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Human Cancer Risk from the Inhalation of Formaldehyde in Different Indoor Environments in Guiyang City, China

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Abstract This study was conducted to estimate the risk of human cancer from the inhalation of formaldehyde in different indoor environments in Guiyang City in China. Offices had the highest mean formaldehyde concentration (0.11 mg/m^3) and classrooms had the lowest mean formaldehyde concentration (0.04 mg/m^3). The cancer risk levels in different indoor environments ranged from 6.96×10^{-6} to 2.48×10^{-4} and were greater than the acceptable cancer risk 1×10^{-6}. High human formaldehyde risks imply a critical influence on human health in Guiyang City. The highest cancer risk values occurred in bedrooms (ranging from1.87 in 10,000 to 2.48 in 10,000). For office workers, offices were the highest risk environment after bedrooms where formaldehyde concentration levels were identified. Students were the most sensitive population, and the highest priority should be given to protecting their health in indoor environments. Regulations nd standards for low emission materials and public education in relation to indoor pollution are highly recommended in China to protect human health.

Keywords Formaldehyde · Cancer risk · Human health risk · Indoor

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Human health risk assessment is a methodology to understand public health risks which are potentially associated with exposures to particular pollutants in different environments (USEPA 2004). Formaldehyde is a carcinogen to humans. Epidemiological studies have found a link between long-term human exposure to elevated levels of formaldehyde and cancers in the nose, mouth, throat, digestive system, lungs, skin and blood (IARC 2006). Therefore, formaldehyde is a high risk air pollutant for the human population, and the level of human cancer risk arising from its inhalation is a significant issue for public health.

This study was conducted in Guiyang. As the capital of Guizhou Province, Guiyang has been one of the fastest growing cities in China in the past two decades. Located in the eastern part of the Yun-Gui Plateau, the city plays an important role in the strategic development of Western China. As Guiyang has emerged in Southwest China as a new and modernized city, the housing conditions in the city have improved substantially. Formaldehyde is the most widely used chemical in equipment and materials indoors. The negative impact of indoor air pollution is also becoming obvious.

The objective of this study was to understand the human cancer risk level arising from inhalation of formaldehyde in different indoor environments in Guiyang. This kind of cancer risk assessment can also enhance our recognition of the potential health risks generated in our indoor environments.

Materials and Methods

Cancer risk was expressed simply as the product of the chronic daily intake (CDI) and a slope factor (SF) of a specific carcinogenic air pollutant (Eq. 1).

$$\text{Cancer risk} = \text{CDI} \times \text{SF} \quad (1)$$

The SF was calculated from Eq. 2

$$SF = \frac{URF \times BW \times CF}{IR \times AR} \tag{2}$$

where: SF is the slope factor $(mg/kg/day)^{-1}$; URF is the unit risk factor $(\mu g/m^3)^{-1}$ (1.3×10^{-5} for formaldehyde) (USEPA 2003); BW is the adult body weight (70 kg assumed); CF is the conversion factor (1,000 µg/mg); IR is the human inhalation rate (20 m^3/day assumed); AR is the absorption rate (1 assumed unless otherwise specified) (USEPA 1989a).

The CDI in mg/kg/day was calculated from Eq. 3.

$$CDI = \frac{C \times IR \times ED}{BW \times AT} \tag{3}$$

where: C is the air pollutant concentration (mg/m^3); IR is the inhalation rate (m^3/day); ED is the exposure duration (h); BW is body weight (kg); AT is lifetime (h).

The mean formaldehyde concentration in different indoor environments used in the risk calculations are shown in Table 1 and are based on field measurements. Five representative environments were selected in this study, namely offices, classrooms, living rooms, bedrooms and kitchens. To make a comprehensive, objective and systematic assessment, choosing a representative sample of monitoring sites is critical. A total of 74 indoor monitoring sites were selected. The sites included three types of geographical location (urban area near traffic, urban area in the green zone, and suburbs). On-site sampling started in March 2004 and ended in January 2005, and covered three seasons: spring, fall and winter. Samples were taken two or three times per day for two to three consecutive days. When air samples were taken three times per day, the sampling periods were 8:00–10:00, 12:00–14:00, and 18:00–20:00; when air samples were taken twice per day, the sampling periods were 9:00–11:30, and 14:30–17:00.

A Portable Formaldehyde Analyzer (InterScan Model 4160) was used to measure the formaldehyde concentrations. This instrument uses an electrochemical gas detector which operates under diffusion controlled conditions. The instrument gives a measurement range of 0–19.99 ppm with a lowest detection limit of 0.01 ppm. The instrument was calibrated by an authorized institution against the corresponding standard method (China National Standard Method GB/T16129). Prior to sampling, calibration checks were performed for instrument zero. Zero-point was calibrated by cleaning the air with a carbon filter before each environmental measurement. Span was calibrated by a known formaldehyde concentration once per half year. To obtain reliable data, sample handling was conducted following the QA/QC procedures. Selection of sampling sites and locations followed the national guideline for design of protocols for environmental monitoring and sampling (China National Standard Method GB 12997-91) and technical specifications for environmental monitoring. Field sampling was conducted by trained lab technicians. To assure the validity of the samples, procedures for sample handling, storage and transportation outlined in the methods were strictly followed.

Table 1 Formaldehyde concentrations in different indoor environments (mg/m^3)

Indoor environment	N	Mean	Median	S.D.	Min	Max
Living room	237	0.06	0.05	0.03	0.01	0.17
Bedroom	236	0.06	0.07	0.02	0.01	0.15
Kitchen	222	0.06	0.05	0.04	0.01	0.27
Classroom	105	0.04	0.03	0.04	0.01	0.23
Office	169	0.11	0.07	0.13	0.01	0.74

The exposure time in various indoor environments is another important parameter in the risk calculations. Four different populations were considered in this study, namely female office workers, male office workers, housewives and students. Table 2 is a summary of average daily life exposure time for different populations in different indoor environments in China. These data were based on best professional judgment from the exposure perspective according to a survey across the whole country of Chinese time allocation (Ma and Zhang 2004), which is the only available information related to time allocation in China.

In China, office workers on average spend 8 h in their office per day. They work 5 days per week and normally have 114 rest days annually, including weekends and public holidays. The work lifetime is assumed to be 40 years. A housewife is assumed to be a woman who does not have a full-time job and who looks after her family at home. In terms of this assumption, housewives spend most time at home compared to other populations. Students in China attend school on average 5 days per week. Students usually stay at school for an average of 8 hours per day, and have 166 school holidays per year, including weekends, summer vacation, winter vacation and public holidays. School children must attend school for 12 years from primary school through high school. All of this information was used in the risk calculations in this study.

The USEPA suggests the standard values for body weight and inhalation rate as shown in Table 3. These values were used to calculate risk in this study (USEPA 1989b).

Because distribution information relating to the exposure time, inhalation rate and body weight parameters from the exposure perspective is not available in China at present, the distribution of risk could not be calculated. Therefore, this study used the mean values of each parameter to calculate the mean risk value.

Table 2 Average exposure time for different populations in different indoor environments

	Number of hours per day (h)							
	Female office worker		Male office worker		Housewife		Student	
	Work day	Rest day	Work day	Rest day	Work day	Rest day	Work day	Rest Day
Office	8.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00
Living room	4.00	7.00	4.50	8.00	7.00	7.00	4.75	8.75
Bedroom	8.00	10.00	8.00	10.0	9.00	9.00	8.00	10.0
Kitchen	1.00	2.00	0.50	0.75	4.00	4.00	0.25	0.25
Classroom	0.00	0.00	0.00	0.00	0.00	0.00	8.00	0.00

Table 3 Inhalation rate and body weight for different populations[a]

	Male adult	Female adult	Child
Inhalation rate (m^3/day)	15.2	11.3	8.7
Body weight (kg)	70	60	36

[a] Data from USEPA (1989b)

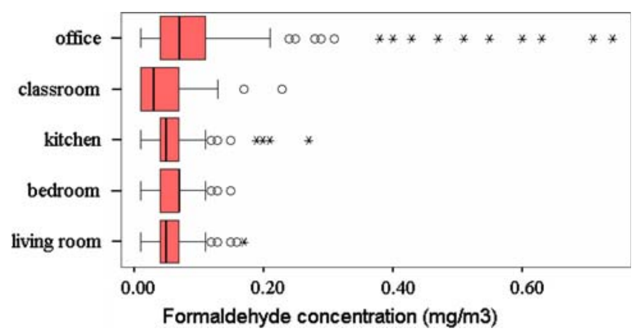

Fig. 1 Box plots of formaldehyde concentration in different environments

Results and Discussion

Offices have the highest mean formaldehyde concentration (0.11 mg/m^3) and classrooms have the lowest mean formaldehyde concentration (0.04 mg/m^3) as shown in Table 1. Box plots[1] of formaldehyde concentration in different indoor environments are presented in Fig. 1. The red broken line is the value of the China National Indoor Air Quality Standard of formaldehyde concentration, which is 0.01 mg/m^3 (IAQMG 2002). The WHO Working Group on Assessment and Monitoring of Exposure to Indoor Air Pollutions also concluded that indoor formaldehyde concentrations higher than 0.01 mg/m^3 were of sufficient concern to call for corrective actions (WHO 1999). From Fig. 1, it is very obvious that some measurements exceed the standard value in all indoor environments, which indicates that formaldehyde pollution in different indoor environments is heavy. From the shape of the distribution, the distribution of office concentrations (0.01 mg/m^3 to 0.74 mg/m^3) is more discrete than others with the biggest median value (0.07 mg/m^3) and mean value (0.11 mg/m^3). They have the highest percentage of measurements which exceed the standard, which indicates that the formaldehyde pollution in offices is heaviest in Guiyang city. Bedrooms have the highest median value (0.07 mg/m^3), which indicates the high proportion of higher concentrations in bedrooms.

Table 4 shows the calculated mean formaldehyde human cancer risks. The cancer risks range from 6.96×10^{-6} to 2.48×10^{-4} (ranging from 6.96 in 1,000,000 to 2.48 in 10,000) and greater than the acceptable cancer risk 1×10^{-6} (1 in 1,000,000) (USEPA 1989a). Except for the risk to students in kitchens, the cancer risks are about 10–100 times higher than the acceptable cancer risk. They represent a very high human formaldehyde risk, and inhalation exposure to formaldehyde therefore has a critical influence on human health in Guiyang City.

The highest cancer risk values occurred in bedrooms (ranging from 1.87 in 10,000 to 2.48 in 10,000), which had the highest formaldehyde concentrations. Since people spend a lot of their time in bedrooms, this implies that carcinogenic effects in bedrooms are a significant concern. Students have the highest risk (2.48 in 10,000) in bedrooms, as they have the highest inhalation rate to body weight ratio and the longest exposure time in bedrooms amongst all the populations. The cancer risk levels of students in living rooms, classrooms and kitchens are also greater than the acceptable level. As students are the most sensitive population, high priority should be given to protecting their health in the different indoor environments in which they spend most of their time, especially in

[1] A box plot is a type of graph which is used to show the shape of the distribution, its central value, and spread. The box of the plot is a rectangle which encloses the middle half of the sample, with an end at each quartile. The length of the box is thus the interquartile range of the sample. A line is drawn across the box at the sample median. Whiskers sprout from the two ends of the box until they reach the sample maximum and minimum. The crossbar at the far end of each whisker is optional and its length signifies nothing. Outliers and extremes are shown as ○ and * respectively.

Table 4 Mean formaldehyde human cancer risks in different indoor environments

	Female office worker	Male office worker	Housewife	Student
Office	1.25×10^{-4}	1.44×10^{-4}	NA	NA
Living room	1.07×10^{-4}	1.40×10^{-4}	1.52×10^{-4}	1.83×10^{-4}
Bedroom	1.87×10^{-4}	2.16×10^{-4}	1.95×10^{-4}	2.48×10^{-4}
Kitchen	4.34×10^{-5}	1.45×10^{-5}	8.68×10^{-5}	6.96×10^{-6}
Classroom	NA	NA	NA	1.39×10^{-5}

Table 5 Uncertainty analysis

	Uncertainty analysis
Exposure concentration	The concentrations used in this study were based on short-term measurement, and ignored potential daily variations over prolonged periods.
Exposure time	As no relevant information relating to exposure time is available in China, the professional judgment used in this study could not accurately represent the real exposure time in actual populations.
Inhalation rate body weight	As no such information based on the exposure perspective is available in China, this study used information from an America survey, which could not represent real inhalation rate and body weight characteristics in China.
Calculation method	This study used the mean values of each parameter to calculate the mean risk value. However the distribution of risk values could not be presented in this study because distribution information relating to exposure time, inhalation rate and body weight parameters from the exposure perspective is not available in China at present.

classroom and home environments. For office workers, offices are the highest risk environment after bedrooms. The female and male office workers' formaldehyde cancer risks are 1.25 in 10,000 and 1.44 in 10,000 respectively, which is very similar with Wu's study. Wu et al. (2003) reported that the population formaldehyde cancer risks in offices ranged from 2.06 in 10,000 to 1.75 in 1000 in Taiwan. From both studies, it is clear that the human formaldehyde cancer risks in offices are generally higher because the highest level formaldehyde concentrations are commonly found in offices rather than in other environments (Dingle et al. 2000; Cheong and Chong 2001). Housewives have the highest risk in kitchens (8.68 in 100,000) among all the populations as they have the longest exposure time in kitchens, but their risk in kitchens is still about 30% lower than female office workers' risk in offices.

Scientific uncertainties are inherent in each step of the risk assessment process (USEPA 2004). These include measurement uncertainties, scenario uncertainties used to estimate population exposure scenario (USEPA 2004), and the uncertainties introduced in risk characterization due to day-to-day, place-to-place variations in concentrations and so on (Kim et al. 2002). Table 5 shows the uncertainty analysis of this study. Most of the uncertainties are scenario uncertainties, because the basic data are still not available in China. A survey based on the exposure perspective should be performed in China to make future research more scientific.

The high level cancer risks estimated from this study show that identifying the formaldehyde sources and adopting methods to eliminate them in indoor environments are imperative in Guiyang city for protecting human health. Therefore, the development of regulations and standards for the emission of materials in China and implementing them strictly is highly recommended. In addition, public education in relation to indoor air pollution is extremely limited in China. This kind of education, including the possible sources of indoor air pollution, identifying low emission materials and the importance of ventilations, deserves more and more efforts.

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