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Comparison between particulate matter and ultrafine particle emission by electronic and normal cigarettes in real-life conditions

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ABSTRACT

Aims. Electronic cigarettes may be safer than conventional cigarettes as they generate less indoor pollution in terms of particulate matter (PM); however, recent findings in experimental conditions demonstrated that secondhand exposure to PM may be expected from e-cigarette smoking. The aim of the present study was to investigate the emission of PM generated by e-cigarettes and normal cigarettes under real-life conditions.

Methods. Real-time measurement and comparison of PM and ultrafine particles (UFP) generated by electronic cigarettes with and without nicotine and by normal cigarettes in a 50 m^3 office of an Italian comprehensive cancer center was performed. PM mass as PM1, PM2.5, PM7, PM10, total suspended particles (TSP) in $\mu g/m^3$ and UFP in number of particles per cubic centimeter from 10 to 1,000 nanometers were measured. Outdoor concentrations were measured contemporaneously to compensate for urban background changes.

Results. Regardless of their nicotine content, e-cigarettes generated lower PM levels than conventional cigarettes. Notably, nicotine-enriched e-cigarettes produced lower PM levels than their nicotine-free counterparts.

Conclusion. E-cigarettes appear to generate less indoor pollution than normal cigarettes and may therefore be safer. Further studies are required to investigate the long-term health-related effects of secondhand e-cigarette exposure.

Key words: electronic cigarette, normal cigarette, particulate matter, ultrafine particles, indoor pollution.

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Introduction

An electronic cigarette (e-cigarette) is a battery-powered device that produces an aerosol containing a mixture of nicotine, propylene glycol and flavoring, depending on the different commercial brands[1]. Its use is increasing all over the world as an alternative to traditional tobacco smoke, especially in adult and young smokers[2].

E-cigarettes pose a regulatory challenge to the medical community, as they may reduce the harm of cigarette smoke but at the same time reinforce addictive smoking behavior[3]. Uncertainties also exist as to whether they do promote a clinically relevant cessation rate in smokers who use e-cigarettes to quit smoking[4].

Furthermore, e-cigarettes are supposed to emit much fewer pollutants in both particulate matter (PM), fine particles (FP), ultrafine particles (UFP) and volatile organic compounds (VOC), even if a recent paper demonstrated that an increase in FP/UFP and VOC could be measured in an 8 m^3 emission test chamber after use of an e-cigarette. The authors concluded that secondhand exposure to pollutants may be expected from e-cigarettes[5].

Tobacco smoke is a cause of PM indoor pollution[6] and has been declared a Group 1 carcinogen by the International Agency for Research on Cancer (IARC)[7].

Since e-cigarettes are commonly considered safer than conventional cigarettes, we report our preliminary data on the emission of PM generated by an e-cigarette under real-life conditions. Our aim was to assess the possible health risks of the mainstream vapors and PM to e-cigarette users and people exposed to "passive vaping"[5].

Methods

The primary endpoint of the study was to analyze the PM and UFP content of e-cigarette sidestream smoke in a confined space similar to the indoor environment encountered in everyday life and to compare it with that of a normal cigarette in the same space and conditions. The study was approved by the Local Ethics Committee (approval 108/13).

The selected confined space was a 50 m^3 office on the fifth floor of the Fondazione IRCCS Istituto Nazionale dei Tumori, a large Italian comprehensive cancer center. The room was furnished with tables and chairs and the air conditioning was turned off. Using the carbon monoxide (CO) decay method (i.e. CO generated by an incense stick burning), we measured 0.80 to 0.86 air changes per hour.

PM mass expressed as PM1, PM2.5, PM7, PM10 and total suspended particles (TSP) in g/m^3 was measured using a pre-calibrated Aerocet, Model 531, Met One Instruments Inc.; UFP in number of particles per cubic centimeter from 10 to 1,000 nanometers was obtained through a condensation particle counter, Model 3007, TSI Inc.

One set of instruments was located inside the room and one outside on a large terrace 10 meters from the room window in order to obtain the concentration of urban background pollutants; both indoor and outdoor instruments were aligned and the differences were compensated mathematically to eliminate or reduce measurement errors.

During the tests inside the room 2 people were continuously present: a volunteer smoker and someone to control the analyzers' operation. Three fans were operating throughout the tests in order to ensure a mixing factor as high as possible.

Three customary volunteer smokers smoked an e-cigarette, Elips Serie C, Tank System (Ovale Europe Srl), refilled with and without 16 mg nicotine (provided by Life Italia Prodotti Srl), inside the room at a fixed rate of 1 puff per minute for 7 minutes followed by 3 minutes' hold to simulate the normal cigarette smoking mode for 2 to 3 hours. E-cigarettes with and without nicotine were smoked in the same room but on different days and the room was ventilated before each test. After completion of the e-cigarette tests, only 1 normal cigarette of a popular brand was smoked to avoid exceeding pollution in the room. All tests were repeated 3 times and were performed on different days with different background levels. The concentrations are therefore expressed as the increase over the background. A parametric Student t-test for paired variables was used, with statistical significance set at <0.05.

Results

With respect to the sidestream smoke of a normal cigarette, the e-cigarettes showed lower levels of PM production, as shown in Table 1; significant differences ($P<0.0001$) in terms of PM1, PM2.5, PM7, PM10 and TSP were seen between both types of e-cigarette (with and without nicotine) and a normal cigarette; interestingly, the e-cigarette without nicotine produced more PM than the nicotine-filled one ($P<0.0038$).

Regarding UFP production, normal cigarette sidestream smoke caused an increase of 143,548 ± 8,150 particles per cm^3 over the background number, whereas the e-cigarette without nicotine caused an increase of 641 ± 185 particles; similarly, normal cigarette sidestream smoke caused an increase of 179,010 ± 9,137 particles per cm^3, while the e-cigarette with nicotine caused an increase of 566 ± 190 particles, as shown in Figure 1.

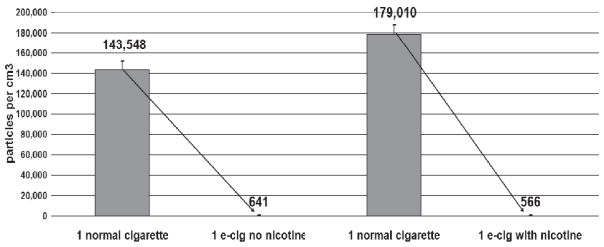
Conclusions

In this preliminary report we sought to investigate the emission of PM generated by a popular e-cigarette in a 50 m^3 office space of our hospital and compare it with that of a normal cigarette. We found that e-cigarettes generated consistently less PM of all measured sizes than a normal cigarette. This difference was particularly evident for the nicotine-refilled device, which showed only marginal PM production in its sidestream smoke, while the e-cigarette without nicotine showed low but

Table 1 - Particulate matter production by e-cigarette and normal cigarette

Micrograms per m^3 (±SD)	PM1.0	PM2.5	PM7.0	PM10.0	TSP
e-cig without nic	3.5±7.3	7.2±9.6	8.7±9.9	9.9±10.3	11.6±15.5
e-cig with nic	0.0±0.3	0.5±1.1	-0.3±3.1	-0.6±4.4	1.2±10.1
normal cig	76±18	139±32	155±36	158±37	160±37
Paired Student's t-test		e-cig with nic		normal cig	
e-cig without nic		$P = 0.004$		$P = 0.001$	
e-cig with nic				$P = 0.001$	

SD, standard deviation; PM, particulate matter; TSP, total suspended particles; cig, cigarette; nic, nicotine.



Particles per cm^3(SD)	1 e-cig no nic	1 normal cig	1 e-cig with nic	1 normal cig
Increase in number of particles over background	641 (185)	143,548 (8150)	566 (190)	179,010 (9137)

Paired Student's t-test	e-cig with nic	normal cig
e-cig without nic	$P = 0.006$	$P = 0.000$
e-cig with nic	$P = 0.000$	

SD, standard deviation; cig, cigarette; nic, nicotine.

Figure 1 - Increase in ultrafine particles (UFP) number over the background.

present production of all PM. This difference also emerged in a recent work by Schober el al.[8], where a similar trend of PM2.5 production between the 2 devices was found. We hypothesize that this phenomenon may be due to changes in the optical properties of the PM (optical particle counters are sensitive to optical PM properties such as color, morphology, etc.) and/or to coagulation/condensation phenomena with other PM or semiliquid aerosols that are present in the environment; however, additional research is necessary to explain and confirm these hypotheses.

Our results indicate that PM production from e-cigarettes is much lower than the new European Air Quality Standard (25 µg/m^3 for PM2.5 and 50 µg/m^3 as 24-hour average and 40 µg/m^3 as annual average for PM10) and the US EPA Air Quality Index (15 µg/m^3 for secondary PM2.5 as annual average and 150 µg/m^3 for PM10 not to be exceeded more than once per year on average over 3 years)[9,10]. However, secondhand exposure to PM deserves more investigation in the light of the recent findings of the ESCAPE trial, which demonstrated that an increased hazard ratio for natural-cause mortality can be seen for each 5 g/m^3 increase in PM2.5[11].

Nevertheless, e-cigarettes with and without nicotine are 479 times and 363 times, respectively, less pollutant than normal cigarettes in terms of UFP. UFP are not regulated by European and US air quality standards, so a comparison with a standard is not yet possible; nevertheless, harm reduction may be expected from e-cigarette vaping because of the reduced environmental pollution compared with normal cigarettes.

However, since UFP have been shown to induce respiratory and cardiac modifications[12,13], the long-term health-related impact of the marginal PM and UFP production by e-cigarettes needs further investigation. Noninvasive markers of pulmonary inflammation may be of help in this matter[8,14].

In conclusion, our investigation proved that e-cigarettes produce less PM than conventional cigarettes and therefore may be less hazardous in terms of secondhand exposure. This finding can be of interest to physicians and policy makers, but we call for further studies that investigate the acute and chronic effects of secondhand exposure to e-cigarette smoke in order to rule out any possible issues of health concern.

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