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Occupational exposures of airborne trichloramine at indoor swimming pools in Taipei

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HIGHLIGHTS

- Providing the first data of airborne NCl3 levels at indoor swimming pools in Taiwan
- Numbers of swimmers and the concentration of FAC are important factors to form NCl3.
- People exposed to NCl3 were more likely to have symptoms of sore throat and phlegm.
- Levels of NCl3 determined in this research were generally lower than other studies.
- Various regulated FAC internationally might cause NCl3 diverse in different studies.

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ABSTRACT

Ten indoor swimming pools in Taipei, Taiwan were included in the study to assess the exposure of people to airborne trichloramine (NCl_3) and also to discover the factors that might affect the associated concentrations. An active air sampling method was performed to determine the levels of NCl_3, while questionnaires were administered to swimming pool workers, including lifeguards, swimming instructors, and management employees. The results show that the concentrations of trichloramine ranged from 0.017 to 0.15 mg m^{-3}, which were generally lower than what have been reported from other studies. Symptoms of sore throat and phlegm were more frequent among lifeguards and swimming instructors (exposure group) than management employees (reference group) (odds ratios were 11.28 and 4.22 for sore throat and phlegm, respectively). It seems that the current exposure limit for airborne NCl_3, which was recommended by WHO, was not lower enough to protect the health of pool attendants. Regulated level of free available chlorine in Taipei (i.e., 0.3–0.7 ppm) is lower than what is required in other countries (e.g., 1–3 ppm in the UK). This might be the main reason why the concentrations of NCl_3 reported elsewhere were higher than what were found in this research. Further international comparisons will help to elucidate if low free chlorine concentration should be adopted as an operating standard. For the indoor swimming pools in Taipei, the air quality is suggested to be improved, since even with the low concentrations of NCl_3, higher respiratory ailments among pool workers were observed.

1. Introduction

Swimming is a popular activity among people of all ages (Bowen et al., 2007). It has also been recommended as a sport for children with childhood asthma (Weisel et al., 2009). Worldwide, millions of people take pleasure in swimming (Massin et al., 1998). However, the World Health Organization (WHO, 2006) has identified potential hazards associated with recreational water use, which include infections caused by feces-associated microbes and protozoa (e.g., *Giardia* and *Cryptosporidium parvum*) (Zwiener et al., 2007).

Disinfection is important for treating pool water quality and destroying microbiological pathogens (Zwiener et al., 2007). Chlorination, usually in the form of sodium or calcium hypochlorite, is used for disinfection (Bernard et al., 2003). When sodium or calcium hypochlorite is introduced into water, hypochlorous acid is formed (Basden, 2006; Zwiener et al., 2007).

In swimming pools, disinfection by-products (DBPs), such as chloramines, trihalomethanes (THMs), and halogenated acetic acids (HAAs), can be formed when HOCl reacts with human-introduced compounds including urea, sweat, skin particles, hair, lotions, sunscreens, and cosmetics (Weaver et al., 2009; Zwiener et al., 2007). Other than THMs and HAAs, the formation of chloramines is also possible from other sources of ammonia (Basden, 2006; Hery et al., 1995, 1998; Thickett et al., 2002).

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For trichloramine, the reactions of formation depend upon pH, temperature, reaction time, and the initial rate between chlorine and nitrogen sources (Basden, 2006; Blatchley and Cheng, 2010).

Among chloramines, Henry's law constant of NCl_3 is four hundred folds higher than NH_2Cl and $NHCl_2$ (Holzwarth et al., 1984). Hence, NCl_3 is distributed mainly as gaseous form in the atmosphere above swimming pool water (Basden, 2006; Gagnaire et al., 1994; Holzwarth et al., 1984; Thickett et al., 2002). Among other volatile compounds at indoor swimming pools, it was reported that airborne trichloramine has the highest concentration (Weng et al., 2011).

Trichloramine has a pungent chlorine-like odor, and is a strong irritant and lacrimator (Barbee et al., 1983; Basden, 2006; Gagnaire et al., 1994). Indoor swimming pools with poor water chemistry control and inadequate ventilation accumulate trichloramine in the air. People at indoor swimming pools, including swimmers, lifeguards, and swimming instructors can be exposed to elevated levels of trichloramine. It has been reported that respiratory ailments, such as eye irritation, sore throat, sneezing, cough, and chest tightness, are associated with high levels of airborne trichloramine (Bowen et al., 2007; Dang et al., 2010; Jacobs et al., 2007; Kaydos-Daniels et al., 2008; Massin et al., 1998; Thickett et al., 2002; Uyan et al., 2009; Bougault et al., 2009).

The levels of airborne trichloramine at indoor swimming pools and its respiratory effects in Taiwan have never been reported. Therefore, the purpose of this study is to measure the indoor swimming pool airborne concentrations of trichloramine in Taiwan, and to discover the possible health effects associated with elevated exposures. The factors contributing to indoor air quality (IAQ) which might affect the formation of airborne trichloramine were also determined.

2. Materials and methods

2.1. Sampling sites

There are twelve districts in Taipei City, and all of the districts have large sport centers with exercise facilities and training courses including swimming pools. For this study, six indoor swimming pools from different sport centers were selected. In addition, four other indoor swimming pools from two universities, one high school, and one middle school in Taipei were also included. Nine of the swimming pools were equipped with automatic systems, which regularly monitored water temperature, free available chlorine (FAC) concentration, and pH values.

All the swimming pools investigated had filtration systems with quartz sand filters to remove dust, leaves, hair etc. Some of the pools used automatic pool vacuums to clean the swimming pool bottom once a week. Water temperatures of the ten pools ranged from 26 to 30 °C. Pool sizes ranged from 412.5 to 1800 m^3. To maintain the air quality of the indoor pools, opened windows were mostly used, and a few swimming pools had independent ventilation systems.

2.2. Air sampling method for trichloramine

The air sampling method for trichloramine, which has been described elsewhere (Dang et al., 2010; Hery et al., 1995, 1998), was adopted for this study. The sampling device contained two parts, a 6 mL cartridge tube and a 37 mm cassette. The cartridge tube, which contained silica gel coated with sulfamic acid, was used to trap hypochlorite, monochloramine and dichloramine (i.e., soluble chlorine). The cassette contained a 37-mm quartz filter treated with sodium carbonate (40 g L^{-1} Na_2CO_3) and diarsenic trioxide (4 g L^{-1} As_2O_3), was used to collect trichloramine. The sampling device made it possible to distinguish trichloramine from monochloramine, dichloramine, hypochlorite, and chlorine (Hery et al., 1998).

2.3. Field sampling

At each swimming pool, the sampling points were chosen to be equally distributed around the pool area. For air sampling, the flow rate was set at 1 L min^{-1}, the sampling time was 90 min, and the calibrations were performed both before and after sampling (Dang et al., 2010; Hery et al., 1995, 1998). The air sampling devices were set at a height of 1 m (Jacobs et al., 2007; Thickett et al., 2002). A total of 54 air samples were collected from 10 swimming pools from April through October 2010.

2.4. Sample analysis

After sampling, the samples were stored in the dark in a refrigerator. The cartridge tube was analyzed within two days, and the cassette was analyzed within six days (Dang et al., 2010). The analytical method for cartridge and cassette is as follows.

2.4.1. Cartridge tube

The silica gel was placed into a 20 mL sample vial for extraction (King et al., 2006). The desorption was performed by using 10 mL of 1 g L^{-1} sulfamic acid solution, 0.5 mL of 0.1 M potassium iodide solution, and 1 mL of acetate buffer solution (Dang et al., 2010; Hery et al., 1998). The sample vial was periodically agitated for 30 min (Dang et al., 2010).

After desorption, the Pocket Colorimeter™ II (range of detection: 0.02–2.00 mg L^{-1} Cl_2) was used to analyze the concentrations of total chlorine, including hypochlorite, monochloramine, and dichloramine.

2.4.2. Cassette

The quartz filter was removed from the cassette, and was placed into a 20 mL sample vial. 10 mL of twice-distilled water was added for desorption (MilliQ Academic, USA) (Dang et al., 2010; Hery et al., 1998; King et al., 2006). Ion chromatography (DIONEX DX-120; IONPAC® AS4A-SC 4 × 250 mm column, USA) was performed for the analysis of chloride ion. The mobile phases were 1.8 mM Na_2CO_3 and 1.7 mM $NaHCO_3$ and the flow rate was 2 mL min^{-1} (Hery et al., 1998).

2.4.3. Calibration and quantitations

Standard solutions of chloride ion with concentrations ranging from 0.025 μg mL^{-1} to 0.25 μg mL^{-1} were prepared. After analysis with ion chromatography, good linearity was obtained with $R^2 = 0.99$. The lowest concentration was analyzed seven times to determine the method detection limit (MDL) based on the calculation procedures suggested by the USEPA (where MDL = standard deviation of replicate analyses × Student's t value for the 99% confidence level with $n - 1$ degrees of freedom) (US EPA, 1998). The MDL was calculated to be 0.0017 μg mL^{-1}.

2.5. Characteristics of swimming pools

Characteristics of the swimming pools studied in this research were collected during field sampling, including the concentrations of total chlorine and FAC in water, number of swimmers during sampling, water temperature, size of the swimming pools, and type of disinfectants used. The Pocket Colorimeter™ II was used to analyze the concentrations of total chlorine and free available chlorine (i.e., HOCl and OCl^-).

2.6. Questionnaires

Questionnaires were given to swimming pool workers, such as lifeguards, swimming instructors, and management employees. The questionnaires contained information about demographic characteristics, lifestyle, work-related conditions and health-related symptoms (Dang et al., 2010; Jacobs et al., 2007). Questions regarding common respiratory symptoms were based on the findings from a previous study (Jacobs et al., 2007). Symptoms were considered