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Review

Characterization of air freshener emission: the potential health effects

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ABSTRACT — Air freshener could be one of the multiple sources that release volatile organic compounds (VOCs) into the indoor environment. The use of these products may be associated with an increase in the measured level of terpene, such as xylene and other volatile air freshener components, including aldehydes, and esters. Air freshener is usually used indoors, and thus some compounds emitted from air freshener may have potentially harmful health impacts, including sensory irritation, respiratory symptoms, and dysfunction of the lungs. The constituents of air fresheners can react with ozone to produce secondary pollutants such as formaldehyde, secondary organic aerosol (SOA), oxidative product, and ultrafine particles. These pollutants then adversely affect human health, in many ways such as damage to the central nervous system, alteration of hormone levels, etc. In particular, the ultrafine particles may induce severe adverse effects on diverse organs, including the pulmonary and cardiovascular systems. Although the indoor use of air freshener is increasing, deleterious effects do not manifest for many years, making it difficult to identify air freshener-associated symptoms. In addition, risk assessment recognizes the association between air fresheners and adverse health effects, but the distinct causal relationship remains unclear. In this review, the emitted components of air freshener, including benzene, phthalate, and limonene, were described. Moreover, we focused on the health effects of these chemicals and secondary pollutants formed by the reaction with ozone. In conclusion, scientific guidelines on emission and exposure as well as risk characterization of air freshener need to be established.

Key words: Indoor pollutant toxicity, Air freshener, Ozone initiation reaction, Ultrafine particles

INTRODUCTION

A number of commercial products are widely used in a variety of indoor spaces to improve hygiene or sensory appeal. However, recently many such products have been discovered to be major indoor air pollutants that may be responsible for harmful health effects (Table 1). For example, there are several studies on the effects of using humidifiers. In Korea, the deleterious effects of humidifier disinfectants, which are much more serious in pregnant women and infants, have been reported (Chang *et al*., 2012). Although the damage caused by products commonly used such as humidifiers and air fresheners is on the increase, clear guidelines for these products have not been established. In addition, it is necessary to provide certain toxicological evaluations for these products.

An air freshener is a deodorant that is used to eliminate odors either by a chemical reaction or by providing a refreshing, masking scent. The term air freshener may be misunderstood since these products do not considerably reduce air pollutants, but rather add more substances to the air that have an odor strong enough to mask bad odors. Air fresheners are indiscriminately used for the masking effects of the deodorizing and fragrant components in indoor environments, and their usage is increasing by 4.4%-8.8% every year in Korea (Jung *et al.,* 2010).

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Table 1. Indoor pollutants from commercial products and potential health effects[a].

Pollutant	Source	Potential Health Effects
Volatile organic compound (VOC)	cleaning products, paints, air freshener, printers	respiratory tract irritation, asthma, headache, vomiting,
Formaldehyde	furnishing, insulation, cosmetics, clothes, cigarette smoking	eye, nose, and throat irritation, dizzying, couching, diarrhea, decrease memory
Particular matter (PM)	cooking, aerosol	Reduced lung function, increased risk of heart and respiratory disease, pneumoconiosis.
Carbon monoxide (CO)	heating, cooking application, air freshener	respiratory symptom, central nervous effect, nausea, chest pain, weakness
Nitrogen dioxide (NO_2)	cooking application, aerosol, air freshener	lethal at high levels, potential chronic effects at low level, chronic respiratory symptom
Allergens	molds, house dust, mist	asthma, irritation, causation of wheezing
VOC and ozone (O_3)	cleaning products, printer, painter, air freshener	asthma, sensory irritation, respiratory symptom, cardiac symptom
Odorous	source of odorous	loss of appetite, vomiting, insomnia, allergy

[a]Wolkoff *et al*., 2012; Hansen *et al*., 2013; Nielsen *et al*., 1999; Weschler and Shields, 2000b.

Air fresheners have diverse forms including incense, scented candles, aerosol liquid wick and electric diffusers, and gels. Over the past decade, many studies have determined air fresheners to be sources of various volatile organic compounds (VOCs) found in indoor environments (Singer *et al*., 2006a; Destaillats *et al*., 2006; Carslaw, 2007).

The major basic components of air fresheners include VOCs such as benzene, toluene, ethylene, and limonene, etc., which have toxic effects. VOCs are hydrocarbon compounds that easily evaporate and have high vapor pressure. Because of their high volatility and low boiling points, these compounds generate ozone or odors. Furthermore, the chemicals contained in air fresheners differ depending on the type. Aerosol and liquid spray may contain ethanol and isopropanol as an organic solvent while aerosols may also include propane and butane as high-pressure gas spray. Conversely, the gel and powder forms of the chemical content of air fresheners are relatively lower than the liquids and aerosols. Benzene is contained in incense products and is released from liquid air fresheners. Small amounts of formaldehyde, naphthalene, xylene, cresol, and ethanol are contained in air fresheners, including scented candles and plug-in air fresheners. However, exposure to formaldehyde from plug-in-type air fresheners and scented candles is considerable compared to exposure from other types of air fresheners, as they are frequently used (Nørgaard *et al.,* 2014a; Singer *et al.,* 2006b). Investigators have reported the result of the potential human risk associated with exposure to these compounds.

Terpenes are one of the VOCs that are widespread in nature, mainly as primary plant constituents of essential oils and aromatic compounds. Because of their pleasant smell, terpenes are widely used as ingredients in air fresheners. In addition, terpenes are used as solvents and in paints. Terpenes constitute about 13% of the total VOC concentrations used in pine wood used as flooring material (Rosell, 1995). Because terpenes are comprised of one or more C=C bonds, the structures extremely react with atmospheric constituents such as ozone, hydroxyl (OH) radicals, and other types of radicals (Nazaroff and Weschler, 2004; ECA, 2007). As a result, these reactions produce toxic contaminants such as formaldehyde and secondary organic aerosols (SOA). Among the terpenes, limonene and linalool are widely used as common fragrances in numerous air fresheners (Wainman *et al*., 2000; Singer *et al*., 2006a).

The types of constituents emitted by air fresheners are influenced by several factors, including indoor environmental conditions and human factors. The importance factors of regulating the air exchange rate (AER), indoor ozone level, and temperature are related to the formation of secondary pollutants such as formaldehyde, secondary organic aerosols (SOA), ultrafine particles, and oxidation products.

Ozone is a common indoor pollutant, and outdoor air represents the most important source because of infiltration and ventilation or direct indoor emissions caused by the use of various types of electric devices. Numerous indoor products such as photocopiers, laser printers, and cleaning agents generate ozone in indoor environments (Weschler, 2000a; Wolkoff *et al*., 2000). Ozone is typically present indoors at levels that are 20-70% of concurrent outdoor levels, and varies in concentration between 1 and 100 μg/m^3 (Singer *et al*., 2006b; ECA, 2006). The indoor and outdoor ozone concentration depends on the AER (Weschler, 2000a), which is the critical factor determining indoor air quality (IAQ) (Wolkoff *et al*., 2000). In addition, conditions such as temperature, relative humidity, and pressure determine the indoor concentration of ozone (Liu *et al*., 2004; Fadeyi *et al*., 2013).

Some components included in air fresheners may be strong toxins, which react rapidly with ozone to produce secondary pollutants such as oxidative products, secondary aerosol particles, formaldehyde, (Wang *et al*., 2007; Waring *et al*., 2011; Pathak *et al*., 2012; Waring, 2014), aldehydes, organic acids, ultrafine particles, and free radicals (Wolkoff *et al*., 2000). The reactions are most likely to occur by gas-phase chemistry reactions (homogeneous) and surface chemistry reactions (heterogeneous) (Petrick and Dubowski, 2009; Hunt *et al*., 2015). Such reactions can also result in the formation of fine particles (Afshari *et al*., 2005; Coleman *et al*., 2008).

The reaction between the air freshener chemical compound VOCs and ozone may have a greater effect on IAQ and health than the chemicals alone, because the emission of VOCs from air fresheners may be considerable under certain conditions, and sensory irritants could contribute to visual perception and upper airway effects (Nøjgaard *et al*., 2005; Wolkoff *et al*., 2000; Wolkoff *et al*., 2012). These formations may also have effects on the lungs. Limonene, which is sensitive to exposure, causes respiratory disease as well as damage to the liver, kidney, and nervous system. Benzene is a known carcinogen that causes cancers, including leukemia, while toluene affects the growing fetus. In addition, ethylbenzene and xylene induce neurotoxicity and cause damage to the liver and kidney (ECA, 1991). Concentration of and exposure to ozone are especially associated with human disease including dysfunction of lung, emphysema, asthma, and bronchitis. It has been suggested that ozone and VOC reaction may cause sensory irritation to the eye and airways (Fiedler *et al*., 2005). The short-term exposure to these compounds may cause irritation, chest pain, shortness of breath, headache, drowsiness, and dizziness as well as long-term exposure has been shown to cause skin irritation, weakness, and dizziness. As a result, the use of air fresheners has major potential health hazards such as hypersensitivity and sensory irritation. In addition, ultrafine particles that are formed by these reactions cause acute inflammation, respiratory symptoms, and cardiovascular diseases. Vulnerable people such as the elderly, children, people who are obese, and those with diabetes are more affected. The health effects vary depending upon the period of exposure to ultrafine particles, short-term exposure initiates disorders while long-term exposure exacerbates the disease. In particular, more serious health conditions occur with $PM_{2.5}$ exposure.

This review focuses on the characterization of chemical compounds found in air fresheners and the significance of air pollutant resulting from the use of air fresheners and their reaction with ozone. Exposure to secondary pollutants that are produced by reactions between ozone and VOCs from air fresheners may lead to sensory irritation and lung damage. In addition, depending on indoor conditions such as AER, concentration of ozone, and human activities, the effects on health are different. Although the VOCs emitted by air fresheners are known to be human hazards, pollutant emission standards or test methods have not been established. Because laboratory studies and assessments in humans are lacking, it is necessary to elucidate the effects on humans and characterize the emissions of air freshener compounds.

DESCRIPTION OF AIR FRESHENER CONSTITUENTS

Composition of air freshener

There are various types of air fresheners, including incense, natural products, scented candles, gel air fresheners, and liquid and electric diffusers. These air freshener products emit certain substrates such as VOCs that are primary emission compounds (Nazaroff and Weschler, 2004). Major VOCs include terpene (e.g. limonene, α-pinene, and linalool), benzyl alcohol, benzene, formaldehyde, toluene, and xylenes, which are emitted by air fresheners (Table 2) (Liu *et al*., 2004). Some air fresheners release 9-14 mg/kg of constituents that have toxic effects, such as ethanol, benzaldehyde, benzyl acetate, and α-terpinene. Benzene, toluene, ethyl-benzene, *m,p*-xylene, and limonene are detected in more than 50% of gel-type air fresheners products (Jo *et al.,* 2008).

Benzene

Benzene is an aromatic hydrocarbon that exists as colorless, volatile, and highly flammable liquid. Exposure to benzene mainly occurs through inhalation of polluted air, consumption of contaminated food, and dermal exposure. Incense air fresheners emit benzene and these compounds at concentrations of up to 221 μg/m^3 are detected in indoor air. Liquid air fresheners also emit this com-

Table 2. The contents and the detected chemical compounds in the air freshener[a].

Compound	Max. (mg/kg)[b]	Mini. (mg/kg)[c]
Benzene	0.7	0.005
Formaldehyde	96	4.9
Benzyl alcohol	46.4	7.8
d-limonene	1.507	0.15
Linalool	228	93
α-pinene	596.3	0.06
Toluene	11.9	0.04
Xylene	0.7	0.003

[a] Nazaroff and Weschler, 2004; Carslaw, 2007; Wolkoff, 2013a.
[b] Max. Con.: The maximum detected concentration in air fresheners.
[c] Mini. Con.: The minimum detected concentration in air fresheners.

pound, which attains air concentration up to 8 μg/m^3. A recent study using scented candles reported air concentration of benzene in the range of 0.03-3.9 μg/m^3. Other studies found that diverse brands of diffusers produced levels of benzene in the range of 18-117 μg/m^3 under indoor conditions (BEUC, 2005). Short-term exposure to high levels of benzene is harmful to the central nervous system and causes drowsiness, dizziness, headache, shortness of breath, and loss of consciousness. Long-term exposure to low concentrations causes harmful effects on hematopoietic cells and increases the hazards of anemia and leukemia (ECA, 1991). The cancer risk associated with benzene from air fresheners is too low owing to its low concentration in air fresheners. However, benzene exposure limits range from 0 to 5.1×10^{-5} for women (Lim *et al.*, 2014). Following long-term exposure, benzene can cause hematological effects in humans (WHO, 2014). Benzene may induce a genotoxic chemical *in vivo* and *in vitro*, showing it to be carcinogenic (Sekine *et al.*, 2011; Lim *et al.*, 2014).

Formaldehyde

Formaldehyde is a colorless, transparent gas that has a strong pungent odor and is volatile at room temperature. Several lines of evidence demonstrated that certain level of formaldehyde (51 to 69 μg/m^3) was emitted from the air freshener. Moreover, the scented candles and electric diffusers produced formaldehyde levels of up to 13 μg/m^3 (BEUC, 2005). These toxic formaldehydes are known to be generated by reactions with VOCs emitted from the air fresheners and ozone in the air (Wolkoff *et al.*, 2000, 2013b). The exposure to high concentrations of formaldehyde (120 mg/m^3) causes eye irritation, vomiting, spasms, and death (Air quality guidelines for Europe, 1987). This damage mostly sensitizes individuals to the ultimate effects of long-term exposure to formaldehyde (Wilkins *et al.*, 2001; Wang *et al.*, 2007; Wolkoff, 2013a). Humans exposed to formaldehyde at levels lower than 0.1 mg/m^3 show sensory irritation (WHO, 2014).

Toluene and xylene

Toluene and xylene are frequently used in air fresheners. Toluene is a colorless, volatile, and flammable liquid, which has been detected at the highest concentration of 67 μg/m^3 under indoor air conditions (BEUC, 2005). Approximately 50% of inhaled toluene is absorbed through the respiratory system. The main effects of exposure to toluene include eye and nose irritations as well as narcotic effects. Exposure to high concentrations of toluene can cause kidney damage (Cohr and Stokholm, 1979). The highest level of toluene detected in most air fresheners is 5.22×10^{-6} mg/m^3 in air and this is a low concentration (Kumar *et al.*, 2014; Lim *et al.*, 2014).

In addition to these compounds, some samples contain styrene, which is released into the indoor air through aerosol sprays, and may attain concentration of 185 μg/m^3 (BEUC, 2005). With the exception of candles (contain 70 μg/m^3), toluene is found in some kinds of air fresheners and other products at low concentrations (Lim *et al.*, 2014; Lee and Wang, 2004). Xylene can be found in liquid detergent and various types of air fresheners. It is detected at concentrations of 2.24×10^{-8} mg/m^3 in, while levels of xylene lower than 0.25 ppm are not detectable (Nazaroff and Weschler, 2004; Lim *et al.*, 2014).

Terpenes (d-limonene)

Terpenes are one of the largest groups of VOCs and consist of over 30,000 chemicals (Forester and Wells, 2011). The most common terpenes in air fresheners consist of monoterpenes such as α-pinene, α-terpinene, linalool, and *d*-limonene (Fig. 1). These terpenes are typically detectable in herbs, spices, flowers, and plants (Rohr, 2013). For this reason, these chemicals are frequently used as fragrances in commercial air fresheners used indoors (Forester and Wells, 2011), and their amount in air fresheners varies from 0.2-26% (Nazaroff *et al.*, 2006). Terpene concentration in indoor air is associated with temperature. This study investigated the correlation of seasons with terpene concentration. The results show a clear difference between warm and cold seasons. The concentration was lower during warmer than during colder seasons. During the experiment, warmer seasons increased the reaction between terpene and ozone, which can produce aldehydes (Geiss *et al.*, 2011b). High levels of terpenes are found in sprays, gel fresheners, and electric diffusers (Larsen *et al.*, 2000; Rohr *et al.*, 2002; Wolkoff *et al.*, 2013b). Ter-

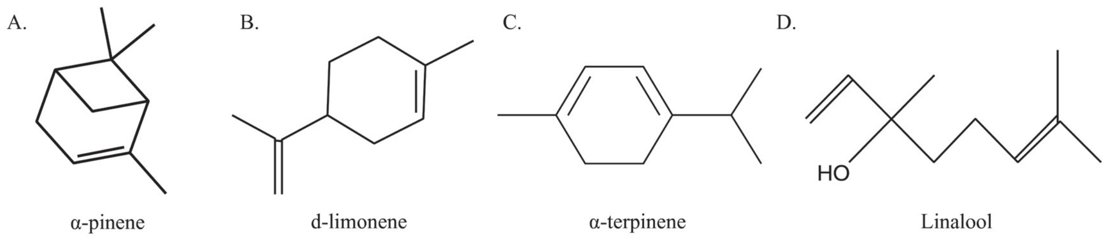


Fig. 1. Terpene components contained in air freshener (A) α-pinene (B) *d*-limonene (C) α-terpinene (D) Linalool.

penoids and terpenes react with ozone to form carbonyl compounds such as formaldehyde, acetaldehyde, organic acid, and hydrogen peroxide, which are secondary organic aerosols (SOAs) and OH radicals. These secondary pollutants are associated with irritations such as skin and eye, and have sensitizing properties. In particular, sensitive people exposed to limonene may develop respiratory diseases as well as damage to the liver, kidney, and nervous system (ECA, 1991).

The terpene linalool has low oral and dermal toxicity. The primary effects of linalool may include respiratory depression and slight dermatitis. It gradually decomposes on contact with oxygen produced during oxidative processes to produce products that may cause an allergic response such as eczema (Chadha and Madyastha, 1984).

Limonene exists in two forms, namely, *d*-limonene and *l*-limonene. Limonene is a natural component of citrus products such as oranges and lemons, and is a flavor additive and scent for fragrances in foods, drinks, and air fresheners . This chemical is widely used as a food additive, and a fragrance in perfumes, air fresheners, and cleaning detergents (ECA, 2007). These fragrant compounds are added to air fresheners, which contain concentrations that range from undetectable to 2,000 $\mu g/m^3$ (BEUC, 2005). Another study found that approximately 20 g of air freshener sprays supplied with limonene was prepared from 100% pure orange, lemon, or lime essences and oil, according to the manufacturer of the product (Afshari *et al*., 2005).

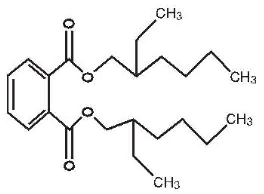
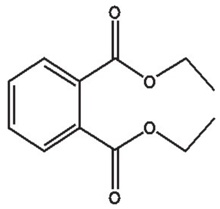
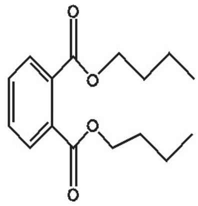
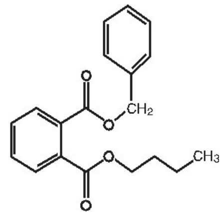
Phthalate

Phthalates are used in many household products including children's plastic toys, adhesive, nail polish, perfumes, and air fresheners. All air fresheners that are labeled as "unscented" and "all natural" contain phthalates. In these air fresheners, they are used as solvents to dissolve or to retain the fragrances for a longer period. The concentration of phthalates from sprays that is directly released into the air is higher than that from gels. When the air fresheners are released into the air, they can be inhaled or land on the skin and enter the eyes, where they are absorbed. Exposure through inhalation is more damaging than exposure through the skin. These chemicals can also alter hormone levels and cause other health problems. Phthalates interfere with the production of hormones such as testosterone and can be associated with reproductive abnormalities (Geiss *et al*., 2009; Wolkoff, 2013a). Most commercial air fresheners contain the toxic phthalates (Table 3) di-ethyl phthalate (DEP), di-n-butyl phthalate (DBP), diethyl phthalate (DEP), and butyl benzyl phthalate (BBP) (Fong *et al*., 2015). These chemicals have been associated with hormonal change and abnormal genital development in humans. In addition, each air freshener product contains these chemicals at different levels. For example, consumer air freshener contain 0.12-4.5 ppm of DBP and 0.49-7,300 ppm of DEP. Usually, more than 10 ppm of total phthalates is considered as the highest level, while less than 1 ppm of total phthalate is a trace level (Solomon, 2007; Wolkoff, 2013a).

THE REACTION BETWEEN OZONE AND VOCS FROM AIR FRESHENERS

In this section, we will refer to the formation of secondary pollutants and ultrafine particles due to reaction between ozone and air fresheners' compounds such as VOCs and briefly mention about the characterization of ozone. Ozone is a common indoor and outdoor pollutant and the most important source is transport from the outdoor air. Although most of the indoor ozone originates from outside, some are released during the use of various types of equipment. Several devices such as electrostatic air cleaners and photocopiers have been shown to produce ozone concentration of up to 490 $\mu g/m^3$ (Britigan *et al*., 2006; ECA, 2007). Components emitted from air freshener and ozone from several devices can produce secondary pollutants, namely, oxidative products and ultrafine particles. These products affect human health both directly

Table 3. Air freshener source of phthalate compounds [a].

	Di-ethylhexyl phthalate (DEHP)	Diethyl phthalate (DEP)	Dibuthyl phthalate (DBP)	Buthy benzyl phthalate (BBP)
Source	PVC related products, flooring, building materials, toys	air freshener, cosmetics	cosmetics, malagma, printing ink, glue, coated film	floor tile, carpet, polyurethan
Health effect	* reproduction toxicity : NOAEL[b] 14 mg/kg/day * effect on development : NOAEL 44 mg/kg/day *liver carcinogen, hepatotoxin, mutagen	*carcinogenicity *mutagen	*mutagen and carcinogen *reproduction toxicity : NOAEL 52 mg/kg/day	*reproduction toxicity *developmental toxicity *carcinogenicity *genotoxicity
structure				

[a] Fong *et al.*, 2015; Wolkoff, 2013a.
[b] NOAEL : No-observed-adverse-effect level.

and indirectly (Fadeyi *et al.*, 2013).

The section focused on the reaction between indoor ozone and air freshener compounds, identify to formatted secondary pollutants, and the factors affecting concentration of secondary pollutants.

Formation of oxidation products

The reaction between ozone and VOCs from air freshener produces secondary pollutants. Reactions between α-pinene and ozone produce formaldehyde, acetone, and picric acid (Rohr, 2013). The reaction between *d*-limonene and ozone can produce formaldehyde, 4-acetyl-1-methylcyclohexen, limona ketone, and limon aldehyde, and the products of isoprene and ozone reactions are primarily formaldehyde, hydrogen peroxide, methacrolein, methylvinyl ketone, methacrylic acid, and 3-methylfuran. Products of VOC oxidation, particularly those of terpene, are produced following reactions with O_3, OH, and NO_3 radicals. These contain free radicals under indoor conditions, and the OH formed can lead to more oxidative chemicals than expected. OH can react with NO, alkanes, alkenes, alcohols, and aromatic compound as well as monoterpene (Destaillats *et al.*, 2006; Laumbach and Kipen, 2010). Chamber studies determined OH formation in the reactions between ozone and a single terpene, two-component terpene mixtures (Forester and Wells, 2011).

In the first order reactions, ozone-induced VOCs in the gas phase are usually simple and appear to be of minor importance, and especially affect low emitting materials. The reactions in the gas phase occur following the collision of two or more molecules of ozone and VOCs, which are emitted by being directly sprayed as a form of air freshener within indoor environments (Nazaroff and Weschler, 2004). The homogeneous reactions both produce and remove odorous compounds, and hence affect the indoor air quality (IAQ) such as odor intensity and preference. For example, limonene or α-pinene and ozone coefficient react and produce pollutants (Weschler, 2000a; Weschler and Shields, 2000b). Ozone removal through these reactions occurs on a similar or faster timescale compared to the removal by air exchange and surface deposition. Therefore, it depends on factors influencing indoor conditions such as ozone concentration, air exchange rate (AER), and surface area (Weschler and Shields, 2000b). VOCs emitted from air fresheners are oxidized by ozone, which may also produce low-molecular-weight aldehydes and ketones (Wolkoff *et al.*, 2000).

The secondary emission source of VOCs is from large surface areas, and are generated though oxidative reactions. The heterogeneous reaction occurs between ozone and the adsorbed VOCs such as terpene or building materials. These VOCs may be emitted slowly from the surfaces, and are characterized by very low odor thresholds (Liu *et al.*, 2004). Some household devices are exposed to ozone and the odor perception may be altered immediately, implying that the emitted VOCs have changed compared to before the devices were exposed to ozone. In addition, ozone is decomposed by a surface catalytic reaction to molecular oxygen, and atomic oxygen may initiate auto oxidative degradation (Clausen *et al*., 2001; Tamás *et al*., 2006; Nørgaard *et al*., 2014a).

The particles formed rapidly in the α-pinene and limonene systems, and slowly in the isoprene system, with smaller particles being formed. Furthermore, the particle yield was higher in the α-pinene and limonene system than that in the isoprene system (Rohr *et al.,* 2002). Concentrations vary broadly following ventilation and other factors such as removal by indoor surfaces. The most researched indoor reaction is that between limonene emitted air freshener and ozone, which produces secondary pollutants, including SOAs. The ozone reacted with limonene and significantly contributed to increasing the indoor levels of SOAs. The sources of *d*-limonene are air fresheners and building materials, and limonene form SOAs though reaction between ozone and limonene depends on an air handling system that human occupancy influences. Humans and their activities influence ozone concentration. A study conducted to test indoor conditions with or without human occupants indicated that a single occupant contributed 10-25% of the overall ozone removal. Many sources of SOA formation were not evident when humans were absent. In addition, several studies show that human activities generate substantial amount of particles larger than 1 μm (Afshari *et al*., 2005; Fadeyi *et al*., 2013).

When reacted with ozone, both single terpenoid and terpenoid mixtures of α-pinene, α-terpineol, and *d*-limonene produced SOAs based on the indoor ozone concentration. The number of SOA products formed depended on the limited ozone concentration with single versus mixtures of terpenes. Results showed that at higher ozone and terpene concentrations, SOA formation followed a linear trend as a function of the initial rate of the reaction. High concentration of ozone and terpenes also commonly led to large particle diameters. With low ozone concentrations, the reactions with α-pinene and limonene alone yielded larger SOA concentrations than the mixtures containing limonene (Waring *et al.,* 2011).

Formation of particulate matter (PM)

The reaction between ozone and terpenes forms intermediates that include secondary organic aerosol (SOA) and particulate matter (PM) (Sarwar and Corsi, 2007). PM is categorized by particle size. Particle sizes larger than 30-70 μm can remain suspended only for short periods. PM_{10} and $PM_{2.5}$ are particulate matter with aerodynamic diameter of less than 10 and 2.5 μm. PM is classified by particle size, and sizes between PM_{10} and $PM_{2.5}$ are coarse, $PM_{2.5}$ is fine, and less than 0.1 μm is ultrafine, also called $PM_{0.1}$ (Kim *et al*., 2015; Englert, 2004; Zhou *et al*., 2014). Ultrafine particles include carbon, ionized compounds, and metals. Depending on dust size, surface of particles, and number, they can influence human health. In particular, ultrafine particles can cause allergies when they penetrate deep into the alveoli (Alessandrini *et al.,* 2006). PM is primarily formed through various combustion processes involving the direct inflow of air. They are secondary compounds that are produced by chemical reaction such as occur with VOCs, NO, and OH interactions.

Weschler and Shields (1999) reported reactions between ozone and terpenes in which the concentration and size of fine particle in a simulated office environment were similar to those produced by ozone in simulated indoor condition where terpenes were introduced in the form of *d*-limonene and terpene–based fresheners. Particle formation was observed in the 0.1-0.2 μm diameter size range from the air fresheners and those from the cleaning products were as much as 20-fold larger in the indoor test. It was demonstrated that ozone/terpene system could be a significant source of fine particles under indoor conditions compared with the control indoor conditions with and without ozone.

Wainman *et al.* (2000) investigated the occurrence of secondary organic aerosol formation in indoor air using a dynamic chamber consisting of inner and outer chamber. They found that significant particles were produced in indoor environments through secondary particle formation via the ozone-limonene reaction, thus, provided basis for assessing the impact of outdoor ozone on indoor particles. Moreover, Liu *et al.* (2004) investigated the simulation of air freshener emissions in the presence of ozone using full-scale chamber-based source emission model. They characterized VOCs emitted from the air freshener but also the reaction products by ozone. Furthermore, they measured size distribution and mass of fine particles generated by the reactions. Another study characterized the indoor sources of particle formation from air freshener sprays. Air freshener sprays may increase the concentrations of aerosol particles. Based on the spray air freshener experiment, ultrafine particles are generated by air freshener sprays at a maximum concentration of particle sizes between 0.3 and 1.0 μm after 4 min. Therefore, this observation can be explained as an indication of a particle growing effect by which air freshener vapors are concentrated to form the particles. In addition, it is believed that primary pollutants may be released from the air fresheners (Afshari *et al.*, 2005).

Factors affecting the concentration of the air freshener components

Exposure to air freshener compounds depends on the identity and concentration of the reactants, exposure, and inhalation. These factors depend on the dynamic behavior including indoor environmental conditions and human exposure factors (Nazaroff and Weschler, 2004). Patterns of exposure may vary depending on the characteristics of products e.g. spray or slow-release gels and liquids. In many cases, subchronic and chronic effects should be considered the relevant endpoints owing to the frequency of use of the products. For instance, the sprays or diffusers are used at different locations, and therefore, the effects can be related to acute or short-term effects. The frequency, amount, and manner of application and the timing of use relative to the occupancy should be considered. A study found that the preference for pleasantly scented products resulted in less product being used for cleaning than when unscented products were used (Kovacs *et al.*, 1997).

The use of air fresheners can enhance inhalation exposure to air pollutants. Volatile and non-volatile constituents of air fresheners can result in gas-phase exposure during or after use. These compounds can also be inhaled though either the application process itself releasing liquid, solid, and aerosol particulates into the air or the residual indoor environment materials that are later suspended (Doty *et al.*, 2004; Nørgaard *et al.*, 2014b).

The human factor linking exposure to intake is breathing rate. Exposure is also affected by the indoor ventilation, especially if the ambient temperature is hot or cold and if there are seasonal variations. There is a general increase in VOC concentration in the cold season, mainly owing to lower ventilation and air exchange rates (Geiss *et al.*, 2011a, 2011b).

Indoor environmental conditions

The pollutants emitted by air fresheners are related to indoor environment conditions. Factors influencing the concentration of air freshener compounds include ventilation and this refers to the AER, which is the flow rate volume of air going out divided by that of the air contained indoors. In addition, to prevent external noise and outdoor pollutants from coming indoors, the rate of ventilation of outdoor and indoor air must be reduced. Therefore, pollutants emitted from air fresheners and building materials accumulate indoors because there is a lack of ventilation, and the IAQ is reduced.

AER may influence the efficiency of the reaction between ozone and VOCs. For example, lower air exchange rates may increase the concentration of reactive VOCs and the time available for the ozone-initiated reaction with VOCs. Some reactions produce secondary pollutants such as formaldehyde that are gaseous and lead to formation of SOAs in low vapor pressure (Nazaroff and Weschler, 2004; Wolkoff *et al.*, 2013b; Nørgaard *et al.*, 2014b). The SOAs formed from the ozone-terpene interaction are related to atmosphere organic aerosol formation. Because of the differences between outdoor and indoor conditions, the effect of external factors on SOA production such as AER and ozone level was investigated. Increasing the ozone supply level increased the mass concentration and yield of SOAs from air fresheners while decreasing the AER increased the yield (Coleman *et al.*, 2008). The importance of ozone concentration indoors is that reactions can occur at such a rate that they compete with the AER (Wolkoff *et al.*, 2000). A low AER increases the concentration of ozone-initiated terpenes in particular, and this may occur in the gas-phase or surface reactions, to produce a host of complex ozone reaction with terpenes.

The statistical analysis of the data in this study reveals a possible association between seasons and indoor chemical concentration levels. A clear difference between warmer and cold seasons was observed with indoor chemical concentrations. Terpenes react strongly with oxidants in ozone and this process increases further in the warm season. This is because a higher photochemical activity occurs during warm seasons and penetrates from the outdoor air. In addition, the ventilation rate increases during the warm seasons. In conclusion, potential increases in the ventilation rate during warm seasons may contribute to enhancing the reaction between terpenes and ozone, resulting in higher concentrations of ozone oxidation reaction products such as aldehydes (Geiss *et al.*, 2011b). However, increased emission, evaporation, product usage patterns, and desorption rates may also play a role (Nazaroff and Weschler, 2004; Sarwar *et al.*, 2004) studied air fresheners containing terpenes at an elevated ozone concentration and at low ozone concentrations. Particle number and mass concentrations increased, and ozone concentrations decreased in this experiment. The terpene-based air fresheners considerably increased the particle number and mass concentration. Homogenous reactions between ozone and terpenes from air fresheners can lead to the increase in fine particles when these products are used indoors (Sarwar *et al.*, 2004). The homogeneous reactions (gas-phase) both produce and remove fragment compounds, thereby affecting the perceived indoor air quality. It appears that VOCs in air fresheners that are oxidized by ozone may result in low-molecular-weight aldehydes and ketones that are characterized by low odor quality (Wolkoff, 2013a).

Human factors

The human factors influencing emission are linked to frequency of use, amount, and manner of application. In the case of frequency of use, the plug-in air fresheners are operated for several days. These air fresheners emit VOCs, e.g. terpenoids, continuously, and their use may increase secondary pollutant levels. Ozone is decomposed following air freshener use, mainly by homogeneous reactions. The sorption of air freshener constituents to material surface appears to cause heterogeneous reactions, which result in half or more of the additional ozone reaction activity. An important human factor that links exposure to intake is the breathing rate. The average breathing rates are estimated by considering the population demographics such as gender, age (child or adult), and position (prone, seated, or standing) (Falk-Filipsson *et al*., 1993; Nazaroff and Weschler, 2004).

HEALTH EFFECTS

In this section, we focused on the damage to health caused by the use of air fresheners. The categories have two sections. First, the components emitted from air fresheners are directly inhaled by the respiratory system through the nose to the alveoli. The eyes, nose and skin are directly affected during usage of air freshener. In addition, this effect is associated with sensory irritation. Most commercial air fresheners have low sensory threshold, and thus damaging health effects come from sensory irritations that are caused by constant use of air fresheners (Wilkins *et al*., 2007; Wolkoff, 2013a). In addition, various VOC compounds such as benzene, terpene, and limonene also cause diseases.

Second, one class of air freshener compounds, VOCs, reacts with ozone to produce secondary pollutants such as ultrafine particles. The particles formed by the reaction affect health in a manner dependent on particle diameter. Secondary pollutants also affect the respiratory system, the central nervous system, and immune response.

Health effects of the components emitted from air freshener

Odor-related health effects are related to two sources: the odor itself and the reaction of the chemicals responsible for the odor, such as mixtures of air freshener constituents (Opiekun *et al*., 2003). Olfaction may be associated with thresholds and sensory irritation. Health effects occur at the threshold for sensory irritation. The range of odor thresholds is from a negligible degree to greater than 100 $\mu g/m^3$. It has been determined that the human nose can perceive several common VOC odors at concentrations of a fraction of a few $\mu g/m^3$ or less (Doty *et al*., 2004). This may be caused by the continuous emission of VOCs during use. The threshold of sensory irritation is lower than that of odor. For example, sensory irritation is more sensitive than odor perception and is detected at low formaldehyde concentrations, but other VOCs are detected following opposite trends (Wolkoff, 2013a; Doty *et al*., 2004). Odor perception is not related directly to health effects, while secondary effects such as sensory irritations are potential outcomes of weak odors (Schnuch *et al*., 2010).

Sensory irritations caused by secondary pollutants like aldehyde include health effects such as burning, irritation, itching, pain, and stinging of the eyes and nose. The thresholds for sensory irritation of the eyes and upper airway are similar in magnitude. However, the threshold for the eyes is slightly lower than that of the upper airway, as eyes are directly exposed to secondary pollutants compared to upper airway (Schiffman and Williams, 2005). In particular, formaldehyde causes sensory irritation of the eyes and upper airways (Leva *et al*., 2009). The primary emission constituents of air fresheners, including aldehydes and VOCs, cause eye and upper airway irritations at levels above the threshold. Conversely, at levels below the sensory irritation threshold, primary emission constituent exposure leads to skin symptoms and allergies (Schnuch *et al*., 2010; Uter *et al*., 2010). During the use of air fresheners, sensory irritation on eye and upper airway is continuous and transient. The low concentrations have a generally long latency and can cause sensory irritations following long-term exposure. In addition, olfaction and sensory irritation differ following continuous exposure and the irritancy increases rapidly for a certain period. This depends on the concentration of chemicals as well as the type of emission constituents from the air fresheners.

A study was conducted to determine the levels of a mixture VOCs and ozone oxidative products, VOCs, and ozone at which the nasal irritation and inflammation occur; the concentration of the mixture was 25 mg/m^3 and 40 ppb respectively. The results showed no significant differences in symptoms and it is also found that VOCs and oxidative products may not cause acute nasal inflammation at low concentration (Laumbach *et al.,* 2005).

However, in another study, the airways of mice were exposed to terpene, terpene and ozone, and a terpene/

ozone/nitrogen dioxide mixture, and their sensory irritation, bronchial constriction, and pulmonary irritation were determined. The experimental concentrations were approximately 4 ppm ozone, 500 ppm terpene, and 4 ppm nitrogen dioxide. The reaction mixtures after 30 sec included up to 0.2 ppm ozone. According to this experiment, the reaction can be formed irritant products, and observed sensory irritation. Therefore, it proposed that strong airway irritation were formed and it is possible that oxidation reaction of common unsaturated compounds will be relevant to indoor air quality (Wilkins *et al*., 2001).

Exposure to upper airway irritants is observed to reduce the respiratory rate, because stimulation of the nasal trigeminal nerves induces a break in breathing after inhalation. When pulmonary irritants are present, the vagal nerves are stimulated and that usually occurs in a pause in breathing before inhalation following reducing the respiratory rate. No-observed-effect-level (NOEL) and concentration effect relationship were determined for ozone, α-pinene, and limonene and some of their major reaction products. Reaction mixtures of terpenes and ozone at levels substantially below their NOEL concentrations resulted in significant upper airway irritation. The reduction of the respiratory rate was from 50% to about 30% and the lowest rate was with individually α-pinene, whereas the highest rate was for the mixture (Wolkoff *et al*., 2000). The NOEL value for the upper airway effects from the reaction with ozone and limonene may be occurred below 0.05 ppm ozone and high level of limonene concentrations. *In vivo* testing indicates that the oxidative products rather than the SOAs are the underlying cause of airway effects (Wolkoff, 2013a).

In summary, most sensory irritations occur at low levels of exposure, and indoor VOC concentration levels are several orders of magnitude lower than their threshold. However, the effects of exposure to VOCs is complex and, therefore, it is difficult to measure the indoor levels. It appears that oxidation products such as formaldehyde cause sensory irritations.

The evident exposure pathway for air fresheners is the inhalation of VOCs. People may come into contact with liquid and solid air freshener constituents through the skin or eyes. In addition, the emitted air freshener components could also possibly contaminate food or drink left open to the indoor air.

Sensory irritation in the eyes and airways has not been shown to result from exposure to a mixture of VOCs in the range of 1 to 25 mg/m^3, except for nasal irritations at 24 mg/m^3. Most odor and nasal irritations decrease to 40% during the exposure. Severe asthmatic attacks occur at high VOC concentrations of less than up to 10 mg/m^3, accompanied by a declined lung function. Because indoor VOC concentrations are too low to cause sensory irritation, the chemical reactions with VOCs are more likely to cause mental distraction (Wolkoff, 2013a).

An analysis of the human exposure and *in vivo* studies revealed that the products from chemical reaction such as ozone-initiated terpenes might trigger sensory irritation from formaldehyde at sufficiently high concentrations. A study involving 150 children , who were patients with atopic dermatitis, investigated the effects of exposure to the level of indoor pollutants such as VOCs in consumer products, and particulate matter (Lee *et al*., 2014). In this study, the use of air fresheners leading to high concentrations of benzene, ethyl-benzene, and TVOC exacerbated atopic dermatitis symptoms. It is shown that atopic dermatitis is closely related to the residential environments that patients reside in (Lee *et al*., 2014). Furthermore, participants in another study , Japanese pregnant women with asthma, atopic eczema, or allergic rhinitis (n = 998) were observed to demonstrate the effects of formaldehyde exposure (Matsunaga *et al.,* 2008). There were four groups of formaldehyde levels and 47 ppm or more were related to an increased abundance of atopic eczema (Matsunaga *et al.,* 2008). In another study (Choi *et al*., 2010), children also exhibited the same effects because the exposure to the residential concentration of VOCs induced allergic airway diseases. Inhalation of high concentrations of VOCs, including fragrances, resulted in systemic allergy and increased skin symptoms (Schnuch *et al*., 2010). The study examined symptoms of mothers and infants, which were relevant to the use consumer products that raised indoor level of VOCs. High concentrations of VOCs are associated with the use of air fresheners and aerosols. The use of air fresheners possibly contributes to infant diarrhea, earache, and vomiting (Farrow *et al*., 2003).

Psychological stress is enhanced by a mixture of indoor air volatile organics. Fiedler *et al.* (2005) investigated the health effect of exposure to VOCs with/without ozone on women (n = 130). The subjects were exposed to VOCs 26 μg/m^3 and ozone 40 ppb at 1-week interval. Depending on the presence of ozone, exposure to VOCs did not significantly induce subjective or objective health effects. In summary, exposure to mixtures of VOCs or single VOC did not appear to cause significant variation in symptoms. However, the psychological stressors effectively increase the autonomic arousal, as indicated by salivary cortisol, and appear to increased symptoms of anxiety. One or more typical symptoms are relevant to poor indoor air and include nasal irritation and headache

(Fiedler *et al*., 2005).

The health risks associated with the inhalation of limonene from air freshener exposure and the health effects of the pollutants' reaction with oxidants are not yet known. Limonene, which is classified as a relatively safe additive, is used as a flavoring agent in food and as a fragrance in air fresheners. These routes of exposure account for > 90% of limonene intake, which is inhaled nasally. Acutely, a limonene concentration of 4,500 μg/m^3 may cause sensory irritation. The highest concentration of limonene emitted from air fresheners was 2,000 μg/m^3. Numerous studies have reported that exposure to air freshener compounds is too low to assess the risks (BEUC, 2005). Although limonene at an appropriate concentration may not affect human health, at high concentrations it can react with ozone in the air to generate formaldehyde, causing sick house syndrome. When high concentrations of limonene accumulate indoors, it can be irritating to the eyes and skin. In addition, the reduction of lung capacity and lipid pneumonia were observed in a clinical inhalation study when participants were exposed to a high concentration of 450 mg/m^3 *d*-limonene (Falk-Filipsson *et al*., 1993). Exposure to limonene though inhalation is accompanied by pulmonary edema, pneumonia, cough, and difficult breathing. Several primary compounds from air fresheners may undergo reactions to form by-products that may induce deleterious health effects (Wilkins *et al*., 2001; LoVecchio and Fulton, 2001; Sunil *et al*., 2007). Toxicity of limonene was further demonstrated in a case of a 16-year-old male, who abused hydrocarbons including limonene and α-pinene, which subsequently led to clinical problems. High concentrations of hydrocarbon are rapidly absorbed in the pulmonary system, and peak blood levels are achieved about 15-30 min after inhalation. Lead toxicity affects two primary organ systems namely the central nervous and cardiopulmonary systems (LoVecchio and Fulton, 2001).

The oxidative products of ozone and VOCs (e.g., terpenes) emitted from air fresheners have been shown to cause upper airway irritation. Mice exhibited upper airway irritation following a 30-min exposure to oxidative products and Rohr *et al.* (2002) also evaluated the effect of oxidative products and conducting airways over a longer exposure period. Male BALB/c mice were exposed to oxidative products or hydrocarbons for 30, 60 min, and 6 hr, at an ozone concentration of 3.4 ppm and the following concentrations of VOCs: α-pinene 47 ppm, *d*-limonene 51 ppm, and isoprene 465 ppm. The result showed that long-term exposure can induce the development of airflow limitation for 45 min post exposure (Rohr *et al*., 2002). The reaction of limonene and ozone was determined in a mouse bioassay in which sensory irritation, bronchoconstriction, and pulmonary irritation were measured. The mice were exposed to a mixture of ozone (4 ppm) and limonene (48 ppm) for 30 min. The reaction of ozone and limonene generated secondary pollutants (e.g., acetone, acrolein, and acetic acid), which caused additional sensory irritant effects, but all secondary pollutants could not be responsible for the observed sensory irritation (Clausen *et al*., 2001). One or more strong airway irritations are developed from ozone filtrations from outdoors to indoor and concentration of VOCs under indoor conditions. This contributes to the deterioration of lower airway symptoms in indoor environments (Clausen *et al*., 2001).

Following exposure to an ozone-initiated limonene mixture for 3 hr at 6 ppm limonene and 0.8 ppm ozone distinct changes were observed in the histopathology of the lung, but the regulation of inflammation markers and antioxidant enzymes was minor (Sunil *et al.,* 2007). The daily repeated exposure to low concentrations of indoor pollutant may affect sensitivity of the airway. In a repeated exposure study, the BAL fluid in mice did not observe lung inflammation to a reaction 4 ppm ozone concentration and mixture of 52 ppm limonene. The ozone and limonene reaction products showed no sign of inducing accumulated airway effects. At low exposure levels, the sensory irritations were not evident in a mouse bioassay (Wolkoff *et al*., 2012)

Gminski *et al*. (2011) conducted exposure of human volunteers to VOCs emitted from pinewood (n = 15) and wood-based board (n = 24) for 2 hr in a 48 m^3 test chamber with VOC concentrations at about 5 to 13 mg/m^3 for each chamber. The results before and after exposure showed no detection of sensory irritations as determined by exhaled NO, pulmonary function, and eye blink reflex. Furthermore, exposure following short exposure to high VOC concentrations of up to 13 mg/m^3 did not cause sensory irritation or pulmonary effects.

Benzene is a known carcinogen in humans and animals and is rapidly absorbed by oral consumption and inhalation (Avis and Hutton, 1993). When mice were exposed to 1 ppm benzene, 20-40% of it was absorbed through the skin (Ford *et al*., 2001). Exposure to 10 ppm via inhalation in human results in 7.5 mg/hr benzene being absorbed (Blank and McAuliffe, 1985). Exposure to benzene induces headaches and dizziness, and exposure at high concentrations may result in confusion, seizures, and coma. In addition, short-term (5-10 min) exposure to high concentrations of 700 to 3,000 ppm cause dizziness, drowsiness, headaches, tremors and confusion. However, oral ingestion and inhalation of long-term exposure at the high concentration (approximately 10,000 to 20,000 ppm) of benzene could be fatal (Durstenfeld, 2008).

There are several types of phthalates, including DEHP, BBP, DBP, and DEP and a host of others. DBP is the most toxic phthalate and exposure to it has deleterious effects on reproductive. These effects include damage to the uterus and hormonal disturbances in females. In addition, it causes damage to the DNA of sperm or the quality of the semen may be impaired. Several studies have demonstrated a relation between exposure to DBP and the interference with reproductive development, decreasing testosterone, and reduced sperm production. Exposure to phthalate via usage of air freshener has also been associated with allergic symptom and asthma (Barrett *et al*., 2014; Fong *et al*., 2015; Mendell, 2007). The components emitted from air fresheners accumulate in the fatty tissues from long-term exposure, increasing the risk to the body. In addition, the presence of these chemicals in fat tissues can make weight loss difficult. Toxic substances in the human body are stored in the fat, and as it decomposes, it releases toxins. Therefore, the body resists fat loss as a defense mechanism and to protect the immune system. Thus, toxic substrates may accumulate in the fat due to exposure to phthalates from air fresheners, and this affects the immune system. DEHP suppresses the central nervous system following exposure to high levels, but is harmless at low concentrations. Repeated exposure causes damage to the nerves, and irritates the eyes and skin. Thus, using a spray air freshener for long periods should be avoided (Chiang *et al*., 2014; Hao *et al*., 2012).

Health effect of the ultrafine particles formed by chemical reaction

Ozone and terpenes generate SOAs and PM, including ultrafine particles. Long-term exposure to particles causes inflammation in the airway and causes a number of responses in the cardiovascular system via the autonomic nervous system. This involves the indirect and the direct systemic circulation pathway. Formation of particles may directly cause cardiac dysfunction as well as pulmonary and inflammatory symptoms though reactive oxygen species (ROS) production (Zhou *et al*., 2014).

PM is an important factor in acute and long-term effects. A study found that air pollution from NO, CO, and SO, including $PM_{2.5}$, is associated with cardiovascular ailments, cardiac insufficiency, and diabetes among the elderly (Delfino *et al.,* 2009; Lee *et al*., 2003). Conversely, short-term exposure is mostly related to traffic pollutants and polluted air inflow to indoor environments from outdoors (Laumbach *et al*., 2010). In this case, exposure caused few symptoms, such as lung effects and inflammatory responses (Seagrave, 2008). In combined exposure to ozone and PM, the effects may be minor and may evolve into to sensory irritations but hardly progress to the point of affecting lung function. Exposure to PM and air pollution appears to exacerbate asthma in children (McConnell *et al*., 2003; Nielsen *et al*., 2007). Delfino *et al*. (2004) demonstrated that the 19 children with asthma who were continuously exposed to the PM for 24 hr exhibited a transient change in the forced expiratory volume 1 (FEV1). The study found a stronger association between personal PM and allergies. The results showed effects of PM in children with asthma from ambient backgrounds and personal exposure under indoor conditions. Ultrafine particles can affect innate and acquired immunity, and induce oxidative stress, which affects human health. Exposure to ultrafine particles causes chronic inflammatory responses, accompanied by cytokines and chemokine release (Seagrave, 2008). Particles greater than 10 μm are filtered in the nose and upper airway, while smaller particle sizes are inhaled into the lungs, which filter out the ultrafine particles through the actions of eosinocyte, neutrophils, and macrophages (Olsen *et al*., 2014). In addition, ultrafine particles cause sinusitis, bronchitis, asthma, and lung cancer, as well as chronic bronchitis (McConnell *et al*., 2003). The health effects of ultrafine particles during short-term exposure involve obstructive pulmonary disease with acute exacerbation, while lung-related disease occurs with long-term exposure. This effect is especially observed with particles in the range less than $PM_{2.5}$, which induce serious diseases. In the study, PM_{10} and $PM_{2.5}$ had a particularly strong effect on cardiovascular and cardiac mortality for the elderly: a 3.9% rise in deaths from cardiovascular disease and 4.4% rise in deaths from cardiac problems for people older than 74 years old. This result shows that the PM is significantly associated with the increased heart disease incidence and the cardiac mortality (Pascal *et al.*, 2014).

In summary, exposure to ultrafine particles is related to considerable risk of cancer, including lung cancer, which increases the death rate. This suggested that there is a need for more strict regulations to reduce ultrafine particles.

CONCLUSION

Air fresheners contain toxic chemicals, such as benzene, limonene, xylene, aldehyde, and toluene. Emission of these chemicals also increases the change of chemical reactions of VOCs in air fresheners with ozone, which produce potentially biohazard intermediates, such as SOAs, formaldehyde, and oxidative products. These reactions are dependent on indoor conditions

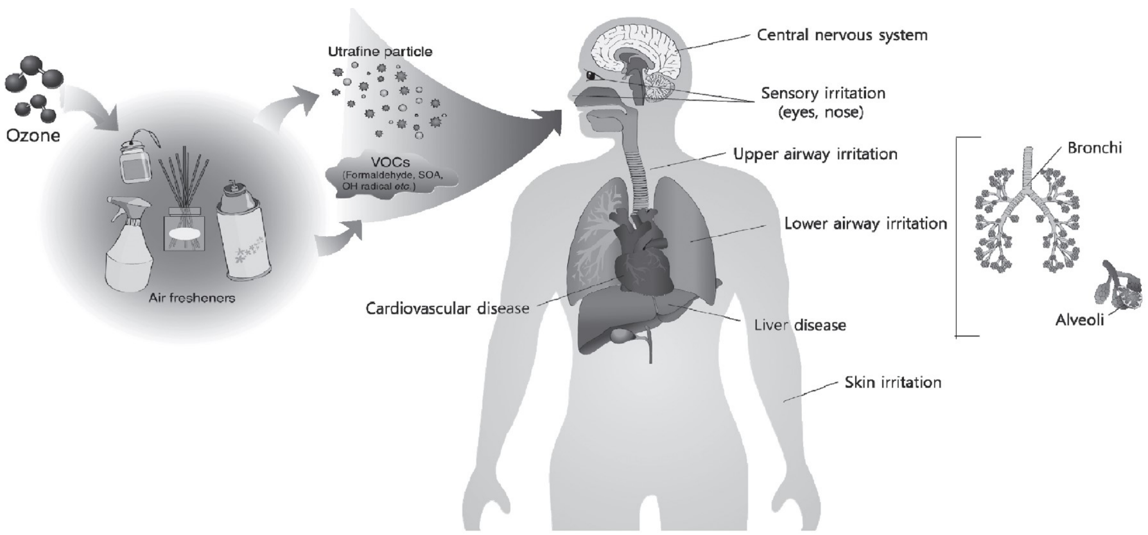


Fig. 2. Potential health effects of air freshener components on human health.

and are classified into two categories: homogenous and heterogeneous reactions. Reactions between ozone and air freshener compounds that produce secondary pollutants and their effect on human health are summarized in Fig. 2. Although there are numerous studies on VOC reactions with ozone, the vast majority of research on this topic has focused on the chemical components generated indoor and the impact on human health. Some of the studies have underlined the importance of reducing and preventing respiratory diseases by indoor environmentally emitted toxins through household use of air fresheners. However, the concentrations of indoor pollutants and the exact components inside air fresheners that can be detrimental to health have not been completely identified. Recent studies have suggested that oxidative products, especially terpene from air fresheners generated by the reaction with ozone, might cause several symptoms. The concerns about the effects of indoor pollutants on health are associated to the release of products included in air fresheners.

This review suggests that exposure to air freshener compounds, such as VOCs that react with ozone to form secondary pollutants, causes diverse health issues. In addition, several key compounds such as benzene, terpenes, and phthalate *etc.* of air pollutants are related to air freshener use. We suggest that the use of air fresheners should be avoided, and there is a need to reduce chemical components which are potentially reactive with ozone in air fresheners. However, the risk assessment of exposure to air freshener compounds is not clearly established since more toxicological knowledge is required. So far there are a few published data on the quantitative analyses of the harmful pollutants in the air fresheners. However, only few quantitative analyses have been conducted to examine the potentially hazardous effects of air fresheners on human health. Therefore, in summary, there is a need for elucidation of the quantitative relationship between exposure and the adverse effects on human health. Thus, we propose that the assessment of sensory irritations caused by emitted compounds from air fresheners should be conducted. Moreover, based on the results of the assessment, the standardized evaluation of selected air fresheners and full scale human studies should be performed. Throughout these studies on air fresheners, the regulation on the use of the products and international guidelines will be established.

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Conflict of interest---- The authors declare that there is no conflict of interest.

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