. It exists in minute amounts in the atmosphere (0.02-0.3 ppm).1 CO is the leading cause of poisoning in the United States, accounting for approximately 3,500 deaths annually.4 Common sources of CO include fires, automobile exhaust, water heaters, kerosene space heaters, and furnaces.2 Carbon monoxide has approximately 200 to 250 times greater affinity for hemoglobin than oxygen. Carbon monoxide displaces oxygen from hemoglobin, markedly diminishing its oxygen-carrying capacity. However, it is the effects at the cellular level that are most important in CO poisoning.5 A stove is often used for cooking and heating in out door activities. White gas, kerosene, and butane are the most commonly used fuels for stoves. In May 1986, two young, healthy mountain climbers succumbed to fumes generated by a small cook stove in the enclosed space of their tent at 14,200 feet at Mount McKinley.3 Mountain eers and climbers also discuss whether burning a stove inside a tent represents a potential health hazard. In winter, it is commonplace to use kerosene stoves for heating and cooking in military operations and mountaineering. Under such conditions, the stoves are often used in confined spaces like tents. We were unable to identify any studies measuring the level of carboxyhemoglobin (COHb) in blood while burning a stove inside a tent. The aim of the study was to investigate if burning a cooking stove inside a tent is a potential health hazard.

METHODS

Seven, young (18-38 years, median 28 years), healthy, non-smoking men with normal weight (body mass index 19-24 kg/m2) burned a kerosene camping stove (Optimus III, Gnosjo, Sweden) in three tents for 2 hours. They were using the stove for snow melting, like in a normal winter bivouac. The tents were of the “igloo type” (Helsport, Arctic Base Camp, Norway) with space for three persons. The tents were made of the same material (cotton/polyester). The tents were placed on snow-covered ground, but not dug into the snow. The ventilation canals were open and the zip fasteners were closed. During the study, which took place in April, there was no wind, 5 to 6° and clear skies. The campsite was situated at 200 m above sea level, during daylight, and no additional light sources were used. The stove fuel was standard kerosene, and the measurements were started after the stove was lit. The stoves were placed on the tent floor, with study subjects resting in the sitting position, faces approximately 50 cm above the floor. For continuous measurement of CO levels in the ambient air, we used a Neotox-xl gas sensor (Neotronics Limited, Dorset, UK). The sensor was placed at head level. Every 15 minutes, venous blood samples were obtained from a catheter in the cubital vein for analyses of COHb. The subjects took the test settings. A heart rate (HR) and peripheral oxygen saturation (SpO2) were also recorded every 15 minutes with a Siemens Micro O2. The blood samples were stored on ice for maximum of 8 hours before analyses in a hospital laboratory. COHb was measured by oximetry using a Chiron 855 blood gas analyzer (Chiron, Medfield, MA). The subjects were free to leave the tents at any time if they felt ill. Two physicians were present outside the tents keeping verbal contact during the entire session. The test settings were comparable to normal conditions for soldiers, climbers, and hikers in winter. The study was approved by the local ethics committee. Mean values of COHb, HR, and SpO2 were compared by t tests. A P value of less than .05 was considered statistically significant.
RESULTS

The study was conducted as planned and every subject completed the 120-minute session. None of the subjects had any symptoms of imminent CO poisoning, like headache, dizziness, fatigue, or nausea. The print out of the measured CO levels in the ambient air turned out to be alarmingly high. Already after 15 minutes, the CO concentration was above 150 parts per million (ppm), and 30 minutes after the stoves were lit, the CO levels in the ambient tent air were between 350 ppm and 500 ppm (Fig 1, panel A). One of the tents had a concentration above 600 ppm for a short time. The CO levels in the same tent fell after 20 minutes as a result of the need to replace a nonfunctioning venous catheter. The placement of a new catheter lasted for approximately 30 minutes, including several openings of the zipper. The same tent also experienced that the stove stalled twice after 80 minutes, concomitant with the “spikes” on the graph.

The results of the analysis of the venous blood samples also revealed significantly elevated COHb levels. The mean starting value for COHb was 2.9% standard deviation (SD), 0.34. After 30 minutes the measured levels started to increase in a linear fashion until the last blood sample at 120 minutes. Then the mean COHb had significantly increased to 21.5% (SD, 2.36) (T = 2.45 two-tailed, P < .05) (Fig 1, panel B). Regarding HR, all men experienced a significant increase in heart rate from a mean of 63 (SD, 13.0) to 90 (SD, 17.2) after 120 minutes (T = 2.45 two-tailed, P < .05). There was a slight but significant fall in SpO₂ by 2.7% (SD, 1.1) (T = 2.45 two-tailed P < .05) (Fig 1, panel C) There was also a slight fall in mean SpO₂ from 98% (SD, 1.00) at the start of the study to 95.3% (SD, 1.25) after 120 minutes. This change was also significant (T = 2.45 two-tailed, p < .05) (Fig 1, panel C).

DISCUSSION

The conditions for this study were similar to those one would see under normal conditions when spending a night in a tent during winter, during camping, climbing, or military expense. During the experiment, the ventilation through air channels was standard, and it is also standard that the zippers are closed when it is cold outside. The exposure period of 120 minutes was chosen because this is the normal time used for melting snow and food making for three persons in a tent during winter.

The results indicate that kerosene camping stoves produce significant amounts of CO when used in a tent. When a stove burns without a kettle, less amounts of CO are produced, but with a kettle, the CO emission will rise substantially.6 The explanation for this is that the flame cools on contact with the cold kettle surface, changing the chemical process. It has been reported that this increases the CO production from the commonly used stove (Optimus 111), increasing 10 to 15 times.6

The Norwegian National Institute of Occupational Health recommends 35 ppm as the upper limit in the inspired air during an 8-hour working period. The CO concentration in one tent was 16 times higher than this recommendation. Figure 1A shows some variation in CO concentration during the experiment. This variation is probably the result of difficulty holding the intensity level of the stove constant. The flame temperature is lower when there is snow in the kettle, and increases when the snow melts and water is warming up to boiling. Other studies have shown that the kerosene burner used in this experiment stalls when the CO₂ concentration passes over 4% or when oxygen concentration falls under 12%.7 When all three stoves nearly stalled after 90 minutes, opening the zipper for some minutes made them burn normally.

The severity of poisoning depends on the inspired concentration of CO, the length of exposure, and the general health status of the individual.8 COHb levels less than 10% are usually not associated with symptoms, and 10 to 30% could cause only headache and mild exertional dyspnea after an acute exposure. The symptoms of repeated exposure to low concentrations of CO include headache, fatigue, diffi-
culty in thinking, dizziness, paresthesia, chest pain, palpitations, visual disturbances, nausea, diarrhea, and abdominal pain. The study would have been planned differently if we had known that using a kerosene stove under normal conditions would produce such high levels of CO as we found. We did not specifically elicit symptoms of acute poisoning because we did not expect that significant amounts of COHb would be found in the blood samples. Most of the volunteers reported slight headache and dizziness. The relation between these symptoms and CO poisoning is uncertain because of very warm and moist air inside the tents. Two hours after the experiment was finished, none of the subjects reported any discomfort. The results indicate a near-linear increase in the COHb levels, and one can only guess the possible maximum value if the experiment had been prolonged.

All volunteers experienced a significant increase in heart rate. We did not measure pO₂ or pCO₂ during the experiment. These values would have been interesting and could have been explained if the increased heart rate resulted from hypoxemia or hypercapnia. The increase in HR could also be the result of physical activity inside the tent combined with the heat. There was only a slight decrease in oxygen saturation. This was expected because the Siemens Micro O2 analyzer (Siemens, Danvers, MA) does not distinguish between oxyhemoglobin and carboxyhemoglobin.

The half-life of CO in blood is between 4 and 6 hours. Because the COHb concentration in blood is cumulative over time prolonged exposure to low concentrations of CO can result in considerable poisoning. In a tent during winter, one must use the stove in the morning as well as in the evening for cooking, heating, and the melting of snow for water. A hike or a military maneuver over a period of days could therefore lead to a dangerous rise in COHb and chronic poisoning. There is a need for further studies to explore to what extent the use of stoves in tents represents a health hazard, and if so, how it can be reduced.

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