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Brief Report

Carbon Monoxide Poisoning Among Recreational Boaters

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Objective.—To describe the case characteristics of a series of patients poisoned with carbon monoxide (CO) while boating for recreation.

Design.—Cases of patients referred for treatment of CO poisoning with hyperbaric oxygen were reviewed. Those cases that occurred during recreational boating were selected for analysis.

Setting.—A private, urban, tertiary care center studied from July 1984 to June 1994.

Patients.—Thirty-nine patients ranging in age from 6 months to 69 years who were poisoned in 27 separate incidents.

Main Outcome Measures.—Characteristics of the poisoning incidents were assessed at initial patient presentation, immediately following treatment, and with follow-up telephone interviews.

Results.—Of 512 patients treated for acute unintentional CO poisoning, 39 cases (8%) occurred in 27 incidents related to recreational boating activities. Individuals typically lost consciousness as a result of the poisoning. Most cases occurred aboard a boat that was older than 10 years, had an enclosable cabin, was longer than 22 feet, was powered by a gasoline engine, and was without a CO detector on board.

Conclusions.—Carbon monoxide poisoning is a serious hazard associated with recreational boating. The installation of CO detectors aboard boat types typically associated with this syndrome should be strongly encouraged.

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RECREATIONAL boating is common in the United States, with more than 75 million persons engaging in this activity annually.[1] Injuries commonly occur while boating for recreational purposes, but previously published reports have typically been limited to musculoskeletal trauma.[2,3] During the past decade, we have treated numerous patients for carbon monoxide (CO) poisoning sustained while boating for recreational purposes.

Carbon monoxide intoxication is common in the United States, with an estimated 10 000 persons seeking medical attention or missing at least 1 day of normal activity because of the syndrome each year.[4] Based on death certificate reports compiled by the National Center for Health Statistics, approximately 3500 individuals die annually from unintentional or suicidal CO poisoning, making it the most common cause of death from poisoning.[5] Many cases of CO poisoning result from activities not recognized to be hazardous by the victim.[6,7]

Few reports of CO poisoning among boaters have been previously published. We review our experience with CO poisoning among recreational boaters, describe the risk factors and characteristics of this syndrome, and suggest possible prevention measures.

Methods

Records of patients treated for CO poisoning in the Hyperbaric Department of Virginia Mason Medical Center, Seattle, Wash, from July 1984 through June 1994 were reviewed. A case of CO poisoning was defined as an individual with a history of CO exposure exhibiting symptoms characteristic of CO intoxication (eg, headache, nausea, dizziness, or loss of consciousness) and an elevated blood carboxyhemoglobin (COHb) level. An elevated COHb level was defined as greater than 2% for nonsmokers and greater than 9% for smokers.[8] Individuals with COHb levels less than those limits were still considered to be poisoned if supplemental oxygen had been administered prior to obtaining the blood sample. All poisonings that occurred during recreational boating activities were selected for this report. Individuals poisoned during commercial boating activities were excluded. Information was collected from emergency department and hyperbaric department records. Telephone interviews with patients and/or their parents were subsequently per-

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Source of Carbon Monoxide vs Boat Type and Activity at the Time of Exposure for 27 Exposures

	Powerboat (n=23)		Sailboat (n=4)	
Carbon Monoxide Source	Cruising	Moored	Cruising	Moored
Engine exhaust				
Properly vented	7	5	0	0
Exhaust leak	6	2	1	0
Water heater exhaust	0	0	1	1
Space heater exhaust	0	1	0	1
Generator exhaust	0	2	0	0

formed to obtain missing data and to determine long-term outcome. Frequencies reported for specific data variables represent calculations based on obtainable information.

Carboxyhemoglobin levels reported are the values measured during initial emergency department evaluation at our institution or another facility. Prior to obtaining blood samples for COHb determination, all patients had been removed from the source of CO exposure and some received supplemental oxygen during transfer.

Patients were treated with hyperbaric oxygen in a multiplace hyperbaric chamber. Treatment consisted of hyperbaric oxygen administration at 2.8 to 3.0 atm absolute pressure for 46 to 92 minutes, followed in some cases by administration of additional oxygen at 1.9 atm absolute pressure. Duration of treatment was based on the severity of clinical presentation.

Results

During the decade reviewed, 512 patients were treated on an emergency basis for unintentional acute and severe CO poisoning. Of these, 39 patients (8%) were poisoned with CO while boating for recreation in 27 separate incidents. Complete information was not obtainable in every case because of inability to contact two patients for follow-up and lack of recall of all details by others.

All 27 incidents took place in calm seas on a cool day (mean±SD temperature, 14±9°C [57±15°F]). Additionally, every incident occurred between the hours of 8 AM and 11 PM with 18 (67%) in the 6-hour midday period from 10 AM to 4 PM. Poisonings demonstrated a seasonal distribution with 13 incidents (48%) occurring during the 3-month winter period from January through March. Incidents typically occurred aboard boats in salt water rather than in fresh water.

All boats were longer than 22 feet (range, 23 to 47 feet; mean±SD, 30±7 feet) with enclosable cabins. Cabins were defined to include both those that are permanent (hard cabins) and those that are constructable on deck (soft cabins). It was equally common for incidents to occur on boats while cruising (56%) or moored to a buoy or dock (44%). Boats were typically older, with 17 (71%) older than 10 years (mean±SD age of boat, 17±7 years). Incidents predominantly occurred on powerboats (85%) as opposed to sailboats (15%), and most boats had a single engine for propulsion.

In every case, the source of CO was from within the incident boat (Table). The source of CO was determined to be engine exhaust in 21 incidents, water heater exhaust in two incidents, space heater exhaust in two incidents, and generator exhaust in two incidents. Of the 21 incidents caused by engine exhaust, 95% occurred on powerboats, and 5% occurred on sailboats. Engine exhaust exposures were attributed to properly vented exhaust in 12 incidents and to exhaust system leaks in nine incidents. All engine-associated incidents occurred in boats with inboard or stern-drive (inboard/outboard) engines, powered by gasoline fuel. Of the 21 incidents caused by engine exhaust, 14 (67%) occurred while the boat was cruising. Among the six incidents caused by nonengine CO sources, three occurred on sailboats, accounting for 75% of the sailboat incidents. Water heaters implicated as CO sources used propane fuel. One space heater burned propane fuel, and the other used kerosene. Both generators used gasoline fuel.

For the 39 patients, ages ranged from 6 months to 69 years (mean±SD, 37±19 years), and there were 22 men (56%) and 17 women (44%). Carboxyhemoglobin levels for all patients ranged from 0.8% to 38.4% (mean±SD, 22.1±8.8%). All patients exhibited signs or symptoms of CO poisoning. Loss of consciousness occurred at least transiently in 25 (64%) of the 39 patients. Other symptoms occurring in more than 25% of patients were headache (n=22; 56%), nausea (n=18; 46%), weakness (n=16; 41%), dizziness (n=12; 31%), and dyspnea (n=10; 26%). Less frequent symptoms included chest pain, agitation, vomiting, confusion, abdominal pain, seizures, tinnitus, and paresthesias.

Patients were asked whether alcohol was being consumed aboard the boats at the time of the CO exposure. Alcohol use was reported in five (19%) of the 27 incidents. Blood alcohol levels were not obtained on any patients.

Data regarding occupancy were available for 25 incidents, and in 22 of those incidents the person poisoned with CO was not alone on the boat. However, in 19 (70%) of the 27 total incidents, only one person was referred for hyperbaric oxygen treatment. Exposure time to CO was estimated by the patients to average approximately 1 hour. Poisonings were reported to occur within boat cabins in 23 (85%) of the 27 cases. Among such cabin events, the rear cabin door was usually open (n=16; 70%) and the bow hatch closed (n=17; 74%).

Patients reported that symptoms persisted for variable amounts of time after hyperbaric oxygen treatment in 15 (41%) of the 37 incidents. Headache, weakness, and difficulty concentrating were the most commonly reported residual symptoms.

One boat was reported to have an operational CO detector on board. This did not indicate the danger, for unclear reasons.

Comment

Recreational boating is increasingly popular in the United States. In 1962, the US Coast Guard estimated that 5.95 million boats were in use in the country,[3] and usage increased to 20.6 million boats in 1993.[3] Traumatic injuries are not infrequent during recreational boating activities and have been well described.[2,3] The majority of recreational boats in the United States are less than 20 feet long, and most traumatic accidents occur in this size boat.[2]

This case series suggests that recreational boaters are also at risk for accidental CO poisoning. This risk has rarely been reported previously. We were able to locate only one published case in the English-language[9] medical literature and one published case in the European[10] medical literature. The total incidence of this problem is unknown, but it is likely that additional cases of both similar and lesser severity occurred in the Seattle area during the same period. These cases may not have been referred to our facility for treatment because of the lack of need for hyperbaric oxygen treatment, patient death, or failure to recognize the syndrome.[11] Typical symptoms experienced by patients in this study (headache, nausea, weakness, and dizziness) may be attributed by boaters to seasickness, viral illness, or other causes. In fact, some of the patients poisoned with CO initially believed their symptoms to be the result of these more benign etiologies. It is also likely that similar cases occur throughout the United States and that our experience is not simply a reflection

of excess recreational boating activity in our region. Washington ranks 18th nationally with regard to number of boats licensed statewide, containing only 2% of boats registered in the United States.[3]

The typical poisoning incident in this study occurred during the afternoon of a cool winter day on a boat in salt water. The characteristic boat involved was older than 10 years and longer than 22 feet and had an enclosable cabin. Additionally, the boat was propelled by a gasoline-powered inboard or sterndrive (inboard/outboard) engine and did not have a CO detector on board. The boat was either cruising or moored at the time of the poisoning incident. The individuals poisoned were usually located in the cabin at the time of the exposure and usually inhaled CO from engine exhaust. Patients treated at our facility typically had lost consciousness with the poisoning, although others were frequently present who were less severely poisoned.

We speculate that these factors contributed to the risk for CO exposure in a combination of ways. Carbon monoxide is a byproduct of incomplete combustion, and it is present in large quantities in gasoline engine exhaust.[12] All involved boats were relatively long and had an enclosable cabin, which potentially allows for accumulation of fumes containing CO. This is likely a significant risk factor for CO poisoning since the majority of recreational boats in the United States are shorter in length and presumably do not have cabins.[3] The incidents typically occurred in cool weather, possibly increasing the amount of time individuals spent within the cabin. A CO detector was rarely present to warn of the hazard. Because individuals frequently attributed early symptoms to alternate causes such as seasickness, they may have prolonged their exposure by remaining within the toxic environment.

Accumulation of exhaust fumes in the rear of moving vehicles such as station wagons and pickup trucks has been previously described.[6] As a vehicle moves through air, a relative vacuum is generated behind it by the Venturi effect. This negative pressure may draw fumes into the rear of the vehicle. In the current study, boats were frequently cruising. When cruising, the rear cabin door was usually open and the bow hatch closed. We speculate that exhaust was drawn into boat cabins by the same mechanism as that described in motor vehicles.[6] The "wind" produced by boat motion may actually contribute to, rather than prevent, CO accumulation in the cabin.

Some boats were moored at the time of the poisoning incident. The mechanism of CO exposure in these cases was variable, including accumulation of fumes from leaking exhaust systems, blowing by wind of properly vented exhaust into the cabin, and local CO production by nonengine sources (water heaters, etc). The mechanism here is obviously different than that invoked in moving boats and involves simple accumulation of CO within the boat.

It is apparent that these individuals were unaware or unconcerned about the risk of CO intoxication aboard their boats. This is evidenced in part by the fact that only one of 27 boats involved had a CO detector on board. In the single case where a detector was present, it was not the type that emits an audible warning to alert persons nearby. Furthermore, most treated individuals stated that they had no concern about the risk for CO exposure at the time of their accident.

These findings have several implications for prevention of future CO poisonings among recreational boaters. First, boat exhaust systems should be regularly maintained and inspected to minimize the incidence of leaks. Second, strong consideration should be given to installation of CO detectors within the cabins of boats similar to those described. If it is possible for individuals to be at locations within the cabin that are out of sight from the detector, an electronic sensor that emits an audible alarm may be preferred over a colorimetric CO detector that provides only a visual cue. Finally, public educational programs may be helpful. Among recreational boats involved in accidents in 1993, only 25% of the operators were reported to have received any formal instruction in boating safety.[3] Programs directed at improving awareness of the mechanisms of CO exposure on boats and early symptoms of CO intoxication could help minimize unintentional CO poisoning.

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References

1. National Marine Manufacturers Association. *Boating 1994*. Chicago, Ill: National Marine Manufacturers Association; 1994.
2. Gomez GA, Martin LC, Castro MR. Nautical accidents: unique injuries. *Surg Clin North Am*. 1991;71:419-432.
3. US Dept of Transportation, US Coast Guard. *Boating Statistics 1993*. Washington, DC: US Dept of Transportation; September 1994.
4. Program Development Branch, Environmental Health Services Division, Center for Environmental Health, Centers for Disease Control. Carbon monoxide intoxication: a preventable environmental health hazard. *MMWR Morb Mortal Wkly Rep*. 1982;31:529-531.
5. Cobb N, Etzel RA. Unintentional carbon monoxide–related deaths in the United States, 1979 through 1988. *JAMA*. 1991;226:659-663.
6. Hampson NB, Norkool DM. Carbon monoxide poisoning in children riding in the back of pickup trucks. *JAMA*. 1992;267:538-540.
7. Hampson NB, Kramer CC, Dunford RG, Norkool DM. Carbon monoxide poisoning from indoor burning of charcoal briquets. *JAMA*. 1994;271:52-53.
8. Radford EP, Drizd TA. *Blood Carbon Monoxide Levels in Persons 3-74 Years of Age: United States, 1976-80*. Hyattsville, Md: US Dept of Health and Human Servies; Advance Data 76; March 17, 1982. US Dept of Health and Human Services publication PHS 82-1250.
9. Koren G, Sharav T, Pastuszak A, et al. A multicenter, prospective study of fetal outcome following accidental carbon monoxide poisoning in pregnancy. *Repro Toxicol*. 1991;5:397-403.
10. Tan ES, van Veldhuisen DJ, Lie KI. Carbon monoxide poisoning as a trigger for myocardial infarction. *Ned Tijdschr Geneeskd*. 1993;137:2266-2268.
11. Grace TW, Platt FW. Subacute carbon monoxide poisoning: another great imitator. *JAMA*. 1981;246:1698-1700.
12. Piantadosi CA. Carbon monoxide intoxication. In: Vincent JL, ed. *Update in Intensive Care and Emergency Medicine*. New York, NY: Springer-Verlag NY Inc; 1990;10:460-471.

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