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E-Cigarettes: A Hazy Hazard

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In Brief

- Electronic cigarettes (e-cigarettes or e-cigs) are battery-powered devices that deliver vaporized nicotine and other substances, such as flavorings, to users without smoke or combustion. They are commonly marketed as smoking cessation tools and, as such, are promoted as being a healthier alternative to smoking.
- A common misperception is that that e-cigarettes only release water vapor. In reality, though, these devices release nicotine and other chemicals in a vapor form that can expose both the user (a.k.a., the vaper), as well as those in the immediate vicinity, to those contaminants. While the health risks of e-cigarettes compared to regular cigarette smoking is greatly reduced, many toxic compounds are still present.
- The rapid increase in use of electronic cigarettes has generated a potential concern for indoor air quality in that there is still limited data on potential exposures and human health risks for users, or for others through second- and third-hand exposures.

Electronic Cigarettes: Not Just Water Vapor

Introduction

The surge of the use of electronic cigarettes (e-cigarettes or e-cigs) has raised many questions for safety and health professionals as to whether the use of such products should be allowed in the workplace. After all, if they are a smoking cessation device, shouldn't we be encouraging employees to quit smoking through the use of these devices? And what's the harm, really – isn't it just water vapor?

E-cigarettes were originally designed in 1963 by Herbert Gilbert, and patented in 1965 as a “smokeless nontobacco cigarette” intended to provide a “safe and harmless” means of smoking (Patent US3200819 A, 1965). In January 2014, researchers estimated that there were some 460 different e-brands and more than 7700 unique flavors currently on the market (Zhu, 2014). It is anyone's guess how much those numbers have increased since then. E-cigarette sales in the U.S. in 2014 were estimated at \$2.2 billion (Rigotti, 2015) with an annual growth of sales for the foreseeable future expected to be over 50% (Mickle, 2015).

While there are many generations of e-cig configurations, the typical components include a fluid-filled reservoir, which contains the liquid “e-fluid” or “e-juice” to be vaporized, an atomizer (heating coil) to vaporize the liquid, and a battery (typically a lithium battery) to power the atomizer. “First generation” e-cigarettes resemble traditional cigarettes, “second generation” e-cigs have a distinct reservoir tank and larger battery, and “third generation” e-cigs are fully modifiable by the user, in many cases to increase vaping power, output, and/or battery life (Floyd et al., n.d.). Because there is no combustion source or tobacco, which forms cancer-causing byproducts when burned, the intent is for users to inhale nicotine and/or flavored vapors without the potential cancer risks associated with traditional tobacco cigarette use (Maron, 2014).

Components and Byproducts

The primary components of most e-juices are propylene glycol and/or vegetable glycerin (glycerol), which are used as delivery vehicles for the added nicotine and flavorings, and to create the vapor cloud that is exhaled by the user (Riker, et al., 2012). Several studies have measured varying ranges of airborne concentrations of propylene glycol from e-cigarette usage, and reported exposures will vary depending on types and numbers of e-cigarettes used, room size, ventilation rates, etc. Pellegrino et al. (2012) measured propylene glycol concentrations of 1650-1600 mg/m³ and 580-610 mg/m³ of glycerin in the vapor emitted from e-cigarettes. Schober et al. (2013) showed ranges of propylene glycol from 110 µg/m³ to 215 µg/m³ and glycerin in the range of 59 µg/m³ to 81 µg/m³ in the gas phase of emissions during an e-cigarette vaping study. McAuley et al. (2012) reported airborne concentrations of propylene glycol ranging from 2.25 mg/m³ to 120 mg/m³. Geiss et al. (2015) estimated lung concentrations of 160 mg/m³ for propylene glycol and 220 mg/m³ for glycerol for users vaping traditional e-cigarette refill liquid. In comparison, exposure to propylene glycol, when used in theatrical fog at concentrations ranging from 0.02 to 4.11 mg/m³, has been reported to contribute to various respiratory health issues, such as asthma, wheezing, chest tightness, decreased lung function, irritation, and airway obstruction (Varughese et al., 2005). The AIHA (2011) recommended Workplace Environmental Exposure Level (WEEL)[®] value for propylene glycol is an eight-hour TWA of 10 mg/m³ and the ACGIH Threshold Limit Value (TLV) for glycerin mist is 10 mg/m³ (OSHA, 2006). Studies have shown that when glycerol is heated, such as in the coil of an e-cig, pyrolysis occurs which may lead to the formation of acrolein, formaldehyde, and acetaldehyde in the vapor (Goniewicz, Knysak et al., 2013; Geiss, et al., 2014; Uchiyama et al., 2013). Formaldehyde, a recognized human carcinogen, is a known degradation product of propylene glycol and glycerol,

and is found in higher airborne concentrations in e-cigarettes that operate at high voltage or feature a variable voltage battery (Jensen et al., 2015). This may be of particular concern in newer generation e-cigarettes with adjustable voltages which allow users to generate a thicker vapor.

Nicotine

Nicotine is present in most e-liquids, and has even been found in some e-cigarette cartridges that were labeled as containing no nicotine (FDA, 2009). Typical nicotine content ranges from zero to 3.6 percent, although levels as high as 15 percent have been found in some e-liquids (Goniewicz et al., 2015). Health effects from exposure to nicotine are well documented and include an increase in heart rate, respiratory rate, blood pressure, and level of alertness (CDC, 2014a). Nicotine, which is highly addictive, is a teratogen (CDC, 2014a) and can promote tumor growth (Davis et al., 2009). Exposure to nicotine during adolescence can affect brain development and predispose youth to future tobacco use (Rigotti, 2015; Leventhal et al., 2015). Ingestion or inhalation of nicotine can cause nausea, vomiting, abdominal pain, headache, dizziness, confusion, agitation, restlessness, and possible burning sensation in the mouth, throat, and stomach (CDC, 2014a). Nicotine can also readily pass into the bloodstream via dermal contact, which is of concern if e-liquid is spilled on the skin.

CDC (1994) uses a human oral lethal dose of 60 mg for a 70 kg adult (around 0.8 mg/kg), but this value has been challenged in context with the e-cig movement (Mayer, 2014). However, using the 0.8 mg/kg value results in a lethal dose of around 8-11 mg for a 10-14 kg toddler. Nicotine content measured in 15 common brands of e-liquid cartridges in one study ranged from 1.6 to 19 mg (Goniewicz et al., 2015), spanning this potentially lethal range for small children. According to the U.S. Centers for Disease Control and Prevention (CDC), calls

related to poisoning from the liquid nicotine used in e-cigarettes ran at a rate of roughly one per month in 2010, but jumped to 215 in February of 2014 (CDC, 2014b). CDC states that more than half of the poison center calls involved children aged 5 and younger, while 42 percent involved people aged 20 and older. Ingestion of e-liquid accounted for nearly 70 percent of the exposures, while dermal exposures accounted for six percent (CDC, 2014b). In 2015, the American Association of Poison Control Centers (AAPCC) received 3,073 exposure reports to e-cigarettes and liquid nicotine for the year. By comparison, in all of 2011 there were a total of 271 exposures reported (AAPCC, 2016).

Airborne concentrations of nicotine have been detected in second-hand emissions from e-cigarettes, although the reported average concentrations found are lower than those found in second-hand tobacco smoke (McAuley et al., 2012; Czogala et al., 2013). Compounding the potential second-hand emission concerns from e-cigarettes is a lack of strong quality control standards or labeling requirements (Goniewicz, Kuma et al., 2013). Several studies have found that cartridges containing nicotine delivered varying concentrations of nicotine – in some cases two to five times greater than stated on the packaging - while other cartridges labeled as non-nicotine-containing did, in fact, contain nicotine (FDA, 2009; Goniewicz, Kuma et al., 2013).

Flavorings

One of the greatest potential health concerns, with regard to e-cigarettes, is the widespread use of various flavoring agents. Manufacturers of e-liquids use a wide variety of natural and artificial flavoring agents, many of which are used as flavoring in food products. Flavors such as cotton candy, bubble gum, gummy bear, apple pie, pina colada, cherry and buttered popcorn are readily available on the internet and local shops. The use of commercially available flavors that imitate common foods, candies, and liquors has raised concerns among

many that these products may serve as a gateway for children and young adults to nicotine addiction and traditional cigarette use (Primack, 2015; Rigotti, 2015).

Many of the flavorings used in e-liquids were initially used in food products. The Flavor and Extract Manufacturers Association maintains an independent program that evaluates the safety and “GRAS” (generally recognized as safe) status of substances for use as flavor ingredients in food products. However, the safety of the use of such products in e-cigarettes has not been tested or proven. A product that may be safe when ingested may not be similarly safe when inhaled. A classic example of this issue is the use of diacetyl as a buttery flavoring for popcorn and other food products. While ingestion of diacetyl is generally regarded as safe, inhalation of volatilized diacetyl has been associated with bronchiolitis obliterans, a rare, and potentially fatal, lung disease (Egilman & Schilling, 2012).

Intentional inhalation of some flavorings in a vapor form can, potentially, be very hazardous. Farsalinos, Kistler, et al. (2015) analyzed 159 samples of sweet-flavored e-cigarette liquids, purchased from 36 manufacturers and retailers in seven different countries, for the presence of diacetyl and acetyl propionyl (aka, 2,3-pentanedione). Both of these compounds are GRAS when ingested, but are associated with significant respiratory disease when inhaled. Diacetyl and/or acetyl propionyl were found in 74.2% of the samples, even in samples from manufacturers who clearly stated that these chemicals were not present. The authors estimated that an average user’s consumption “would result in 490 times higher daily intake compared to the NIOSH [occupational exposure] limit” for diacetyl.

Another study, conducted by Allen, et al. (2015), reportedly found diacetyl in the vapor, but not in the liquid, of 39 of 51 different e-liquid flavors that were tested. Benzaldehyde has been detected in cherry flavoring, methyl anthanilate was detected in grape flavoring, 1-hexanol

was detected in apple flavoring (Brown et al., 2014), and none of these or other flavoring compounds have toxicological data on the potential health effects from inhaling the vapor form. In addition, there is very little research on what type of thermal degradation products are generated by the heating and vaporizing of the myriad different e-liquid flavors and combinations that are available. The science continues to expand, but there is still a wide gap of knowledge on health effects from inhaling flavorings and other ingredients that have not been evaluated for inhalation toxicity or for potential thermal degradation products (AIHA, 2014).

Ultrafine Particulates

Adverse health effects from exposure to fine and ultrafine particles in ambient air pollution have been well documented. Significant associations have been found between elevated cardiovascular and respiratory disease mortality, and exposure to fine and ultrafine particulates (Wichmann et al., 2000). Exposure to fine and ultrafine particulates may also exacerbate preexisting respiratory ailments, such as asthma (Sacks et al., 2010). Studies have shown that e-cigarette emissions may contain large amounts of particulates ranging anywhere between 10 and 1000 nanometers (nm) in size, with an average size of 400 nm (Zhang et al., 2013). Schober et al. (2013) reported that $PM_{2.5}$ concentrations during vaping sessions with e-cigarette users were around 373 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), with levels as high as 514 $\mu\text{g}/\text{m}^3$ measured during some of the vaping sessions. Floyd et al. (n.d.) reported that with the newer, higher powered e-cigarettes, that as power vaping increases, a greater fraction of aerosol is in the respirable fraction ($\leq 2.5 \mu\text{m}$), however, the persistence of these particulates (the half-life) in air can be short due to rapid evaporation (Bertholon et al., 2013). E-cigarette aerosol, therefore, may present a new source of particulates in the indoor environment and pose a potential exposure hazard to bystanders, but further study is needed.

Second- and Third-hand Exposure Concerns

Aerosols generated from electronic cigarettes have been found to contain tin, silver, iron, nickel, aluminum, sodium, copper, magnesium, lead, chromium, manganese, potassium, zinc, silicates, and nanoparticles of tin, chromium, and nickel (Williams et al., 2013). Other studies, of exhaled aerosol, have revealed the presence of nicotine, propylene glycol, glycerin, ethylbenzene, benzene, toluene, m,p-xylene, acetone, formaldehyde, acetaldehyde, acrolein, propanal, diacetyl, fine/ultrafine particles, and tobacco-specific nitrosamines (TSNAs) (AIHA, 2014; Farsalinos, Gilbert et al., 2015). TSNAs are very potent carcinogenic chemicals that have also been shown to form on surfaces as a reaction of deposited nicotine and ambient nitrous acid (Sleiman et al., 2010). Such deposition products and byproducts can present a potential hand-to-mouth exposure from touching surfaces (third-hand exposures), which can be of significant importance in settings with young children.

Disposal Issues

In addition to exposure concerns, e-cigarettes contain lithium ion batteries and nicotine, both of which are considered by the U.S. Environmental Protection Agency (EPA) to be a hazardous waste. This may pose potential concerns when disposing of e-cigarettes and e-liquids. EPA's proposed rule for management of hazardous waste pharmaceuticals, published in the September 25, 2015 Federal Register, proposes that "unused (unsold, expired, or returned) nicotine-containing products, including patches, gums, lozenges, inhalers, nasal sprays, and e-cigarettes, are classified as P075 listed acute hazardous wastes when discarded" (p. 58072). While these products are for personal use, if used in the workplace, and found in the employer's waste stream, potential compliance concerns could be raised.

Safety Issues

Several incidents of explosions and fires involving e-cigarettes and have been reported. The most commonly reported cause of fires and explosions has been from the use of incorrect chargers for the lithium-ion batteries used in the e-cigarettes (FEMA, 2014). Unfortunately, there are no requirements for e-cigarette manufacturers regarding mandated overcurrent or overcharge protection, especially in newer generation modified e-cigs, so if they are left charging, there is the possibility of overheating, which can cause a fire or cause the battery to explode (FEMA, 2014). One unfortunate consequence of the design of the e-cig is that the battery is installed in a device that has its weakest point at the ends of the device, so when a battery fails, it can be “propelled across the room like a bullet or small rocket” (FEMA, 2014, p. 5).

Current Regulatory Status

Although nicotine is derived from tobacco, electronic cigarettes contain no tobacco and are, therefore, not automatically regulated as a tobacco product. However, the Food and Drug Administration (FDA) (2016) has extended its authority to regulate e-cigarettes, vape pens, and hookah tobacco effective August 8, 2016. The FDA will be able to require manufacturers, importers, and retailers to report ingredients, place health warnings on products and advertisements, and limit sales to persons under 18 (FDA, 2016). In addition, various states, municipalities, and other entities have adopted their own restrictions on sales and bans on the use of e-cigarettes in public places, transportation facilities, and restaurants and bars. According to the American Nonsmokers’ Rights Foundation (ANRF), as of January 1, 2016, twenty-four different states have passed laws restricting the use of e-cigarettes in certain settings. Additionally, 475 different cities/counties have enacted local laws restricting e-cigarette use in venues that had previously established smoking bans (ANRF, 2016). Many U.S. airlines, commuter rail lines and transit entities have also modified their no-smoking policies to

specifically include e-cigarettes (AIHA, 2014).

Recommendations

The American Industrial Hygiene Association (AIHA) set out to explore the current known science about e-cigarettes in the indoor environment and published a White Paper with the findings known at the time of publication. AIHA recommended, “e-cigarettes should be considered a source of VOCs and particulates in the indoor environment that have not been thoroughly characterized or evaluated for safety.” AIHA then went on to state “because e-cigarettes are a potential source of pollutants (such as airborne nicotine, flavorings, and thermal degradation products), their use in the indoor environment should be restricted, consistent with current smoking bans, until and unless research documents that they will not significantly increase the risk of adverse health effects to room occupants” (2014, p.22-23).

The CDC’s National Institute for Occupational Safety and Health (NIOSH) Current Intelligence Bulletin 67: *Promoting Health and Preventing Disease and Injury Through Workplace Tobacco Policies* recommends that employers “establish and maintain smoke-free workplaces that protect those in workplaces from involuntary, secondhand exposures to tobacco smoke and airborne emissions from e-cigarettes and other electronic nicotine delivery systems” (2015, p. xi).

Addendum c to ANSI/ASHRAE Standard 62.1-2013, published in 2015, clarifies that the definition of environmental tobacco smoke (ETS) “includes smoke produced from the combustion of cannabis and controlled substances and the emissions produced by electronic smoking devices” and recommends that “provision of acceptable indoor air quality is incompatible with the presence of ETS, including cannabis smoke and e-cigarette emissions” (p. 3).

The World Health Organization (WHO) states that electronic nicotine delivery system (ENDS) users should be “requested not to use ENDS indoors, especially where smoking is banned, until exhaled vapour is proven to be not harmful to bystanders and reasonable evidence exists that smoke-free policy enforcement is not undermined” (2014, p. 11).

Conclusion

So what does all of this mean to the safety and health professional? Until more science is known about the potential hazards, many scientific organizations, such as AIHA, NIOSH, ASHRAE, and the WHO, recommend including e-cigarettes in existing smoke-free policies, thus limiting use in the indoor environment. AIHA further recommends, “For organizations and businesses that have smoking bans, especially those required by law, it would be advisable for them to update their bans to specifically include e-cigarettes in order to eliminate potential confusion among patrons as well as employees charged with enforcing those bans” (2014, p. 19). Knowing that the emissions from e-cigarettes are not “just water vapor” can go a long way in helping safety and health professionals understand and apply the potential risk when establishing and enforcing employer smoking policies.

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