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Hidden Formaldehyde in E-Cigarette Aerosols

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TO THE EDITOR: E-cigarette liquids are typically solutions of propylene glycol, glycerol, or both, plus nicotine and flavorant chemicals. We have observed that formaldehyde-containing hemiacetals, shown by others to be entities that are detectable by means of nuclear magnetic resonance (NMR) spectroscopy, can be formed during the e-cigarette “vaping” process. Formaldehyde is a known degradation product of propylene glycol that reacts with propylene glycol and glycerol during vaporization to produce hemiacetals (Fig. 1). These molecules are known formaldehyde-releasing agents that are used as industrial biocides. In many samples of the particulate matter (i.e., the aerosol) in “vaped” e-cigarettes, more than 2% of the total solvent molecules have converted to formaldehyde-releasing agents, reaching concentrations higher than concentrations of nicotine. This happens when propylene glycol and glycerol are heated in the presence of oxygen to temperatures reached by commercially available e-cigarettes operating at high voltage. How formaldehyde-releasing agents behave in the respiratory tract is unknown, but formaldehyde is an International Agency for Research on Cancer group 1 carcinogen.

Here we present results of an analysis of commercial e-liquid vaporized with the use of a “tank system” e-cigarette featuring a variable-voltage battery. The aerosolized liquid was collected in an NMR spectroscopy tube (10 50-ml puffs over 5 minutes; 3 to 4 seconds per puff). With each puff, 5 to 11 mg of e-liquid was consumed, and 2 to 6 mg of liquid was collected. At low voltage (3.3 V), we did not detect the formation of any formaldehyde-releasing agents (estimated limit of detection, approximately 0.1 μg per 10 puffs). At high voltage (5.0 V), a mean (±SE) of 380±90 μg per sample (10 puffs) of formaldehyde was detected as formaldehyde-releasing agents. Extrapolating from the results at high voltage, an e-cigarette user vaping at a rate of 3 ml per day would inhale 14.4±3.3 mg of formaldehyde per day in formaldehyde-releasing agents. This estimate is conservative because we did not collect all of the aerosolized liquid, nor did we collect any gas-phase formaldehyde. One estimate of the average delivery of formaldehyde from conventional cigarettes is approximately 150 μg per cigarette, or 3 mg per pack of 20 cigarettes. Daily exposures of formaldehyde associated with cigarettes, e-cigarettes from the formaldehyde gas phase, and e-cigarettes from aerosol particles containing formaldehyde-releasing agents are shown in Figure 1.

Inhaled formaldehyde has a reported slope factor of 0.021 kg of body weight per milligram of formaldehyde per day for cancer (http://oehha.ca.gov/risk/pdf/TCDBcas061809.pdf). Among persons with a body weight of 70 kg, the incremental lifetime cancer risk associated with long-term cigarette smoking at 1 pack per day may then be estimated at 9×10⁻⁴. If we assume that inhaling formaldehyde-releasing agents carries the same risk per unit of formaldehyde as the risk associated with inhaling gaseous formaldehyde, then long-term vaping is associated with an incremental lifetime cancer risk of 4.2×10⁻³. This risk is 5 times as high (as compared with the risk based on the calculation of Miyake and Shibamoto shown in Fig. 1), or even 15 times as high (as compared with the risk based on the calculation of Counts et al. shown in Fig. 1) as the risk associated with long-term smoking. In addition, formaldehyde-releasing agents may deposit more efficiently in the respiratory tract than gaseous formaldehyde, since publication of his article, the author reports no further potential conflict of interest.


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and so they could carry a higher slope factor for cancer.

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Disclosure forms provided by the authors are available with the full text of this letter at NEJM.org.

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