WILDERNESS & ENVIRONMENTAL MEDICINE, **24,** 280–284 (2013)

BRIEF REPORT

Effect of Fuel Type on Carbon Monoxide Accumulation in Tents of Varied Design

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Objective.—The use of backpacking stoves in tents has been recognized to result in elevated carboxyhemoglobin levels and even death among tent inhabitants. A study was performed to evaluate carbon monoxide production occurring in varying tents with variable fuel types.

Methods.—Using a popular backpacking stove, both white gas and regular unleaded gasoline were used to heat a pot of water inside 2 tents of differing levels of weather resistance ("3-season tent" and "4-season tent") under controlled settings. A remote carbon monoxide sensor measured levels over a 20-minute period. Multiple 20-minute runs were performed with varying fuel and tent combinations to assess peak levels and rates of carbon monoxide production.

Results.—Mean peak carbon monoxide levels were obtained in the 3-season tent and 4-season tent when white gas was burned measuring 60.5 ppm (95% CI: 31.2 to 89.8) and 154.5 ppm (95% CI: 112.8 to 195.7; $P = .002$), respectively. The use of regular unleaded gasoline in the 3-season and 4-season tents resulted in mean peak carbon monoxide levels of 102.9 ppm (95% CI: 77.8 to 128.0) and 210.6 ppm (95% CI: 37.4 to 383.1; $P = .06$), respectively. Using regular unleaded gasoline resulted in significantly increased mean peak carbon monoxide levels compared with white gas in the 3-season tent ($P = .006$); however, the difference was not significant in the 4-season tent ($P = .23$).

Conclusions.—The use of backpacking stoves in tents produces varying levels of carbon monoxide related to fuel type and tent styles. Efforts should continue to educate persons of the risk of carbon monoxide poisoning with the use of any stove while inside tents.

Key words: carbon monoxide, camping stove, tent, stove, backpacking

Introduction

Potentially deadly carbon monoxide exposures are no longer limited to persons exposed to toxic levels in an indoor environment. Experienced outdoor enthusiasts and even the casual weekend camper looking to escape to the great outdoors are not without potential risk as well. In the camping and backpacking community, anecdotal reports and published cases of carbon monoxide poisoning among tent and snow cave inhabitants while using gas burning stoves have been reported for more than 75 years.[1–3] It is estimated that 15 to 20 deaths occur annually in the United States from these exposures.[1]

The extent of carbon monoxide accumulation when using camping stoves has previously been demonstrated in experimental models to be influenced by factors such as flame color, pan size, and fuel type.[4–6] It would be presumed that other variables such as variations in tent style and design that influence insulating properties would lead to variations in carbon monoxide accumulation as well. We elected to conduct this experiment in an outdoor environment in a semicontrolled fashion in an attempt to mimic a scenario that may be encountered among persons using gas camping stoves inside enclosed tents of varied design. The aim of the study is to determine the extent of carbon monoxide production

Presented at the American College of Emergency Physician's Scientific Assembly, Chicago, Illinois, October 2008.

Disclaimer: The authors of this paper have no conflicts of interest to report. The authors have no financial interest in any commercial product mentioned in this paper nor in any products that may compete with these products.

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that may occur in this setting and how levels may be influenced by tent style and alteration of fuel types used by camping stoves.

Methods

A popular backpacking stove capable of burning multiple fuel types (Whisperlite International; Cascade Designs, Seattle, WA) was used under controlled settings to heat a pot of water placed inside 2 arbitrarily chosen tents of differing levels of weather resistance: a Coleman Sundome "3-season tent" (Coleman, Richmond, CA) and a Mountain Hardware EV III "4-season tent" (Mountain Hardware, Wichita, KS). The Whisperlite International stove is a lightweight backpacking stove capable of using several fuel types including unleaded gasoline, white gas, and kerosene. Two individual stoves were purchased new and used twice for 10-minute burn times before the beginning of the study. Fuel bottles were filled with either standard 88 octane unleaded gasoline or Coleman "white gas" camping fuel with 20 pumps of pressure applied as recommended in the Whisperlite International User's Guide. The Coleman Sundome tent is described by the manufacturer as "great for small family car campers, solo travelers, and first time campers." The Sundome has a floor space of 4.55 m^2 and a height of 1.34 m. The Mountain Hardware EV III tent is a 3-person tent described by the manufacturer as a "light, strong, expedition tent, designed for the rigors of high altitude mountaineering." The EV III has a floor space area of 4.51 m^2 with a height of 1.03 m.

Three individual 20-minute burn time trials were performed with each fuel type and tent style combination (Table). One stove used solely white gas whereas the other stove used solely unleaded gasoline. Each stove was used for three 20-minute runs in the 4-season tent, followed by 3 individual runs in the 3-season tent. Each trial included heating 0.5 L water that was initially at 10ºC and placed in a Coleman 16-ounce aluminum cooking pot. After each trial, the tents were allowed to self-ventilate until carbon monoxide levels inside the tents were below 2 ppm. The cooking pans were allowed to cool until they were able to be touched comfortably with an ungloved hand and were then refilled with water. The tents were erected with all zippered ventilation areas closed on level ground approximately 9 m from each other in an unobstructed field located approximately 262 m above sea level. Stoves were placed in the direct center of each tent on a small towel located at ground level.

Table. Study design involving 12 total varying tent/fuel type combinations

	Unleaded gas	*White gas*
Three-season tent	3 × 20-minute runs	3 × 20-minute runs
Four-season tent	3 × 20-minute runs	3 × 20-minute runs

Carbon monoxide levels were measured using a wireless remote sensor (RAE Systems Area Gamma Multi-Gas Detector; RAE Systems, San Jose, CA) that recorded carbon monoxide levels in parts per million (ppm), every 30 s over the 20-minute study period. This device was placed 30 cm from the tent entrance with the recording component located 15 cm from the ground. The study was performed from 8:00 AM to 3:00 PM on a November day with local ambient conditions recorded by the US National Weather Service as a temperature of 3.9ºC to 7.2ºC, wind speed of 0 to 9.3 km/h, and average atmospheric pressure of 30.24 mm Hg.

The relationships between tent type, gas type, and time was analyzed using a repeated measures analysis of variance conducted using a generalized estimation equation (Proc GENMOD, SAS version 9.2; SAS Institute, Cary, NC). The main effects of tent, gas, and replication were tested along with linear and curvilinear effects of time. Sequential carbon monoxide readings were assumed to have AR(1) autocorrelation. Main effects and interaction effects were tested using type 3 score statistics. To illustrate specific effects, we tested the statistical significance of differences in the highest peak carbon monoxide levels for the possible tent and fuel combinations using unpaired 2-tailed Student *t* tests with a $P < .05$ considered significant. Discrete data are expressed as mean with 95% confidence interval.

Results

The progression of measured carbon monoxide levels for the 4 possible tent and fuel type combinations over time is shown in the Figure. Overall, both gas type and tent type demonstrated significant main effects ($P < .05$) with higher carbon monoxide level in the 4-season tent and regular gasoline. Significant interaction effects were found between tent and time ($P = .004$) and gas and time ($P = .01$), indicating that the both gas and tent type had complex curvilinear effects over time.

When comparing peak carbon monoxide levels, significantly lower mean peak carbon monoxide level were noted when white gas was used in the 3-season tent (60.5 ppm, 95% CI: 31.2 to 89.8) compared with white gas use in the 4-season tent (154.5 ppm, 95% CI: 112.8 to 195.7; $P = .002$). Differences in mean peak carbon monoxide levels were not noted to be statistically significant when comparing the use of regular unleaded gasoline in the 3-season tent (102.9 ppm, 95% CI: 77.8 to 128.0) and 4-season tent (210.6 ppm, 95% CI: 37.4 to 383.1; $P =$

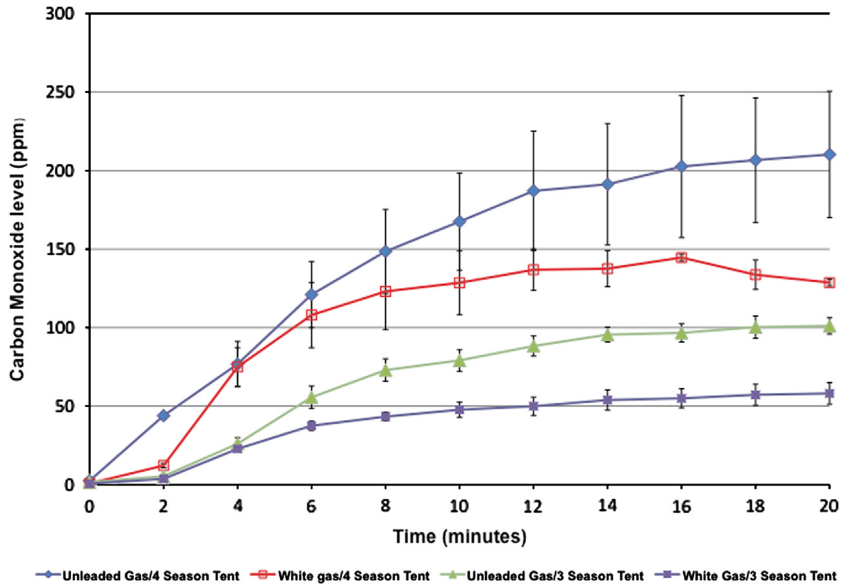

Figure. Mean carbon monoxide levels (±SE) over 20-minute burn times for varying tent and fuel type combinations. Blue diamonds, unleaded gas/4-season tent; red squares, white gas/4-season tent; green triangles, unleaded gas/3-season tent; purple squares, white gas/3-season tent.

.06). When comparing the difference in mean peak carbon monoxide levels based on fuel type in the tents of different style, it was found that regular unleaded gasoline resulted in a significantly increased mean peak carbon monoxide level compared with white gas in the 3-season tent (102.9 ppm, 95% CI: 77.8 to 128.0, versus 60.5 ppm, 95% CI: 31.2 to 89.8; $P = .006$). There was no significant difference in mean peak carbon monoxide levels obtained, however, when white gas and unleaded gas were used in the 4-season tent ($P = .23$).

Discussion

Previous efforts to quantify carbon monoxide accumulation from stoves burning in tents and other temporary outdoor enclosed structures found levels comparable to those obtained in our study. Despite the many variables that would be assumed to exist in an outdoor setting, carbon monoxide levels peaked just slightly lower than our findings ranging from 33 ppm to 190 ppm.[7,8] Turner et al[7] conducted a series of measurements looking at 3 white gas burning stoves (Optimus111B, Optimus 8R, and MSR Firefly) in high altitude environments conducted in ventilated tents, snow caves, and igloos. At altitudes ranging from 2300 m to 5300 m, peak carbon monoxide levels in the tent, igloo, and snow cave were 110 ppm, 140 ppm, and 190 ppm, respectively. Thomassen et al[9] identified mean carboxyhemoglobin levels of 21.5 % in 7 persons exposed over 2 hours to a kerosene burning stove in a partially ventilated military tent. Peak carbon monoxide levels in this controlled experiment were found to approach, and temporarily exceed, 600 ppm, with all persons exposed describing subjective complaints such as headache and fatigue.

In our experiment, we attempted to demonstrate how varying tent style and fuel type will influence carbon monoxide levels that may occur under "typical" outdoor camping settings. As expected, the tent designed for keeping extreme environmental conditions outside was also noted to allow more carbon monoxide to accumulate with varied fuel types. When directly comparing fuel type, in the 3-season tent, a significantly greater amount of carbon monoxide was noted when using unleaded fuel compared with the cleaner burning white gas. The mean peak value was also higher in the 4-season tent than in the 3-season tent; however, this difference was not statistically significant. Previous work suggesting that less clean burning fuel sources will produce more elevated carbon monoxide levels identified a similar difference among fuel types. Schwartz et al[6] compared several fuel types in a simulated 0.4 m^3 unventilated snow cave model constructed of cardboard. After 5 minutes, average mean peak levels carbon monoxide produced by unleaded gasoline were higher than those produced by white gas—464 ± 31.6 ppm vs. 348 ± 70.6 ppm, respectively. When kerosene was used in this model, carbon monoxide levels greater than 999 ppm were recorded as early as 3 minutes into the experiment. In a brief trial run using kerosene with our stove, the amount of smoke generated in our nonventilated tents led us to believe that inhabitants would be forced out of the tent within minutes due to heavy smoke accumulation before carbon monoxide clinical effects might occur.

In both tents in which white gas was used, a mean level that was 90% of the mean peak carbon monoxide level was reached within 10 minutes from starting the stove. This rapid increase followed by a leveling off of carbon monoxide levels may be hypothesized to occur when a steady state is reached between rate of carbon monoxide production by the stove and diffusion of carbon monoxide through the tent. The possibility of a decreased rate of carbon monoxide production may also be raised as both the pressure in the fuel tank and heat production decreases over time since the initial stove ignition. It has been demonstrated that flame color is an important factor in carbon monoxide production that would be influenced by pump pressure.[4] Flame color change over time was not observed in this study.

Mean peak carbon monoxide levels using both fuel types in the 4-season tent surpassed the American Conference of Governmental Industrial Hygienists excursion limit of 150 ppm (the level that should not be exceeded for 15 minutes or longer) during the 20-minute burn time. When using the 4-season tent and unleaded fuel combination, the mean peak carbon monoxide levels surpassed the Occupational Safety and Health Administration maximum allowable ceiling limit of 200 ppm as early as 8.5 minutes after the stove ignition. Estimating carboxyhemoglobin levels and clinical effects based upon carbon monoxide exposure levels is difficult to determine. The Coburn-Forster-Kane equation suggests carboxyhemoglobin levels of 30% with exposures to 300 ppm.[10] Predicting clinical effects based upon exposure levels is also difficult and dependent on a multitude of variables influencing ultimate physiologic response. Conditions frequently encountered in harsh mountaineering environments such as high altitude, dehydration, and an increased respiratory rate undoubtedly would lead to variation in peak carboxyhemoglobin levels reached and ultimate clinical manifestations.

Case reports have identified persons with extremely elevated measured carboxyhemoglobin levels after prolonged exposure. In 1984, the death was reported of 2 persons inside a mountaineering tent who had fallen asleep with a stove running; on autopsy, they were found to have carboxyhemoglobin levels of 57% and 66%.[3] The effect of large amounts of snow that accumulated around the tent, contributing to increased insulating effects, was speculated to have further contributed to the elevated carboxyhemoglobin levels. The deaths of 4 adults and children occurred in Georgia in 1992; they were being found with a propane stove still burning, and post-mortem carboxyhemoglobin levels of 67% to 88% were found.[1] There is uncertainty how levels such as these would be obtained with exposures that may fall into the range of carbon monoxide levels produced in our study. The effects of prolonged exposure to carbon monoxide while sleeping or unconscious may contribute to these very elevated and lethal carboxyhemoglobin levels.

STUDY LIMITATIONS

Several limitations and unanswered questions may be raised from this study. A large variation in carbon monoxide production occurred among progressive runs in the 4-season tent and unleaded gasoline combination. The ultimate carbon monoxide peaks progressed from 141 ppm to 209 ppm to 281 ppm over the 3 different 20-minute runs. It was observed that, as multiple 20-minute runs were performed, increased moisture accumulated in the tent, creating a steamy saunalike effect with water droplets adhering to the inside of the tent. The impact of this effect on carbon monoxide accumulation is unknown. Increased amount of carbon monoxide produced may have occurred on subsequent runs because the stoves demonstrated progressive accumulation of black carbonaceous material at their base. The small number of 20-minute runs with each fuel type and tent combination may have limited our ability to determine how significant the effect of recurrent usage was on peak carbon monoxide levels produced. The question may be raised as to what type of carbon monoxide production might occur from a stove and pan that have had multiple uses, some separated by months if not years while in storage.

Carbon monoxide measurements that leveled off at the end of 20 minutes, as previously mentioned, may have been related to decreasing flame strength due to loss of pressure in the fuel tank. The decision to use a burn time of 20 minutes was arbitrarily chosen. Should burn times have been prolonged with subsequent hand pumps provided by tent inhabitants, it is possible that rising carbon monoxide levels may have occurred. Our stoves were placed in the main compartment of our tent. It is difficult to extrapolate from our results those levels that would be obtained with stoves more appropriately placed in intermittently ventilated vestibule areas of tents. Our study demonstrates the levels obtainable in persons making inappropriate choices who are clearly not following warnings established by tent manufacturers. Changes in the microclimate at our study site were also not measured, with episodic changes in wind speed and temperature fluctuations throughout the day potentially affecting our results. Our study also used 2 tents of contrasting style, shape, and volume, making it difficult to determine with any degree of certainty the true variables that caused carbon monoxide to rise to their measured levels. Given the large number of tents and camping stoves available, actual carbon monoxide levels produced would likely vary from the levels we achieved.

Conclusions

A potential risk of carbon monoxide poisoning clearly exists in the backpacking community for persons using stoves in temporary enclosed structures such as tents. The type of fuel used as well as variations in tent design will likely impact the amount of carbon monoxide that tent inhabitants will be exposed to. Further education among outdoor enthusiasts should take place to help minimize the likelihood of these potentially life-threatening exposures.

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