Global Health Matters

This article by Chen, Ma, and Fontaine provides a unique perspective through a natural experiment that resulted from the severe ice storms of 2008 in Hunan Province, China. It is an elegant example of "shoe leather" epidemiology and investigation conducted by the Chinese Centers for Disease Control and Prevention in collaboration with the U.S. Centers for Disease Control and Prevention.

As the authors point out, the individuals who suffered from carbon monoxide (CO) poisoning had no occupational exposure; the poisonings were simply the unfortunate result of a natural event that impacted residents for a period of almost two months. The causes of the poisonings during the storm event centered around poorly ventilated stoves, improper selection of stoves, and stoves that were too old and not functioning well. The basic public health message is one that can be applied almost anywhere in the world: improperly ventilated stoves should not be used for supplemental heat, especially in bedrooms and sleeping areas. Of course, that is much easier said than done. It is interesting to note that the incidence of CO poisoning was significantly higher in urban areas than in rural areas, with an incident rate that was nearly 10 times higher in urban settings.

McCracken et al.[1] and Smith et al.[2] report that approximately half of the world's households depend on biomass (e.g., wood, crop residues, and animal dung) and coal for cooking and heating. Most of this solid-fuel use occurs in developing countries, where poor households generally use open fires or inadequately vented stoves. These fuel-stove combinations result in high indoor levels of fine combustion-generated particles and other pollutants. Proper ventilation and maintenance of these stoves greatly reduces harmful effects from particulates and other combustion products, including CO. Novel and inexpensive programs supported by the World Health Organization and others have proven to be effective in reducing tragic outcomes such as the incident in Hunan.

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RISK FACTORS OF NON-OCCUPATIONAL CARBON MONOXIDE POISONING DURING THE 2008 ICE STORM IN GUIYANG COUNTY, HUNAN PROVINCE, CHINA

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Carbon monoxide (CO) is a colorless, odorless, and tasteless toxic gas produced by incomplete combustion in fuel-burning devices. People with CO poisoning often overlook the symptoms (e.g., headache, nausea, dizziness, or confusion), yet undetected exposure can be fatal.[1] In several countries, the maximum safe level of exposure to CO for a one-hour period is between 32 and 40 parts per million.[2–5] In China, some health education programs claim that adequate ventilation alone can be an effective preventive measure against CO poisoning. However, this claim is not very comprehensive, as it takes other specific measures to prevent CO poisoning. Previous literature only noted that CO poisoning occurred in the absence of good ventilation and did not elaborate on the associated behavioral and conditional factors. This study attempted to determine the risk factors of behaviors and conditions that cause CO poisoning.

BACKGROUND

At the beginning of 2008, a massive ice storm hit a large region in Southern China. Soon after the disaster, the Chinese Centers for Disease Control and Prevention (CDC) conducted a series of rapid-filed investigations to determine the impact of the ice storm on public

health in the affected areas. Preliminary results showed that non-occupational CO poisoning cases (hereafter, CO poisoning cases) increased dramatically (70 cases in 2008 vs. five cases in 2007 during the same time period) in three hospitals in Guiyang County, Hunan Province, which suffered serious damage from the ice storm (Figure). From April 14 to 25, 2008, we conducted an in-depth investigation to study the extent of CO poisoning cases in Guiyang County during the ice storm and to identify risk factors of CO poisoning.

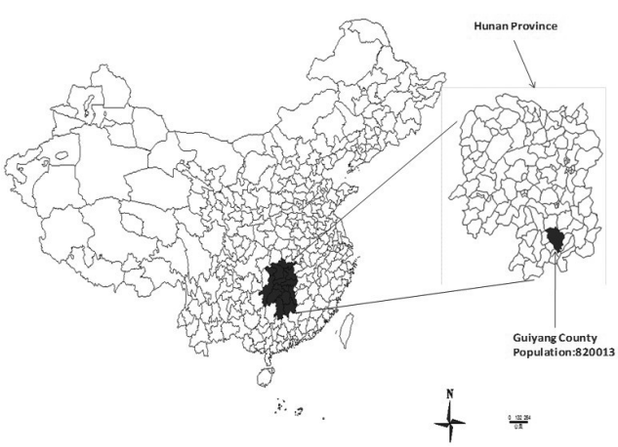
METHODS

Because the 2008 ice storm lasted from January 13, 2008—when rain, snow, and frost began—to March 6, 2008—when the electric power supply was restored—we defined a probable CO poisoning case as someone living in Guiyang County who had (*1*) non-occupational exposure to CO poisoning between January 13 and March 6, 2008, and (*2*) at least two of the following symptoms: fatigue, headache, dizziness, nausea, vomiting, cyanosis lips, disturbance of consciousness, and shock. A confirmed CO poisoning case was a probable case whose carboxyhemoglobin concentration in the blood was higher than 10% (normal concentration is <2% for nonsmokers and 5%–9% for smokers).[6]

A CO poisoning event may include single or multiple victims. If a number of CO poisoning cases occur during the same incident, these CO poisoning cases are considered one CO poisoning incident.

The limit of exposure to CO is 5% concentration of carboxyhemoglobin in the blood.[7] We categorized cases into three groups according to the severity of poisoning. The first group experienced mild poisoning and had at least one of the following symptoms: severe headache, dizziness, floppy limbs, nausea, vomiting, mild or moderate disturbance of consciousness, or more than a 10% concentration of carboxyhemoglobin in the blood. The second group experienced moderate poisoning and included mild cases with disturbance of consciousness, those who recovered after rescue without significant complications, or those who had a 30%–50% concentration of carboxyhemoglobin in the blood. The third group experienced severe poisoning and included cases with any of the following symptoms: (*1*) a disturbance of consciousness up to the cerebral cortex or deep unconscious state; (*2*) a disturbance of consciousness with the presence of any of the following: cerebral edema, shock or severe myocardial damage, pulmonary edema, respiratory failure, upper gastrointestinal bleeding, focal brain damage (e.g., the cone system), or extrapyramidal signs of damage; and (*3*) more than 50% concentration of carboxyhemoglobin in the blood.[8]

Figure. Geographic location of Guiyang County, Hunan Province (in relation to China)



We searched for cases in 45 hospitals in Guiyang County by collecting clinical symptoms records from outpatient logs and laboratory results. However, we found four cases in communities or villages where the case was located. Because we found four cases without a hospital record in the investigation, we only collected clinical symptoms from cases or cases' families.

We considered that residents in urban and rural areas may have had different behaviors when using coal-burning heating devices. As such, we conducted a 1:3 frequency-matched (by urban and rural area) case-control study to identify the risk factors for CO poisoning at the household level. Cases included households that had coal-burning stoves with CO poisoning (n=43, 93%). Controls (n=129) were households that had coal-burning stoves without CO poisoning. Controls were randomly selected by the village or community where the case households were located. We used household questionnaires to identify specific factors associated with coal burning at home (e.g., disposal of stove fire, gas appliance installations, fuel, ventilation, and other factors).

Meteorological data and information on power outages were collected from the local weather bureau and electric power company. We entered data using EpiData 3.0[9] and analyzed it using EpiInfo™ 3.4.1.[10] We analyzed the differences between case and control households using Chi-square tests (>5 observations in all cells), Fisher's exact tests (≤5 observations in ≥1 cell), or t-tests. All tests were two-sided and an alpha level of $p<0.05$ was considered statistically significant.

Table 1. Sources of carbon monoxide poisoning during the 2008 ice storm in Guiyang County, Hunan Province, China

Poisoning source	*Cases (n=46)* N *(percent)*
Coal burning in home	43 (94)
Charcoal burning in home	1 (2)
Generating electricity by fuel in home	1 (2)
Gas burning in home	1 (2)

Table 3. Incidence of carbon monoxide poisoning during the 2008 ice storm in urban vs. rural areas of Guiyang County, Hunan Province, China

Area	*Number of cases*	*Incidence per 100,000 population*	*Rate ratio (95% CI)*
Urban	40	49.0	9.1 (5.8, 14.0)
Rural	39	5.4	

CI = confidence interval

RESULTS

We identified 89 cases from 86 CO poisoning incidents from the ice storm of 2008. Among them, 83 incidents involved one case and the other three involved two cases. We found a total of 85 cases from 45 hospitals, while the remaining four were from residential communities without hospital records. The cases ranged in age from 4 to 78 years. The mean age of cases was 39 (95% confidence interval 35, 43). About 73% of the cases were female. The case-fatality rate was slightly more than 3%. During the same time period in 2007, only 17 CO poisoning cases were reported. We interviewed 46 cases, among which 43 were coal-burning cases (Table 1). The remaining cases were not interviewed because a detailed address was not provided. We used the 43 coal-burning CO poisoning cases as the case group in our case-control study.

Table 2. Clinical symptoms of 85 (96%) carbon monoxide poisoning cases during the 2008 ice storm in Guiyang County, Hunan Province, China

Clinical symptoms and severity of cases	*Cases* N *(percent)*
Clinical symptoms	
Fatigue	68 (80)
Headache	67 (79)
Dizziness	71 (84)
Nausea	65 (76)
Vomiting	60 (71)
Mild disturbance of consciousness	33 (39)
Moderate disturbance of consciousness	15 (18)
Severe disturbance of consciousness	25 (28)
Lips cyanosis	26 (31)
Shock	3 (4)
Cerebral edema	2 (2)
Myocardial damage	2 (2)
Pulmonary edema	3 (4)
Respiratory failure	3 (4)
Focal brain damage	3 (4)
Severity of cases	
Severe poisoning	12 (14)
Moderate poisoning	13 (15)
Mild poisoning	60 (71)

Table 2 shows a list of clinical symptoms of the 85 hospital-reported CO poisoning cases. Fatigue, headache, dizziness, and nausea were the main reported symptoms. Mild symptoms were of a higher proportion. Table 3 compares the incidence of CO poisoning in urban and rural areas, showing the incidence of CO poisoning to be higher in urban areas than in rural areas. Table 4 lists the severity of the 43 coal-burning cases, indicating that most cases (79%) were mild. Based on our finding that coal burning was the primary source of CO poisoning, we were able to identify the risk factors for indoor CO poisoning in the case-control study.

Table 5 lists risk factors for the occurrence of CO poisoning when burning coal in the house. Using a mud stove, putting the stove in the bedroom, having sealed window gaps, and having unsealed tunnel joints were risk factors for indoor CO poisoning. Tunnel clearing, awareness of CO poisoning, knowledge of CO poisoning prevention, and proper ventilation measures were all shown to be protective factors. When the mud stove was in use, CO leaked out at the top and the bottom, as shown in the Photo. Table 6 shows the dose-response effect of the frequency of ventilation. We found a negative correlation between the frequency of opening windows or doors and the possibility of CO poisoning.

Table 4. Case severity rating in a case-control study of carbon monoxide poisoning during the 2008 ice storm in Guiyang County, Hunan Province, China

Case severity	*Coal-burning cases (n=43)* N *(percent)*
Severe poisoning[a]	6 (14)
Moderate poisoning	3 (7)
Mild poisoning	34 (79)

[a]Severe carbon monoxide poisoning resulted in one death.

DISCUSSION

During the 2008 ice storm, there was a sharp increase in CO poisoning occurrence than during the same time period in 2007 in Guiyang County. Inadequate ventilation measures, such as closing windows and doors when using coal-burning heaters, sealing window gaps, and using stoves inappropriately, were all risk factors for CO poisoning. Protective factors included a clear smoke tunnel, adequate ventilation, awareness of CO poisoning, and knowledge of prevention.

As a comparison, the CO source in Guiyang County (i.e., coal burning) during the 2008 ice storm differed from the CO source in Maine during its 1998 ice storm. In Maine, the CO source was gasoline-powered electric generators in 30 incidents (71%), kerosene heaters in eight incidents (19%), and propane heaters in four incidents (10%).[11] We are not aware of the number of

Table 5. Risk factors of CO poisoning among 43 cases and 129 controls, by exposure, during the 2008 ice storm in Guiyang County, Hunan Province, China

	Exposed	*Univariate analysis*	*Multivariate[a] analysis*	
Risk factors	*Case* N *(percent)*	*Control* N *(percent)*	*Crude OR (95% CI)*	*M-H OR (95% CI)*
Stove type				
Mud stove	10 (23.3)	6 (4.7)	5.9 (1.8, 20.0)	6.1 (1.8, 21.7)
Steel barrel	2 (4.7)	2 (1.6)	3.6 (0.2, 50.0)	NS
Brick stove	2 (4.7)	18 (14.0)	0.4 (0.0, 1.9)	NS
Steel stove	29 (67.4)	103 (79.8)	Ref.	Ref.
Stove location				
Bedroom	19 (44.2)	27 (20.9)	4.4 (1.2, 17.8)	4.6 (1.2, 19.7)
Hall	20 (46.5)	77 (59.7)	1.6 (0.5, 6.2)	NS
Kitchen	4 (9.3)	25 (19.4)	Ref.	Ref.
Sealing window gaps	18 (41.9)	15 (11.6)	5.3 (2.2, 13.0)	5.3 (2.2, 13.0)
Tunnel joints not sealed	6 (14.0)	3 (2.3)	5.8 (1.1, 38.0)	8.7 (1.3, 52.7)
Clearing tunnel	6 (14.0)	41 (31.8)	0.1 (0.0, 0.4)	0.1 (0.0, 0.6)
Know CO can cause poisoning	18 (41.9)	110 (85.3)	0.1 (0.0, 0.3)	0.1 (0.0, 0.3)
Know how to prevent CO poisoning	15 (34.9)	109 (84.5)	0.1 (0.0, 0.2)	0.1 (0.0, 0.2)
Ventilation	21 (48.8)	116 (89.9)	0.1 (0.0, 0.3)	0.1 (0.0, 0.3)
Flue pipe construction				
Metal	22 (51.2)	53 (41.1)	1.5 (0.7, 3.2)	NS
Cement	1 (2.3)	1 (0.8)	3.1 (0.0, 114.4)	NS
Brick	0 (0.0)	1 (0.8)	0.0 (0.0, 53.0)	NS
Ceramic	0 (0.0)	1 (0.8)	0.0 (0.0, 53.0)	NS
How stove fire is disposed before sleeping				
Increasing coal	40 (93.0)	123 (95.3)	0.7 (0.1, 4.2)	NS
Put out naturally	3 (7.0)	4 (3.1)	2.3 (0.3, 14.0)	NS
Put out by user	0 (0.0)	2 (1.6)	0.0 (0.0, 12.5)	NS
Dogs at home	4 (9.3)	29 (22.5)	0.4 (0.1, 1.2)	NS
Flue pipe measurements	*Mean*	*Mean*	*P-value*	
Length of flue pipe[b]	2.5 ± 0.83	2.8 ± 1.80	0.97	
Diameter of flue pipe[c]	0.1 ± 0.03	0.1 ± 0.04	0.53	

[a]Stratified by urban and rural area OR. Source: Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. J Natl Cancer Inst 1959;22:719-48.

[b]We analyzed the statistics using the Kruskal-Wallis test, whereby H=0.002.

[c]We analyzed the statistics using the *t*-test, whereby *t*=0.63.

CO = carbon monoxide

OR = odds ratio

CI = confidence interval

M-H = Mantel-Haenszel

NS = not statistically significant

Ref. = referent group

Photo: When a local mud stove such as this was in use in the home, carbon monoxide leaked out at the top and bottom of the stove, which is commonly used in Guiyang County, Hunan Province, China.

CO incidents caused by using gasoline-powered electric generators to keep warm in Maine, but we know that these electric generators were a risk factor. Studies in Guiyang County and Maine have demonstrated the importance of knowledge regarding how to keep warm safely in cold weather.

We believe that the local government has a responsibility to educate residents about appropriate usage of CO-generating heating appliances during cold weather. The local government should remind people who use these heating appliances at night of the importance of seeking fresh air immediately when CO exposure is suspected.[12]

In this study, we identified inadequate ventilation as a risk factor for CO poisoning when using CO-generating heating appliances. This result was similar to the investigation of two cases of non-occupational CO poisoning in Shanghai, China.[13] We also identified a negative correlation between the frequency of opening windows or doors when using CO-generating heating appliances and the possibility of CO poisoning. Based on interviews concerning the average frequency of ventilation in using heating appliances, we defined a frequency of one to three times per use of heating appliances as inadequate ventilation, four to seven times as frequent ventilation, and more than seven times as adequate ventilation. It showed that with increased frequency of ventilation, the probability of CO poisoning decreases.

A large population in Guiyang County uses mud stoves for heating. When this type of stove is used, CO gas leaks from the top and bottom of the stove (Photo). Using CO-generating heating appliances in the bedroom increases the possibility of CO poisoning. Sealing window edges when using CO-generating heating appliances leads to poor ventilation. Using heating appliances with unsealed pipeline joints causes poisonous CO gas to leak. These dangerous behaviors or conditions ultimately cause CO poisoning.

Limitations

This study had several limitations. We did not determine whether or not the lack of a smoke-exhaust system when using heating devices was a risk factor for CO poisoning (no statistical significance). However, common sense indicates that the lack of a flue system when using heating devices is likely to enhance CO exposure. It is possible that the control group ventilated through doors or windows when using heating equipment without smoke-exhaust attachments, while the case group did not ventilate.

We also found that the mud stove, which has no flue, was used more often in the case group than in the control group. The ventilation gate at the bottom of the stove is usually covered by an iron sheet and cannot be closed tightly. As such, CO gas would easily leak from the top and bottom of the stove when burning. We considered this stove to be a CO poisoning hazard even with good ventilation.

Table 6. Frequency of ventilation by opening windows or doors when using heating appliances in a study of carbon monoxide exposure during the 2008 ice storm in Guiyang County, Hunan Province, China[a]

Exposure level	*Case*	*Control*	*M-H[b] OR*
Always ventilate	3	37	0.23
Frequently ventilate	2	24	0.27
Seldom ventilate	16	55	Ref.

[a]Adjusted Chi-square trend = 5.4, p=0.02

[b]Stratified by urban and rural area OR. Source: Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. J Natl Cancer Inst 1959;22:719-48.

M-H = Mantel-Haenszel

OR = odds ratio

Ref. = referent group

Also, we did not thoroughly investigate why the CO poisoning rate was higher in urban than in rural areas. It could be that the ventilation condition in rural areas is better, as we found that many rural households did not have glass on their windows. It is also possible that we underestimated the CO poisoning rate in rural areas, as we did not include cases reported by some rural hospitals without clinical symptom records and laboratory results. In the case-control study, the number of cases (incidents) was not sufficient, and some cases could not be interviewed because a detailed address was not provided.

CONCLUSIONS

The cause of death in many cases of CO poisoning can be attributed to faulty equipment or a lack of awareness of risk. Proper installation and regular maintenance of home-heating appliances; cleaning of obstructed chimneys; and careful attention to ventilation during the use of butane and kerosene space heaters, wood stoves, and charcoal grills will reduce risk.[14] These effective measures can be applied to prevent the occurrence of CO poisoning cases.

Based on the findings of this study, we suggest that the local government should promote health education, informing local residents about the dangers of CO poisoning, with a focus on prevention. Some points should be emphasized. First, smoke-exhaust pipes must be cleaned frequently. This suggestion is similar to that of the investigation of 327 CO poisoning cases in He Ji Hospital.[15] Second, the smoke tunnel joints should be sealed. Third, mud stoves should not be used, as they can easily leak CO gas. Fourth, adequate ventilation should be ensured when using stoves. Fifth, stoves should not be used in the bedroom, especially when sleeping. The government should also put more effort into banning the sale of shoddy stoves. Future research should also examine the reason for the high CO poisoning rate in urban areas.

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