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Exposure and cancer risk assessment for formaldehyde and acetaldehyde in the hospitals, Fortaleza-Brazil

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ABSTRACT

The levels of internal and external concentrations of formaldehyde and acetaldehyde, as well as occupational risk based on individual exposure to and potential carcinogenic effects of these, were evaluated in eight environments of two hospitals in the city of Fortaleza-CE during September and October of 2009. The results depicted a variation of 1.98–24.87 $\mu g\,m^{-3}$ formaldehyde and of 9.38–55.10 $\mu g\,m^{-3}$ acetaldehyde; the main sources of emissions were internal. The exposure levels showed values above the allowable limits for some of the environments studied (permissible exposure limits estimated as an 8-h time-weighted average (PEL-TWA)). The estimation of total cancer risk is of a similar magnitude to other studies, and the risk is 12–18% greater for women than men.

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1. Introduction

Air pollution and how to control it has been extensively researched in recent decades and is now a major topic in environmental preservation, particularly with regard to human health. However, air pollution is not limited to the outdoors. Air pollution can be significant in occupational and home ambient air [1–4].

In the case of hospital environments that have intensive care units (ICU), neonatal units (UTN) and surgical sites (SC), air quality can exert a direct influence on the health and recovery of patients, as well as the occurrence of infections, thereby endangering the patients and employees of those establishments [5].

According to Wilburn [6], a complex mixture of chemicals circulates in hospital air, and the chemicals are recycled through heating, ventilation and air conditioning, which can function as a vehicle for disease transmission.

Some of the main chemicals present in air from hospital environments are carbonyl compounds (CCs), specifically formaldehyde and acetaldehyde, which are present in materials used in routine cleaning and disinfecting supplies, sterilizing materials, chemical reagents, furniture, paints and construction materials [7–10]. These compounds are described in the literature as strong depressors of human health, due to high toxic and carcinogenic potentials [11,12]. Chronic exposure to formaldehyde causes cancer, and epidemiological studies show adverse effects on allergies and the respiratory system [13,14] Acetaldehyde, however, is a potential carcinogen in humans and can cause irritation to skin, eyes and nose [15,16].

Because of the toxic nature of these compounds, some international agencies have established maximum exposure levels of formaldehyde and acetaldehyde in occupational environments. According to the organizations OSHA [17] and NIOSH [15], permissible exposure limits (PEL-TWA) for formaldehyde are 930 $\mu g\,m^{-3}$ and 20 $\mu g\,m^{-3}$, respectively, for an eight-hour workday. The exposure limits for acetaldehyde are 360,000 $\mu g\,m^{-3}$ and 180,000 $\mu g\,m^{-3}$, respectively.

In Brazil, the Regulatory Norm of January/2003 N° 09 [18], which establishes reference standards for indoor air quality in climate-controlled environments for public use and a value suggested by Aquino Neto and Brickus [19] are the main reference values for Brazilians. The scope of the regulatory standard N°09 applies to hospital environments, but does not establish any standards or exposure

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limits. These regulations only suggest selection of materials and health products that contain few volatile organic compounds.

In this context, the chemical quality of indoor air in hospitals is very important and necessary for the development of mechanisms that prevent exposure and monitor health of employees, patients and visitors. This study assessed the concentrations of CCs, especially formaldehyde and acetaldehyde, and occupational risk based on individual exposure and carcinogenic potential, as well as in national and international law.

2. Experimental methods

2.1. Sampling site description

The study was conducted in two major hospitals in Fortaleza, which will be referred to as hospital A and hospital B, at the request of both institutions. The hospitals are 4100 and 3870 m^2 (building area) and have 100 and 150 employees, serving approximately 400 and 180 people, respectively, per month in various fields. These hospitals were selected for the study because they offer different hospital services, thus covering a diverse array of sample environments (Table 1). No industrial activity is developed in the vicinity of the hospitals studied; however, they are surrounded by populated areas, commercial areas and busy highways with heavy traffic flow. The sites selected for the study are associated with frequent handling of chemicals, hospital supplies, cleansing and disinfecting agents, and sterilizing materials. Samples were taken outside to check for internal/external (I/O) ratios and possible sources of contamination. At each sampling site, a worksheet was tabulated with information about the size of the location, number of people in the room, main activity, temperature and other information (Table 1). The sampling was performed in triplicate at the time of functional activity in the months of September–October 2009 between 8:00 and 12:00 AM hours.

2.2. Reagents and solvents

All solvents and reagents used in this work were chromatography (HPLC, Merck) and PA grade (Synth). The formaldehyde (Merck), acetaldehyde (Aldrich) and DNPHi (Aldrich) standards were purified through three-step recrystallization.

A 0.2% solution of 2,4-DNPHi was prepared by weighing 0.05 g of pure reagent in an analytical balance and dissolving it in 15 mL of HPLC-grade acetonitrile (Merck), 9.75 mL of ultra pure water and 0.25 mL of concentrated phosphoric acid (H_3PO_4) (Synth) so that the final pH was approximately 2. A liquid–liquid extraction was then performed with 4 mL of HPLC-grade dichloromethane (Merck) to purify the solution [20].

2.3. Chromatography method

To analyze the hydrazones that were eluted from the cartridges, a sampling model HPLC Shimadzu TA-20 reverse phase column type octadecylsilane (ODS)-C18 (25 cm × 4.6 mm, 5 μm) detector UV-VIS-diode array (model SPD-M20A) was used at wavelength 365 nm, with an injection volume of 20 μL and a system gradient mobile phase consisting of ACN/H_2O: 70:30 (v/v) for 7 min.; 77:23 (v/v) for 6 min. and 70:30 (v/v) for 2 min. at a flow of 1 mL min^{-1}.

Quantification and identification of formaldehyde and acetaldehyde was carried out using a mixture of standards of hydrazone (2,4-DNPHo − CCs). Identification of the hydrazones was based on retention time and absorption spectra. Calibration curves were prepared using 6 concentrations of standards (0.5–25 μg ml^{-1}), with a correlation coefficient (R) greater than 0.994. The standards were injected at least three times. The limit of detection values were 113.4 μg L^{-1} (formaldehyde) and 49.3 μg L^{-1} (acetaldehyde).

2.4. Sampling

The CCs were collected by suctioning the air with the aid of a pump for 1 hour of active sampling at a flow rate of 0.8 to 1.2 L min^{-1}, forcing the air to pass through two Sep-Pak C18 cartridges that were impregnated with an acid solution of 2,4-DNPHi connected in series [21]. Calibration of the sampling pump was performed prior to each collection, and the error in the calculated variation of the flow was between 2 and 7%. The system was mounted at a height equivalent to the breathing zone, approximately 1.50 m from the floor and far wall. In each environment of the two hospitals, samples were collected on 3 consecutive days. Outdoor samples were collected on a similar schedule (on 3 consecutive days). To obtain a representative sample, an eight-hour (workday) sampling session was performed during the hours of 8:00 to 12:00 AM in the morning during the months of September and October 2009. After collection, the cartridges were sealed, wrapped with aluminium foil, refrigerated and then transported to the laboratory, where elution and chromatographic analyses were performed immediately to minimize the risk of interference.

The collection efficiency was determined with two cartridges in series and over 95% of the eluates were found in the first cartridge.

Table 1
Features of the sampling sites from hospitals A and B.

Indoor sampling sites	Abbreviation	Activity type	Ventilation type	Time spent by employees (h $week^{-1}$)	Area (m^2)	Temp. Amb. (°C)	Emissions source
Hospital A							
Hematology	Ha1	Analysis of Blood	AC	40	35	22	Prod. cleaning
Room small surgery	Ha2	Simple surgery and medicação	AC	40	40	22	Furniture
Room donation of blood	Ha3	Donation and collection of blood	AC	40	15	22	Construction Mat.
Ward	Ha4	Consults and exams	AC	40	60	24	Chemicals
Hospital B							
Hematology	Hb1	Analysis of Blood	AC	40	39,80	22	Prod. cleaning
Room hemoglobin	Hb2	Prepare of solution and Analysis of Blood	AC	40	53	24	Furniture Construction Mat.
Room donation of blood	Hb3	Donation and collection of blood	AC	40	68	23	Chemicals
Ward	Hb4	Consults and exams	AC	40	18,10	23	

AC = Air conditioning.

Table 2
Description of variables used for the estimation of cancer risk.

Parameter	Description	Value	United
CA	Contaminant concentration	–	$mg\,m^{-3}$
IR	Inhalation rate, adult	1.02	$m^3\,h^{-1}$
ED	Exposure duration, adult	40	hour $week^{-1}$
EF	Exposure frequency	36	Week $years^{-1}$
L	Length of exposure	40	years
BW	Body weight, man and woman	70/60	kg
ATL	Average lifetime of man and woman	69/72	years
NY	Number of days per years	365	Days $years^{-1}$
D	Days of work	5	days

Complete recovery of all compounds was noted. The RSDs were below 15%. The average background concentrations from 6 samples were 0.42 and 1.45 mg/cartridge for formaldehyde and acetaldehyde, respectively.

2.5. Potential dose (PDi)

PD is the determination of potential exposure, which indicates an effective dose, in biological terms, of a pollutant that could cause human health effects in a given environment. Mathematically, exposure (PD) for an individual (i) because of the admissions process (inhalation or ingestion) can be calculated from the following equation (USEPA) [22,23]:

$$PD_i = C_j \times (IR)_i \times T_{ij} \quad (1)$$

where C_j is the concentration of pollutant ($\mu g\,m^{-3}$), IR is the reason for contact ($m^3\,h^{-1}$) and T is the exposure time ($h\,day^{-1}$). Due to the difficulty of accurately measuring the correct rate of inhalation for each individual, the PD was estimated for an exposure period of 8 h, and an IR of 1.02 $m^3\,h^{-1}$ (average inhalation) was used, as suggested by the *Exposure handbook factors* [24,25].

2.6. Evaluation of the cancer risk

The calculation of occupational exposure for the lifetime of the studied compounds was estimated by CDI in accordance with Eq. (2) [26]. For evaluation of the CDI, certain values have been assumed according to USEPA (1997a, b) to facilitate calculation of the parameters (Table 2). The application of these models eliminates the need for epidemiologic studies, which are time-consuming and high-cost.

$$CDI = \frac{(CA\ IR\ ED\ EF\ L)}{(BW\ ATL\ NY)} \quad (2)$$

Cancer risk (CR) was estimated by chronic daily intake (CDI) multiplied by the Slope Factor (SF) according to the Integrated Risk Information System (IRIS) [27,28].

$$CR = CDI \times SF \quad (3)$$

According to the IRIS system, the slope factors in this study for formaldehyde and acetaldehyde are 0.0455 $mg\,kg^{-1}$ day and 0.0077 $mg\,kg^{-1}$ day (USEPA), respectively [23–28].

3. Results and discussion

3.1. Concentration of aldehydes in the air

The ranges of variation in the average levels of indoor concentration of formaldehyde and acetaldehyde found in the hospital environments studied are presented in Table 3. The results showed the presence of formaldehyde and acetaldehyde in all environments. The CCs are present in indoor environments from primary (direct) or secondary (from reaction processes) sources. Volatile organic compounds (VOCs) and alcohol contributed significantly to increased levels of CCs through the processes of oxidation and induction of fluorescent lights, which are often used indoors [10,29–31].

There are only a few studies that compare the chemical quality of indoor air in hospitals, but compared with these studies, this study showed that levels of CCs in the studied hospitals were below the levels in most hospital settings reported in the literature (Table 4). Values with the same magnitude as the levels found in the study were verified by Lu et al. [32] in hospitals in China; however, when compared with other studies in Brazilian and Chinese hospitals, the levels of formaldehyde are very low [33–36]. Although most of the CCs studied were present at lower levels, which may be due to lower demand for care in hospitals studied in Fortaleza, some standards are similar. Acetaldehyde levels were higher in hospital A, whereas in hospital B, there was a higher concentration of formaldehyde. This difference is caused by increased ethanol use in environments other than hospitals due to the partial oxidation of ethanol produces acetaldehyde [32]. Ghasemkhani et al. [37] attribute the high levels of formaldehyde found in pathology laboratories, surgery rooms and endoscopy to the use of disinfectants and high and low air exchanges.

The ratio of formaldehyde/acetaldehyde was used to indicate the possible contributing sources of these compounds (Table 4). The results showed that the ratio ranged from 0.102–1.30 for hospital A and 0.833–2.28 for hospital B. In the hospital environment, where alcohol is used as a means of sterilization, there was a considerable correlation between alcohol level and low ratios of formaldehyde/acetaldehyde.

Most hospital environments studied showed concentration levels below the PEL-TWA, as recommended by national and international agencies. Exceptions were the environments Hb1 and Hb4 of hospital B, which presented levels above PEL-TWA for formaldehyde (24.87 $\mu g\,m^{-3}$ and 21.38 $\mu g\,m^{-3}$, respectively), according to NIOSH (Table 4).

Table 3
Variation range and average levels of indoor concentration ($\mu g\,m^{-3}$) for formaldehyde and acetaldehyde obtained in the hospitals studied.

Hospital A – indoor ($\mu g\,m^{-3}$)								
Compound	Ha1		Ha2		Ha3		Ha4	
	Range	$x \pm s$	Range	$x \pm s$	Range	$x \pm s$	Range	$x \pm s$
Formaldehyde	8.64–19.4	12.3 ± 0.09	7.51–20.6	15.0–15.7	4,11–9,43	6.10 ± 1.11	1.30–2.89	1.98 ± 1.27
Acetaldehyde	24.3–85.7	55.1 ± 2.64	4.27–23.1	11.5 ± 1.92	9,92–53,8	43.2 ± 5.69	3.11–42.9	19.0 ± 14.1
Hospital B – indoor ($\mu g\,m^{-3}$)								
Hb1			Hb2		Hb3		Hb4	
Formaldehyde	17.9–32.9	24.8 ± 5.61	4.31–32.8	17.9 ± 2.50	9.98–33.9	19.0 ± 1.92	10.3–35.9	21.4 ± 6.84
Acetaldehyde	11.5–16.9	13.6 ± 3.19	9.92–17.5	14.6 ± 0.64	18.6–25.1	22.8 ± 1.03	8.33–10.2	9.38 ± 3.72

Hospital A: Ha1 = Hematology; Ha2 = Room small surgery; Ha3 = Room donation of blood; Ha4 = Ward.
Hospital B: Hb1 = Hematology; Hb2 = Room Hemoglobin; Hb3 = Room donation of blood; Hb4 = Ward.

Table 4
Averages, formaldehyde/acetaldehyde ratio and I/O ratio of formaldehyde and acetaldehyde concentrations ($\mu g\,m^{-3}$) in different hospitals.

Hospital	Indoor site sampling	Formaldehyde ($\mu g\,m^{-3}$)	Acetaldehyde ($\mu g\,m^{-3}$)	Ratio formaldehyde/acetaldehyde	Ratio I/O		Reference
					Formaldehyde	Acetaldehyde	
Hospital A	Ha1	12.34	55.10	0.224	1.03	8.49	Present work
	Ha2	15.06	11.55	1.30	1.26	1.78	
	Ha3	6.10	43.20	0.141	0.513	6.66	
	Ha4	1.98	19.40	0.102	0.166	2.98	
Hospital B	Hb1	24.87	13.61	1.83	2.9	1.88	Present work
	Hb2	17.79	14.63	1.22	1.71	2.02	
	Hb3	19.02	22.84	0.833	1.82	3.16	
	Hb4	21.38	9.38	2.28	2.06	1.29	
Public hospitals in Brazil	H1	297	263	1.13	–		
	H2	171	241	0.710			
	H3	94.5	76.3	1.24			[16]
	H4	151	194	0.778			
	H5	77.6	69.7	1.11			[33]
	H6	212	207	1.02			
	H7	29.0	17.0	1.71			
Hospital in China	H1	11.4	14.3	0.797	–		[32]
	H2	6.0	21.4	0.280			[32]
	H3	10.8	7.9	1.37			[34]
	H4	5.3	9.4	0.564			[36]
NR-15 (LT-MPT) Annex 11	–	2300	140,000	–	–		[41]
ACGIH (TLV-TWA)	–	370	45,000	–	–		[5]
NIOSH (PEL-TWA)	–	20	180,000	–	–		[15]
OSHA (PEL-TWA)	–	930	360,000	–	–		[17]

NR-15: Resolution Norm Nº15, annex 11; American Conference of Governmental and Industrial Hygienists (ACGIH); National Institute for Occupational Safety and Health (NIOSH); Occupational safety and Health Administration (OSHA).

3.2. Ratio indoor/outdoor (I/O)

Formaldehyde and acetaldehyde are volatile organic compounds emitted by various types of internal and external sources. I/O ratio is an indicator used to assess the influence of external sources in environments because it can be useful in identifying contributing sources of these compounds. The results showed that the I/O ratio was greater than one ($I/O > 1$) for the vast majority of hospital environments studied; this ratio is indicative of primary internal sources and/or secondary processes (Table 3). The high I/O ratio

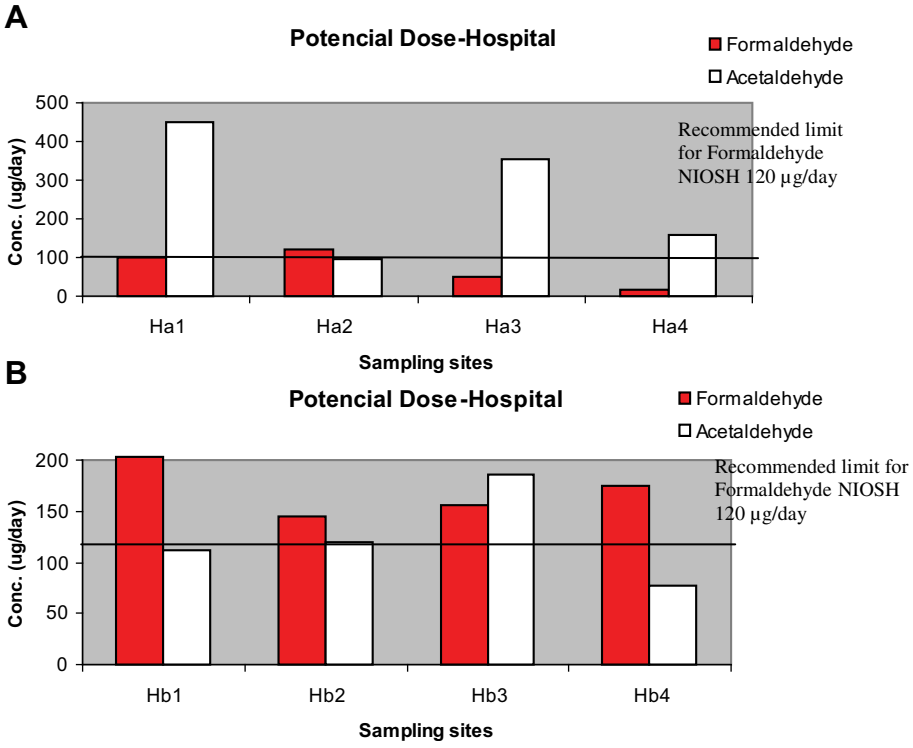

Fig. 1. Dose of personal exposure (PD_i) for formaldehyde and acetaldehyde in the study sites ($\mu g\,day^{-1}$).

Table 5
Occupational exposure to formaldehyde and acetaldehyde for lifetime (CDI) and cancer risk (CR) in the locations studied.

Sampling site	Formaldehyde		Acetaldehyde		Total RC
	CDI mg kg^{-1}day	RC (40 years of exposure)	CDI mg kg^{-1}day	RC (40 years of exposure)	
Hospital A					
Ha1	3.94E−4	1.78E−5	1.76E−3	1.36E−5	3.14E−05
Ha2	4.81E−4	2.16E−5	3.69E−4	2.84E−6	2.44E−05
Ha3	1.95E−4	8.76E−6	1.38E−3	1.06E−5	1.94E−05
Ha4	6.32E−5	2.84E−6	6.20E−4	4.77E−6	7.61E−06
Hospital B					
Hb1	7.94E−4	3.57E−5	4.35E−4	3.35E−6	3.91E−05
Hb2	5.68E−4	2.65E−5	4.67E−4	3.60E−6	3.01E−05
Hb3	6.07E−4	2.73E−5	7.29E−4	5.62E−6	3.29E−05
Hb4	6.83E−4	3.07E−5	3.00E−4	2.31E−6	3.30E−05

compared to the levels of acetaldehyde found in the study may be directly related to the internal sources existing in hospitals. In indoor environments, oxidation and reaction with radicals ($HO_2^{\bullet}$, $NO_3^{\bullet}$ and O_3) and with alcohol and hydrocarbons, especially alkenes, appear as the main CC formation processes [38,39]. In contrast, for the Ha3 and Ha4 environments of hospital A, the low ratios indicate that the external environment strongly influences the internal environment and that room size contributes to the dilution of formaldehyde in these ambient environments [40].

3.3. Personal exposure

Fig. 1 shows the levels of personal exposure for a workday of 8 h, calculated from the PDi using the levels found in this study, as well as the values of the limits set by NIOSH, the standard of rigidity between the national and international agencies. It was determined that environment Ha2 in hospital A (122.9 μg day^{-1}) and Hb1 and Hb4 in hospital B (149.2 and 128.3 μg day^{-1}) showed levels of personal exposure to formaldehyde that were slightly above the limits established by NIOSH (120 μg day^{-1}), as shown in Fig. 1. Similar results were found by other researchers [42,43] studying offices and halls, but the findings of the study were below the levels reported by Cavalcante et al. [20], who studied university laboratories using low and medium rates of inhalation (0.75 m^3 h^{-1} and 1.02 m^3 h^{-1}).

Lu et al. [32], assessing levels of formaldehyde and acetaldehyde in hospitals in China, found the values of potential doses to be below the levels found in this study. However, it is noteworthy that the rate of inhalation used was 0.63 m^3 h^{-1} (very low), which is not recommended for studies of risk and exposure [24], and differences between sites sampled could influence the results.

3.4. Cancer risk of exposure to CCs

Cancer risk was estimated by chronic daily intake (CDI) multiplied by the slope factor (SF) according to the Integrated Risk Information System (IRIS) [28]. The slope factor is an estimate of probability of an individual developing cancer as a result of lifelong exposure to a particular level of a potential carcinogen [26].

The estimated cancer risk was assessed using a slope factor of 0.0455 mg^{-1} kg.day for formaldehyde and 0.0077 mg^{-1} kg.day for acetaldehyde, according to the IRIS system. The results for occupational exposure by lifetime (CDI) and cancer risk (CR) for a time of 40 years of exposure are shown in Table 5. Cancer risk showed a range of 2.84^{-6}–3.57^{-5} for formaldehyde and 2.31^{-6}–1.36^{-5} for acetaldehyde. The obtained ranges of cancer risk are higher than the acceptable cancer risks of 10^{-6} (one in 1,000,000) and 10^{-5} (1 in 100,000) recommended by USEPA [27] for formaldehyde and acetaldehyde, respectively. Similar results were found by Lu et al. [32], who found a cancer risk of 1.1^{-4} and 2.8^{-5} for formaldehyde and acetaldehyde, respectively.

The total range of cancer risk was from 7.61^{-6} to 3.91^{-5} and had the same magnitude as most indoor environments studied by Cavalcante et al. [21], who evaluated the cancer risk in various types of environments that both used and did not use the reagents for functional activities. The cancer risk for women was 12−18% higher than for men; this value is in the range of other studies of risk occupation and physiological.

4. Conclusion

The study showed the presence of formaldehyde and acetaldehyde in all environments studied, and some levels of these chemicals are slightly above the limit recommended by international agencies. The I/O ratio showed that the main emission sources are internal. Exposure levels showed values above of PEL-TWA, from some international agencies. Although few studies are available for comparison, the total cancer risk has the same magnitude as that determined in other studies in the literature, and for women, the cancer risk is 12−18% higher than for men.

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