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Detection rates, trends in and factors affecting observed levels of selected volatile organic compounds in blood among US adolescents and adults

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ABSTRACT

Data from National Health and Nutrition Examination Survey were analyzed to evaluate detection rates, trend in and factors affecting the observed levels of 1,4-dichlorobenzene, benzene, ethylbenzene, o-xylene, styrene, toluene, and m/p-xylene among US adolescents and adults over 2005–2012. Over 2005–20102, among adolescents, detection rates declined by more than 50% for benzene, ethylbenzene, and o-xylene, and among adults, detection rates declined by more than 50% for ethylbenzene and o-xylene and by a little less than 50% for benzene. Among adults, adjusted levels of 1, 4-dichlorobenzene, benzene, ethylbenzene, o-xylene, toluene, and m/p-xylene decreased by 13.7%, 17.1%, 20%, 17.7%, 23.2%, and 18.7% respectively for every two-year survey cycle. Among adolescents, percentage decline in the levels of 1, 4-dichlorobenzene, benzene, ethylbenzene, o-xylene, styrene, toluene, and m/p-xylene was 15.2%, 21.4%, 19.3%, 16.1%, 47.8%, and 17.7% respectively for every two year survey period. The ratio of adjusted geometric means for adult smokers as compared to adult nonsmokers was 10.7 for benzene, 3.5 for ethylbenzene, 2.0 for o-xylene, 3.4 for styrene, 3.5 for toluene, and 2.2 for m/p-xylene. Among adolescents, gender did not affect the adjusted levels of any of the seven VOCs, and the order in which adjusted levels for 1, 4-dichlorobenzene by race/ethnicity was observed was: non-Hispanic white (0.038 ng/mL) < Mexican American (0.102 ng/mL) < non-Hispanic black (0.178 ng/mL) and most of the pairwise comparisons were statistically significantly different ($p <= 0.02$) but race/ethnicity did not affect the adjusted levels for benzene, ethylbenzene, o-xylene, styrene, toluene, and m/p-xylene. For benzene, males had lower levels of adjusted geometric means (AGM) than females (0.021 vs. 0.025 ng/mL). For adults, gender did not affect the adjusted levels of 1, 4-dicholorobenzene, ethylbenzene, o-xylene, styrene, toluene, and m/p-xylene.

1. Introduction

Volatile organic compounds (VOC) volatilize under normal indoor atmospheric conditions and pressure (https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds). Outdoor VOCs are volatized or released into the air during manufacture or use of everyday products and materials. On the other hand, indoor VOCs are released into the air from the use of products and materials containing VOCs (https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds). While more than 100 VOCs have been identified in whole blood and/or urine, US Centers for Disease Control and Prevention, as part of its biomonitoring program, analyzes over 30 VOCs in whole blood and/or urine and data are publically released as data from National Health and Nutrition Examination Survey (NHANES, https://wwwn.cdc.gov/nchs/default.aspxl) every two years. For the purpose of this study, based on the percent observations > = the limit of detection (LOD) so as to be able to do a valid and reliable analysis, seven VOCs were studied to meet the objectives of this study as described later on. These were: 1, 4-dichlorobenzene, benzene, ethylbenzene, o-xylene, styrene, toluene, and m/p-xylene. Relatively higher levels of benzene, ethylbenzene, toluene, styrene, o-xylene, m/p-xylene, and 2, 5-dimethylfuran have been reported among smokers as compared to nonsmokers (Ashley et al., 1995). A brief description of these VOCs along with the adverse health effects associated with their exposure among humans are given below. Most of this information was extracted from documents published by Agency for Toxic Substances and Disease Registry of the US Government.

1.1. 1, 4-dichlorobenzene

1, 4-dichlorobenzene is a colorless or white crystalline material with a mothball odor. It is a fumigant used to control moths, mildew, and mold. It does not occur naturally in the environment. It is also used as an insecticide. According to a document prepared by New Jersey Department of Health and Senior Services (http://nj.gov/health/eoh/rtkweb/documents/fs/0643.pdf) exposure to 1, 4-dichlorobenzene, also known as para-dichlorobenzene, can be via breathing it in or via

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absorption through skin. Breathing 1, 4-dichlorobenzene can irritate nose and throat resulting in coughing and wheezing, and exposure to 1, 4-dichlorobenzene can cause headache, dizziness, swelling around the eyes, nausea, and vomiting. Repeated exposure may lead to damaged nervous system resulting in weakness, trembling, and numbness in the arms and legs. Damage to kidneys and liver may also occur. It may affect lungs and blood cells resulting in anemia. It is also a possible carcinogen since it since it has been shown to cause kidney and lung cancer among animals (http://nj.gov/health/eoh/rtkweb/documents/fs/0643.pdf).

1, 4-dichlorobenzene has been shown to exert toxic effects on photosynthesis in C. pyrenoidosa, especially at concentrations exceeding 10 mg/L (Zhang et al., 2016). In a case study presented by Weidman et al. (2015), mothball inhalation and ingestion lead to toxic encephalopathy. Zhang and Moreno (2014) presented a case of 19 year female with neurotoxicity from chronic toilet bowl deodorizers ("toilet cake") sniffing. Hession et al. (2014) presented a case of a female in her late 30's with left leg weakness, and gait instability and in addition, she subacutely developed an encephalopathy. She was found to have a long-standing history of chewing on toilet bowl deodorizing cakes. Buckman (2013) presented a case of a 40 year old female with history of chronic ingestion of mothballs and toilet cakes who developed toxin-induced leucoencephalopathy. Among the 18 VOCs measured, 1,4-dichlorobenzene was observed to have the greatest cancer risk (Batterman et al., 2014). Du et al. (2014) also reported 1, 4-dichlorobenzene along with benzene and formaldehyde to be the major risk contributors in urban China with the highest median cancer risk estimates. Along with seven other VOCs, 1, 4-dichlorobenzene was reported to be a marker to distinguish between asthmatic and healthy children (Gahleitner et al., 2013).

1.2. Benzene

According to a document published by the Agency for Toxic Substances and Disease Registry (https://www.atsdr.cdc.gov/phs/phs.asp?id=37&tid=14), benzene (i) is a colorless liquid with a sweet odor, (ii) evaporates into air very quickly and dissolves slightly in water and is highly flammable, (iii) comes from both natural and industrial sources, (iv) industrially, it is made mostly from petroleum, (v) its natural sources include emissions from volcanoes and forest fires and is present in crude oil and gasoline and cigarette smoke, (v) once breathed, it passes through the lining of lungs and enters the bloodstream, (vi) if exposure occurs via food or drink, most of the benzene taken by mouth passes through the lining of gastrointestinal tract and enters bloodstream, (vii) during skin contact with benzene or benzene-containing products, it may pass through skin and enter the blood stream, (viii) once in the bloodstream, it travels throughout the body and can be temporarily stored in the bone marrow and fat, (ix) it is converted to a metabolite in the liver and bone marrow, (x) eating foods or drinking liquids containing high levels of benzene can cause vomiting, irritation of the stomach, dizziness, sleepiness, convulsions, rapid heart rate, coma, and death, and (xi) if benzene is spilled on skin, it may cause redness and sores, and benzene in eyes may cause general irritation and damage to cornea. Benzene is a human carcinogen resulting in the cancer of blood forming organs, may be harmful to reproductive organs and studies in pregnant animals have shown that its breathing results in low birth weight, delayed bone formation, and bone marrow damage. In a prospective population-based cohort of 73087 women in Shanghai, Friesen et al. (2017) reported an association between exposure to benzene and non-Hodgkin's Lymphoma. Karaulov et al. (2017) reported a decrease in the total lymphocyte and T cell counts with increased benzene exposure duration among rats, and significant increase in Th2-type cytokine and IL-4, whereas IL-6, CD4 + T cells, CD4+/CD8+ ratio and CD3+ T cells decreased. A recent review by Smith (2010) provides a historical review of the studies done to evaluate associations between benzene exposure and various forms of cancer. Bahadar et al. (2014) discusses the non-cancer effects of exposure to benzene.

1.3. Ethylbenzene

Ethylbenzene evaporates at room temperature and burns easily (https://www.atsdr.cdc.gov/ToxProfiles/tp110-c1-b.pdf). According to this document, ethylbenzene is produced in US to make styrene and is used in fuels. Consumer products that contain ethylbenzene include gasoline, paints and inks, pesticides, carpet glues, varnishes and paints, tobacco products, and automobile products. Ethylbenzene can move from water and soil to air and soil contaminated with ethylbenzene may contaminate groundwater. Sources of exposure to ethylbenzene include air, water, soil, workplace air, and consumer products. Breathing ethylbenzene from air can enter the body via lungs. If the source of exposure to benzene is food or water, it can pass through digestive tract. It may also enter the body by skin contact. Short term exposure to high levels of ethylbenzene may cause irritation of eye and throat. Exposure may also result in vertigo and dizziness. Long term exposure to low levels ethylbenzene can result in irreversible damage to the inner ear and hearing among animals. If the exposure lasts several months and years, kidney damage may result in animals. Cigarette smoke contains ethylbenzene and as such smokers have been found to have higher levels of ethylbenzene than nonsmokers.

1.4. O-xylene

O-xylene, a colorless liquid is used in the manufacture of phthalic anhydride, vitamin and pharmaceutical syntheses, dyes, insecticides, motor fuels (https://pubchem.ncbi.nlm.nih.gov/compound/o-xylene#section=Toxicity-Summary). Exposure to o-xylene can result in severe toxic effects or symptoms of illness depending up on the level and duration of exposure. In animal studies, exposure to o-xylene has been reported to result in increased catecholamine levels, turnover in various parts of the hypothalamus, a decrease in the dopamine turnover in the forebrain of exposed animals, decreases in liver glutathione concentrations, increased hepatic cytochrome P450 concentration and reduced nicotinamide adenine dinucleotide cytochrome C reductase activity (https://pubchem.ncbi.nlm.nih.gov/compound/o-xylene#section=Toxicity-Summary). O-xylene has also been reported to be slightly to moderately toxic to estuarine/marine invertebrates on an acute basis.

1.5. Styrene

According a document by Agency for Toxic Substances and Disease Registry (https://www.atsdr.cdc.gov/PHS/PHS.asp?id=419&tid=74), styrene is a colorless liquid that easily evaporates. In its pure form, it has a sweet smell but manufactured styrene may contain aldehydes which gives it a sharp and unpleasant odor. Small amounts of styrene are produced naturally by plants, bacteria, and fungi. It is also present in cigarette smoke and automobile exhaust. It is also found in consumer products like packaging materials, insulation for electrical uses, insulation for homes and other buildings, fiberglass, plastic pipes, automobile parts, drinking cups and other "food-use" items, and carpet backing. Sources of exposure include breathing air near industries using or manufacturing styrene, indoor and outdoor air, automobile exhaust, and cigarette smoke, and drinking or bathing in water containing styrene. Low levels of styrene occurs naturally in foods, such as fruits, vegetables, nuts, beverages, and meats. Those who are exposed to styrene at workplaces may have their nervous system adversely affected. These health effects include changes in color vision, tiredness, feeling drunk, slowed reaction time, concentration problems, and balance problems. Inhalation of styrene can result in changes in the lining of the nose and damage to the liver among animals. Exposure to high doses has also been reported to be associated with impaired learning and sperm damage among animals. Styrene is reasonably anticipated to