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Exposure to volatile organic compounds and associated health risks in windsor, Canada

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HIGHLIGHTS

- Personal, indoor and outdoor concentrations of VOCs were measured for 50 non-smoking adults.
- None of the residential outdoor measurements provided a good estimate of personal exposure.
- The potential excess cancer cases associated with personal concentration were estimated.
- Inhalation Reference Concentration (RfC) was used to evaluate non-cancer adverse effects.
- Benzene had the highest adverse effects, and 1,3-butadiene ranked second.

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ABSTRACT

Objective: We examined relationships among measurements of volatile organic compounds (VOCs) and performed cancer and non-cancer risk assessments to determine potential adverse health effects.
Methods: Personal, indoor and outdoor concentrations of VOCs were measured for 50 non-smoking adults in Windsor, Ontario during winter and summer 2005. The potential excess cancer cases associated with personal concentration were estimated by the Inhalation Unit Risk (USEPA IRIS) and Tumorigenic Concentration (Health Canada). Inhalation Reference Concentration (RfC) was used to evaluate non-cancer adverse effects. Indoor and personal concentrations were statistically compared. Correlations of personal concentrations were estimated to investigate the associations among VOCs.
Results: Estimated median lifetime excess cancer risks (95th percentile upper-bound) of benzene and 1,3-butadiene were 8.09 and 4.77 per 1 million. Acetaldehyde presented the highest non-cancer risk. For some VOCs, the personal and indoor geometric means were similar, but arithmetic personal means were higher than the arithmetic indoor means ($p < 0.05$). Negative correlations among personal VOC concentrations were not sizable.
Conclusion: Evaluation of potential cancer and non-cancer risks from VOCs at the personal level should not rely merely on ambient (indoor and outdoor) VOC concentrations. Our analysis showed that personal risk had a complicated pattern that needs further investigation. Our results can be used to prioritize mitigation strategies to protect human health.

1. Introduction

Volatile organic compounds (VOCs) are a diverse set of chemicals that can originate from natural and anthropogenic sources. A number of VOCs are known or likely carcinogens. Previous studies have estimated the rate of excess cancer cases linked to VOC exposure: a median of 180 excess lifetime cancer cases per million were associated with exposure to hazardous air pollutants (including VOCs) in the United States in 1990 (Woodruff and Caldwell, 2000). In that study, exposure to polycyclic organic matter, 1,3-butadiene, formaldehyde, benzene, and chromium made up about 75% of estimated cancer risk; the study used data from Cumulative Exposure Project to model outdoor concentrations for the general

List of abbreviations: VOC, Volatile organic compound; GM, Geometric mean; SD, Standard deviation; MDL, Method detection limit.

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population across United States. In another study, it was estimated that a median of 957 and 486 excess cancer cases per million were related to carcinogenic VOCs in New York and Los Angeles, respectively (Sax et al., 2006). The aforementioned study uses personal, indoor home, and outdoor home 48-h samples of VOCs and attributes the highest cancer risk to 1,4-dichlorobenzene, formaldehyde, chloroform, acetaldehyde, and benzene. Several other studies have also estimated the health risks from VOC exposure (Bernstein et al., 2008; Dales and Liu, 2008; Ohura et al., 2009; Loh et al., 2007).

The data used in this study was obtained in Windsor, Ontario (Wheeler et al., 2011; Stocco et al., 2008). Automobile traffic travelling across the Ambassador Bridge, as well as commercial and industrial sources in both Windsor and Detroit, Michigan, contributes to air pollution. High emissions of VOCs have been reported by companies in the Windsor area according to Environment Canada's National Pollutant Release Inventory (Canada).

Our study investigated the possible effects of exposure to known and likely carcinogenic VOCs measured in Windsor and, based on measurements of personal concentration, estimated the excess cancer rates for known carcinogens that would occur from lifetime exposure. We implemented the US Environmental Protection Agency (USEPA) and Health Canada approaches for estimating excess cancer cases. We also used the USEPA Inhalation Reference Concentration (RfC) to estimate the potential non-cancer risks from VOC exposure.

Additionally, reducing the health risks associated with exposure to VOCs depends on identifying emission sources and estimating their relative contribution to potential adverse effects. We looked into the associations of personal concentrations to shed light on the differences among the VOCs and identify the sources of pollution.

2. Methods

2.1. Data collection

A complete explanation of data collection methods is provided in Windsor Exposure Assessment Study (Wheeler et al., 2011; Health Canada, 2006). The selection criteria for the participant households in the personal, indoor and outdoor exposure study in 2005 included no occupational exposure to VOCs, non-smoking, and living in a detached home. Specifically, households with smokers were not recruited as previous studies have shown this may dramatically increase the concentration of VOCs such as benzene and styrene (Adgate and Eberly, 2004). From the pool of potential households, home addresses meeting the aforementioned criteria were randomly selected. Moreover, consideration was given to select a sample that has approximately an even spatial distribution across Windsor. Detailed information regarding participants and their activities was collected with questionnaires during the study. Residential characteristics that might affect VOC exposure, such as the presence of attached garages, were obtained from the questionnaires. A map of the participant households is provided in the paper by Wheeler et al. (2011).

Data collection was performed in eight consecutive weeks in winter (January 24 to March 19) and summer (July 4 to August 27). 48 adults were recruited for participation in a 5-day sampling session in the winter season. Since 5 participants withdrew from this study after the winter due to different reasons, two additional participants were recruited for the summer sampling session. This resulted in sampling of 48 and 45 households in the winter and summer of 2005, respectively, of which 43 participants took part in both seasons. As a result, there were a total of 50 ($48 + 45 - 43 = 50$) distinct households in this study. At the beginning of each sampling week (Monday) a sample of six homes were used for 5 consecutive days for data collection. Samples were collected daily, at 24 ± 3 h intervals, using stainless steel Summa™ canisters.

VOC canisters were operated at flow rates of 3.5 and 0.5 mL min^{-1} for the 6.0 and 1.0 L canisters, respectively. Three canisters were collected from each household: a 6 L canister was located inside the household, typically in the family room; a second 6 L canister was located in the backyard; and a third 1 L canister was carried in a padded backpack by a house member for monitoring personal exposure. Each canister was replaced daily for five successive days in the summer and five in the winter, resulting in 10 days of data per household. Prior to use, the canisters were purged with “zero air” for three days.

VOCs were analysed from the Summa™ canisters at the Environmental Technology Centre in Ottawa, Ontario (Environment Canada) using a cryogenic preconcentration technique (Entech Model 7100 preconcentrator with autosampler, Entech Instruments, Inc., Simi Valley, CA) coupled with a high-resolution gas chromatograph (Agilent 6890) and a quadrupole mass spectrometer (Agilent 5973) (GC–MS). MS was operated in selected ion monitoring (SIM) mode with two or three ions being monitored for each VOC. VOCs were separated on a 60-m long, 0.32 mm I.D. fused silica capillary column with a 1.0 μm film thickness of J&W DB-1 bonded liquid phase (Wang and Austin, 2006). Half of the detection limit value was used to replace the non-detectable.

This study was approved by the Human Research Ethics boards at Health Canada and the University of Windsor, and all participants provided informed consent.

2.2. VOCs in this study

List of measured VOCs in Windsor was screened to select known, possible and probable carcinogens. The selection criteria were based on either the International Agency for Research on Cancer (IARC) or the USEPA rating systems. Only carcinogenic VOCs that had 89% or greater of their indoor samples above the method detection limit during both summer and winter were chosen for this analysis. As a result, a subset of 13 known, possible, or probable carcinogenic VOCs was selected for our analysis (Table 1). Some of the carcinogenic VOCs were measured but had lower detection frequencies and were excluded from analyses, including benzyl chloride, 1,3-dichloropropene, 1,1-dichloroethane, and hexachlorobutadiene. Formaldehyde was not measured in this study.

2.3. Statistical analysis

Shapiro–Wilk test and visual check of the histograms were used to determine whether distributions of the VOCs were normal. Geometric means (GMs) were estimated to summarize and compare the personal, indoor and outdoor concentrations. Furthermore, the data was grouped and analysed seasonally because the concentrations were expected to have significant variations between summer and winter (You et al., 2008). Logarithms of indoor and personal concentrations were used for paired t-tests to compare the means of indoor and personal concentrations. Comparative boxplots were used to assess and compare the pattern of measurements across indoor, outdoor and personal concentrations.

For the three known carcinogenic VOCs for which Inhalation Unit Risk values existed, obtained from the USEPA Integrated Risk Information System (IRIS), the 95% upper-bound excess lifetime cancer risks were estimated based on average 10 day personal exposures for the participants. Only the three known carcinogenic VOCs were considered in this particular analysis.

For a given species, the excess cancer cases from each participant data were calculated as follows: