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Harmful flame retardant found in electronic cigarette aerosol

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ABSTRACT

Studies on the health impact of vaping so far have largely ignored the fact that electronic cigarette (e-cigarette) is essentially an electronic product which is likely to contain a group of endocrine disrupting flame retardants, namely, polybrominated diphenyl ethers (PBDEs) as additives in the combustible components of the product. Thus, the conclusion that e-cigarette is less harmful to health than tobacco smoking may be based on incomplete information. This study reports moderate to elevated levels of PBDEs in 5 out of the 13 samples of e-cigarettes. This finding is suggestive of the continued use of PBDEs in the manufacturing of e-cigarette atomizers and the associated protective casing. This study is unique as it confirms the existence of this developmental neurotoxicant in e-cigarette aerosols. In view of the significant levels of PBDEs and other known carcinogens (polycyclic aromatic hydrocarbons and formaldehydes) in e-cigarette aerosol, there is an urgent need for conducting a thorough review of the health risks of vaping by relevant professionals. A further lesson learnt from this study is that policy makers and relevant product manufacturers should be aware of the possible presence of PBDEs in the aerosol of body care and medical electrical devices such as face steamers, inhalators and nebulizers, especially when PBDEs are utilized in the combustible components of these devices.

1. Introduction

An electronic cigarette (e-cigarette) is a battery driven device mimicking tobacco cigarettes and is being marketed as a less harmful alternative to tobacco cigarette or as an aid for smoking cessation (Pearson et al., 2012). Other than the lithium-ion battery, an e-cigarette comprises of a light-emitting diode light, an atomizer, a microprocessor, and a cartridge containing a liquid solution generally referred to as e-liquid (Lerner et al., 2015). The atomizer assembly mounting base is usually made of rigid plastics containing holes for housing wires extending through the base (Politics and Government Week, 2016). During use, the battery heats up the liquid in the cartridge while the atomizer vaporizes the liquid, emitting it as a mist or aerosol that users inhale. An e-cigarette is essentially an electronic product that is designed to generate aerosols that are directly inhaled by vapers (smokers of e-cigarettes).

Though there is a lack of complete statistics on global e-cigarette consumption, it may be noted that e-cigarette use is growing or persisting across many countries. In the US, the number of adult vapers doubled between 2010 and 2013 (King et al., 2015). Dramatic increases in e-cigarette use among young people in the US have been found since 2013 (US Department of Health and Human Services, 2016). In EU, though the percentage of vaper has remained at 2%, 15% of the population has tried e-cigarette at some point (European Commission, 2017). The growth in the popularity of e-cigarettes is presenting two major research challenges. The first challenge is about the health risk of vapers and the associated indirect aerosol receivers. The second is about the environmental impact of e-cigarette manufacturing and disposal (Lerner et al., 2015). So far, most of the e-cigarette research attention has been directed towards the human health risks associated with vaping (Lerner et al., 2015). A growing body of literature directed toward comparing the health impacts of vaping and smoking is also noted. One view is that there are health benefits in vaping as opposed to smoking. The Royal College of Physicians (2016) offered the view that vapers were more likely to successfully quit smoking and that e-cigarettes were "popular with smokers and offer a viable harm-reduction option" owing to reduced bodily absorption of benzene, tobacco-specific nitrosamines and PAHs in vaping than tobacco smoking. Parker and Rayburn (2017) showed that the leachate from one type of e-cigarette was about ten times less toxic on embryos

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than tobacco cigarette butts. Also by testing one brand of e-cigarette, Azzopardi et al. (2016) demonstrated that aerosol from e-cigarette was significantly less cytotoxic than cigarette smoke. However, some studies showed that nicotine exposure of vapers was not significantly different from smokers (Göney et al., 2016) and the flavorings in e-liquid was causing significant levels of aldehydes to be formed in e-cigarette aerosols (Khlystov and Samburova, 2016).

Although there is no consensus as yet on the health risks of vaping, the World Health Organization (WHO) has recommended that e-cigarettes should not be used in work places or public areas in view of the harmful substances known to be emitted with the aerosol (WHO, 2014). Despite this recommendation, controversies on the merits and demerits of e-cigarettes continue. In line with the WHO recommendation, the Hong Kong Special Administrative Region (HK) government has proposed, among others, to ban the import, manufacture, sale, distribution and advertising of e-cigarettes in the city. Despite the large number of studies on the health risk associated with e-cigarette use, the potential toxicities of inhaling or absorbing the substances and additives used in the e-liquid, atomizer and protective casing continue to be incompletely understood owing to the lack of comprehensive knowledge and evaluation of its benefits and harms. To provide objective scientific evidence for the ban, the Hong Kong Council on Smoking and Health (COSH) commissioned a study to test the concentrations of harmful substances in e-cigarettes available in HK in 2015–2016. The results reported in this paper form part of the COSH study. Substances tested in the aerosols of e-cigarettes include, among others, polycyclic aromatic hydrocarbons (PAHs), nicotine, formaldehydes and polybrominated diphenyl ethers (PBDEs). This paper reports only on the concentrations of PBDEs in e-cigarette aerosol because the concentrations of nicotine, PAHs and formaldehydes in e-cigarette aerosols have already been reported comprehensively in previous studies (e.g., Cheng, 2014).

PBDEs are flame retardants widely used in many products such as building materials, textiles, cars and electronic and electrical equipment. They are applied to combustible components of target products, usually plastics. PBDEs tend to be easily leached out or carried away from the host products (Besis et al., 2014). Coupled with the widespread use of PBDEs, this phenomenon makes contamination ubiquitous. Though not all congeners of PBDEs are harmful to humans, at least one is an endocrine disruptor (BDE-47) while others have been shown to cause cancer in high doses. They exhibit developmental and reproductive toxicity and damage the central nervous system (Schecter et al., 2006). As a result, PBDEs have been recognized as hazardous substances and their use in electrical and electronic products is restricted in the European Union (Directive, 2011/65/EU). Besides, they have been listed as persistent organic pollutants under the Stockholm Convention (The Secretariat of the Stockholm Convention, 2009). PBDEs are bio-accumulative and can be biomagnified. Although PBDEs have been found to be ubiquitous in food, Schecter et al. (2006) argued that dietary exposure alone could not explain the high human body burden. Other sources of exposure include ingestion of dust in workplaces and even households as well as indoor and outdoor air inhalation (Ni et al., 2013). Environmental exposure, resulting from the industrial application of PBDEs in electronic and electrical products is another reason for the high body burden noted. This paper aims to i) enrich the present knowledge on the health risks of vaping versus smoking by presenting the levels of PBDEs in thirteen e-cigarette and two tobacco cigarette samples and calculating the “safe” doses of e-cigarette with respect to specific PBDE congeners; and ii) discuss the implications of such findings on environmental sustainability, public health and clean production.

2. Materials and methods

2.1. Samples and sampling

A total of six different brands of e-cigarettes (A-F) were included in the study by means of convenience and judgement sampling. A convenience sample is a sample obtained by using convenience sampling method which is a type of non-probability sampling. Samples are made up of easy-to-reach individuals. Judgement sampling is also a type of non-probability sampling and selects samples based on expert (the venders) advice. Five brands of e-cigarettes and e-liquids were chosen based on market observations at the time of the study and the results of a 2014 COSH study on the promotion and availability of e-cigarettes in HK. One additional brand (A) was also included based on a supplier's recommendation of its popularity. In total, a sample of thirteen e-cigarettes, four filled with e-liquids and nine connected with e-capsules from six brands were procured through online platforms and normal retail outlets in HK in February 2014 and in June to July 2015. As for the tobacco cigarette samples (RC1 and RC2), two packets of a common commercial brand (G) were acquired. Table 1 lists the types, flavors and nicotine information shown on the samples' labels.

2.2. Experimental set up for testing e-cigarette and tobacco cigarette aerosol

Our experimental set-up was similar to the Sparging Apparatus used by US Food and Drug Administration (2009) for testing of e-cigarettes. It consisted of two 50 mL polypropylene conical test tubes connected together with glass tubes and flexible silica tubings which were further connected to a pump (Model DQA-P104-AA Volts:115 Amps:4.2 HZ 60 USA connecting with CT-1000AC-AC Converter 1000 Watt 50/60 HZ) to suck air from the e- and tobacco cigarette samples. To set the correct puff velocity, the researcher began with the lowest velocity and slowly raised it to a level where it was strong enough to light the e-cigarette. Upon activation of the pump, aerosol from the samples passed through two tubes of solvent mixture. A valid “puff” is indicated by illumination of the LED indicator at the front of the e-cigarette sample and bubbling of the solvent mixture. In each bout, a sample was “lit” for 12 min with each “puff” (by activating the pump) lasting about 4 s–5 s with an inter-puff time of 2 s. This is translated into about 111 puffs per bout. While the 12 min duration for a bout was generally longer than a normal smoking activity and the puff regimes deployed in other e-cigarette studies, the intention was to maximize the collection of target analytes so as to ensure that no harmful substances, not known to the researchers, escape notice. A case in point is Khlystov and Samburova (2016) who admitted that “the small number of puffs” in their test regime was likely the cause of non-detection of target analytes in some samples. In their study, two puffs (each lasts 4 s) were sampled after 15 warm-up puffs (Khlystov and Samburova, 2016). Goniewicz et al. (2014) similarly admitted that since their puff regime was likely to be shorter (1.8 s) than actual situations, their findings might have understated actual quantities of harmful substances inhaled by vapers. Hence, using a longer puff regime (4.5 s) is a sensible approach in the present case. This approach is applied in Health New Zealand Ltd. (2008) and Burstyn (2014) as well.

2.3. Extraction and analysis of PBDEs

The solvents used in the two polypropylene conical test tubes consisted of 12.5 mL of dichloromethane and 12.5 mL of hexane in each tube, i.e., 25 mL in each tube. After 12 min of exposure to e- or tobacco cigarette aerosol, the solvents in the two tubes were