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Use of electronic cigarettes (e-cigarettes) impairs indoor air quality and increases FeNO levels of e-cigarette consumers

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ABSTRACT

Despite the recent popularity of e-cigarettes, to date only limited data is available on their safety for both users and secondhand smokers. The present study reports a comprehensive inner and outer exposure assessment of e-cigarette emissions in terms of particulate matter (PM), particle number concentrations (PNC), volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), carbonyls, and metals. In six vaping sessions nine volunteers consumed e-cigarettes with and without nicotine in a thoroughly ventilated room for two hours. We analyzed the levels of e-cigarette pollutants in indoor air and monitored effects on FeNO release and urinary metabolite profile of the subjects. For comparison, the components of the e-cigarette solutions (liquids) were additionally analyzed.

During the vaping sessions substantial amounts of 1,2-propanediol, glycerine and nicotine were found in the gas-phase, as well as high concentrations of $PM_{2.5}$ (mean 197 $\mu g/m^3$). The concentration of putative carcinogenic PAH in indoor air increased by 20% to 147 ng/m^3, and aluminum showed a 2.4-fold increase. PNC ranged from 48,620 to 88,386 particles/cm^3 (median), with peaks at diameters 24–36 nm. FeNO increased in 7 of 9 individuals. The nicotine content of the liquids varied and was 1.2-fold higher than claimed by the manufacturer.

Our data confirm that e-cigarettes are not emission-free and their pollutants could be of health concern for users and secondhand smokers. In particular, ultrafine particles formed from supersaturated 1,2-propanediol vapor can be deposited in the lung, and aerosolized nicotine seems capable of increasing the release of the inflammatory signaling molecule NO upon inhalation. In view of consumer safety, e-cigarettes and nicotine liquids should be officially regulated and labeled with appropriate warnings of potential health effects, particularly of toxicity risk in children.

Introduction

Environmental tobacco smoke (ETS) is by far the most significant indoor air quality issue, bearing a health risk by inducing lung cancer and cardiovascular disorders in non-smokers (IARC, 2004; US, 2006). It is also considered as important risk factor for asthma, respiratory infections and sudden infant death syndrome in children (EPA, 1992, 1997; Raupach et al., 2008). National regulators in USA and Europe have progressively banned tobacco smoking from public buildings, bars, cafés and restaurants which led to improved indoor air quality in these buildings (Bohac et al., 2010; Gleich et al., 2011). The smoke-free policies and constantly surging tobacco prices prompted consumers to look for alternatives to conventional smoking. New products, especially electronic nicotine delivery systems also known as electronic cigarettes or e-cigarettes, have become popular in spite of insufficient data on their safety for both users and secondhand smokers (Etter et al., 2011).

E-cigarettes do not burn tobacco but produce a respirable aerosol without smoke or flame from a battery-powered heater and liquid-containing cartridges (Trtchounian et al., 2010).

Abbreviations: DNPH, 2,4-dinitrophenylhydrazine; e-cigarette, electronic cigarette; eCO, exhaled carbon monoxide; FeNO, exhaled nitric monoxide; GC, gas chromatography; HPLC, high-performance liquid chromatography; 3-OH-cotinine, trans-3′-hydroxycotinine; 3-HPMA, 3-hydroxypropylmercapturic acid; LOD, limit of detection; MS, mass spectrometry; PAH, polycyclic aromatic hydrocarbons; PM, particulate matter; PNC, particle number concentrations; VOC, volatile organic compounds.

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Depending on the brand, the liquids usually contain nicotine in different concentrations (8.5–22.2 mg/ml) (Cameron et al., 2013), humectants to produce the vapor (especially 1,2-propanediol) and flavors (e.g. tobacco, vanilla, cherry). Despite the growing popularity of e-cigarettes, consumers do not have valid information on the chemical content of liquids or on their safety. In particular, liquids labeled as nicotine-free may contain low levels of nicotine (FDA, 2009), and the risk of impurities (e.g. nitrosamines) is of major concern to health care authorities (FDA, 2009). There is not only a lack of internationally certified manufacturing sites, and liquids freely available via the Internet are not subject to official quality control.

Because e-cigarettes are marketed for delivering nicotine and sometimes other substances, there is a need for regulation, as for other drug delivery devices. Thus far there has been a wide range of responses across countries and states, ranging from no regulation to complete bans (Etter et al., 2011). The empirical basis for these decisions is uncertain, and more research on the health effects of and risks from e-cigarettes must be conducted to ensure that the decisions of regulators, health care providers and consumers are based on scientific evidence.

The aim of our study was to perform a comprehensive exposure assessment by analyzing the indoor air concentration of e-cigarette emissions in terms of particulate matter (PM), particle number concentrations (PNC), volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), carbonyls, and metals. For this purpose, we simulated a real-world scenario (café-like setting) in an environmentally controlled room with predetermined occupancy density and air exchange rate. Before and after the vaping sessions, the concentrations of exhaled carbon monoxide (eCO) and nitric oxide (FeNO) were measured to reveal acute effects of e-cigarette use on physiological parameters. FeNO has already been used in a previous study on e-cigarettes (Vardavas et al., 2012) and is sensitive to a number of factors including eosinophilic inflammation, airway caliber, mucus production, oxidative stress, and enzyme activity, all of which might be affected by e-cigarettes. Additionally, the uptake of nicotine and other VOC was investigated by analysis of urinary nicotine metabolites and mercapturic acids. To support consumer protection, we furthermore analyzed the chemical composition of the e-cigarette liquids and checked for the presence of impurities (nitrosamines).

Materials and methods

Study design

The study was carried out in a room in the office building of the Bavarian Health and Food Safety Authority in Munich, Germany. Room size was 18 m^2 and its volume 45 m^3. The room contained three tables and a wardrobe (café-like setting), and was operated at an average air exchange rate of 0.56 h^{-1}. The measurements were taken on seven days in July 2012 at the same time of the day. On the first day (control day) the air was monitored without vaping activities and on the following six days with e-cigarette consumption. Before the measurements, the room was thoroughly ventilated, and the window was kept tilted during the measurement periods. Subjects were asked to give spot urine before each exposure, and eCO and FeNO were measured using established monitoring devices (BreathCO, Vitalograph, Hamburg, Germany; NIOX MINO, Aerocrine, Bad Homburg, Germany); FeNO was assessed at the standard expiratory flow rate of 50 ml/s. During each vaping session three study subjects took a seat around a table and consumed an e-cigarette filled with a tobacco-flavored nicotine-free liquid (Liquid 1) from 10 am to 12 pm, while recording their individual number of puffs. This procedure was repeated on five consecutive days for the nicotinic variant of Liquid 1 and for another two other tobacco-flavored liquids (Liquid 2 and 3), each of these with and without nicotine (overall six experiments with three volunteers at each session). The equipment for sampling and monitoring was placed on 2 tables at the side of the room about 1 m above floor level and 1 m away from the e-cigarette consumers. After exposure eCO and FeNO were measured again to determine acute effects of e-cigarette use on these measures. For metabolite analysis subjects were asked to collect urine for another 24 h.

Liquids (with and without nicotine, all with tobacco flavor) and e-cigarettes were commercially available (Red Kiwi, Seevetal, Germany). The nicotine content of the liquids was 18 mg/ml according to the manufacturers' declarations. The e-cigarette contained a rechargeable lithium-ion battery, an electronic circuit, a vaporizer, and a mouthpiece with a refillable tank. Batteries were charged before the study and between study days to ensure their correct operation.

Subjects

Nine adult volunteers (all males, 20–30 years old, mean age 24.7 ± 4.2 years, size 173–198 cm, weight 63–85 kg) were recruited for participation in the study. In each vaping session three of them consumed first a nicotine-free and on the day after a nicotinic e-cigarette for two hours. All subjects judged themselves as healthy and were not under medication for at least 15 days before biomonitoring. In particular there was no evidence for pulmonary disease or other chronic conditions (e.g. renal or liver disease) that might influence FeNO and nicotine metabolism. All subjects were occasional smokers with a cigarette consumption of <10 cigarettes per week (no e-cigarettes) and capable of nicotine abstinence 48 h prior to each vaping session. Before taking part in the study, the subjects were familiarized with the device by vaping one e-cigarette under the instruction of the laboratory staff. Thereafter, each subject was given a test set including an e-cigarette and a non-nicotinic liquid to freely practice vaping for one week at home. Participants were asked to refrain from cigarette smoking for at least 48 h prior to their scheduled session. The ethical committee of the Bavarian Medical Association approved the study, and volunteers were enrolled in the study after giving written informed consent. The investigation was conducted according to the Declaration of Helsinki.

Chemical characterization of liquids

1,2-Propanediol, glycerine

To 0.3 g of each liquid 0.1 g internal standard (1,3-propanediol) were added. This mixture was dissolved in 5 ml isopropanol and diluted 1:5 with isopropanol. The GC analysis was carried out on an Agilent 6890 gas chromatograph with flame ionization detector (GC-FID). Separation was performed on an Agilent DB-WAXetr (polyethylene glycol) capillary column with following dimensions: 30 m length, 0.32 mm inner diameter and 1 μm film thickness. The GC oven temperature was programmed from an initial temperature of 150 °C for 2 min, followed by a ramp to 220 °C at 5 °C/min with a hold time of 20 min. 1-μl-samples were injected into the GC inlet at a 40:1 split ratio with helium carrier gas flow rate of 1 ml/min. Temperatures of injector and detector were 240 °C. The analytes were positively identified by comparison of their retention times with those of standards. Quantification followed the internal standard quantification method. The limit of detection (LOD) for 1,2-propanediol was 0.5%. The results were confirmed by analysis via a second GC-column (Agilent HP 5 capillary column) and in the case of glycerine by enzymatic analysis.