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Impact of Electronic Cigarettes on Oral Health: a Review

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Abstract

Electronic cigarettes (e-cigarettes) are widely available, and their use is increasing worldwide. They are promoted as a safer alternative to combustible cigarette smoking and as an effective smoking cessation aid. E-cigarettes are designed to provide smokers with the desired nicotine dose without burning tobacco. They contain flavoured humectants that include nicotine in concentrations of 0–36 mg/mL. Evidence suggests that e-cigarettes are a better nicotine delivery method than combustible cigarettes and have reduced adverse general and oral health effects, compared with combustible cigarettes. However, although e-cigarettes might be an acceptable harm-reduction strategy, the differential effects of e-cigarettes and combustible cigarettes have been based on self-reported perceptions. In addition, a growing number of young people, who have never engaged in combustible cigarette smoking, are smoking e-cigarettes, which may not be harmless. We analyzed peer-reviewed publications available through PubMed to summarize the effects of e-cigarettes on oral health.

The World Health Organization estimated that, in 2015, 19.9% of the world's population over the age of 15 were smokers.[1] The 2017 Canadian Tobacco, Alcohol and Drugs Survey found that the prevalence of current cigarette smoking was 15%, including about 17% of males and 13% of females.[2] The prevalence in teens aged 15–19 years was about 8%, with 10% of males and 6% of females being current smokers. For those aged 20–24 years and those 25 years and older, the prevalence was 16%. Combustible cigarette smoking (CCS) has been causally associated with major morbidity and mortality.[3] Indeed, numerous experimental and clinical investigations have linked tobacco use with over 25 diseases, including lung, heart and oral diseases, such as oral cancer.

The oral cavity is the first site to encounter tobacco smoke, which comes in direct contact with soft and hard tissues. Several studies have linked smoking to an elevated risk of periodontal disease.[4] Cigarette smoke has also been associated with various cancers. A meta-analysis showed that exposure to environmental tobacco smoke is prospectively associated with a significantly increased risk of lung cancer.[5]

Smoking is also associated with oral cancers. Chher and colleagues[6] reported a 4-fold increase in potentially malignant oral disorders among those who smoke tobacco. In a retrospective clinicopathological study, of people with proven cases of oral cancer, 29.4% were only tobacco chewers, 25.5% were only smokers, 42.2% used both types of tobacco (smoke and smokeless) and 2.9% were not tobacco users. For those only chewing tobacco, 83.3% had oral cavity cancers, of which 6.7% were of the oro- and hypopharynx. Among those who only smoked tobacco, 69.2% cases were of the laryngeal and oro- and hypopharyngeal, compared with 11.5% oral cavity cancers.[7] Whatever the mode of tobacco use (smoking, chewing, etc.), there is a high risk of cancer development.

To counter the adverse effects of CCS on human health, various strategies have been introduced, including abstinence and nicotine replacement therapy (NRT).[8] Available since early 1990, NRT products include gum, transdermal patches, nasal spray, inhalers and sublingual tablets and lozenges. Recent reports show that NRT increases the chances of successfully stopping smoking in those attempting to quit.[9] However, long-term success rates are low, as are those for all cessation options.[10] Thus, the possibility of another option available to smokers is appealing, and a new strategy, the electronic cigarette (e-cigarette), has been introduced.

Methods

This review summarizes scientific publications related to the interaction of e-cigarettes with the oral cavity and the possible promotion of oral disease with the use of e-cigarettes. For this purpose, we selected peer-reviewed articles using several search terms and databases, between 2012 and 2020. PubMed, Medline and Google Scholar were searched using the following groups of terms (electronic cigarette and oral health), (electronic cigarette and oral health and smoking), (electronic cigarette and oral health and smoking and nicotine replacement therapy), (electronic cigarette and oral health and smoking and cessation), (electronic cigarette and periodontal diseases), and (electronic cigarette and dental caries). We examined the articles and selected those listed in the References of this review. We also included surveys published by Canadian Tobacco, Alcohol and Drugs Survey (CTADS)[2] and the Centers for Disease Control and Prevention (CDC) *Smoking & Tobacco Use* website.[3]

Electronic Cigarettes

An e-cigarette consists of a cylinder with a cartridge that serves as a reservoir for "vaping" substances on 1 end along with a mouthpiece. The cartridge can be prefilled or fillable. Various capacities have been designed, increasing from first to second and third generations of the e-cigarette. E-cigarette devices also contain a battery-powered heating element or atomizer that transforms the liquid into an aerosol, which is commonly and incorrectly termed "vapour" by suppliers. E-cigarettes are powered by a non-rechargeable or rechargeable battery, which may be nickel-cadmium, nickel metal-hydride, lithium ion, alkaline and lithium polymer or lithium manganese.[11] Many e-cigarette devices use a lithium battery, offering the possibility of storing a large amount of energy in a compact space.

Since their commercialization in 2004, various improvements have resulted in several generations of e-cigarette, with the most recent called pod-based e-cigarettes. The pod-based style (the JUUL) consists of 2 main components: a liquid and heating coil-containing pod and a rechargeable battery. It is a low-powered, high-nicotine device in the shape of a USB flash drive.[12] Pods have a smooth, small "high-tech" look, which makes them unobtrusive and easy to use.[13] Several types of pods are available, including opened and closed systems and those that have features of both these formats.[14] Pod devices use nicotine salt "juice" in combination with the humectants, vegetable glycerin (VG) and propylene glycol (PG), in the ratio of 30 or 40 to 60.[14] Pods represent over 40% of the e-cigarette retail market and are popular with teens.[15]

Liquids Used in E-cigarettes

Liquids used in e-cigarettes are regulated under the Tobacco and Vaping Products Act and the *Canada Consumer Product Safety Act*. These liquids, with or without nicotine, are available in small sealed bottles of approximately 30 mL. In e-cigarettes, they transfer nicotine from the device to the user's airways in the form of aerosol.[16]

The humectants, PG and VG, are used as carrier solvents for nicotine and flavours present in the liquid. When heated, they form an aerosol that is then inhaled. PG is less viscous, producing greater throat stimulation and mimicking the feel of smoking, whereas VG is thick with a natural sweet flavour, producing the esthetically pleasing clouds of vapour for the user to exhale.[17] To combine these sensations, a mixture of PG and VG is used. The ratio is based on personal preference regarding the balance among flavour, throat stimulation and vapour production.[18]

In addition, e-cigarette liquids contain various attractive chemical flavours.[19] Flavouring is the reason most frequently given by young people for starting and continuing to use e-cigarettes.[20] In 1 study,[21] vapers ranked the selection of flavours and unique flavours as 2 of the most important factors affecting their choice between competing vape shops. Thousands of flavours have been designed and incorporated into e-cigarette liquids, including tobacco, sweet flavours, menthol and various combinations to render e-cigarettes more attractive to users.[22]

Prevalence of E-Cigarette Use

The emergence of e-cigarettes has provided smokers with a new alternative way to acquire nicotine. Today, vaping is widespread among both conventional cigarette smokers and non-smokers, including adults and teens.[23,24] Even though most countries have adopted legislation surrounding e-cigarettes, their prevalence is increasing all over the world.

Between February and December 2017, the Canadian Tobacco, Alcohol and Drugs Survey (CTADS) was conducted by telephone interview of 16 349 respondents across all 10 provinces, representing a weighted total of 30.3 million Canadians aged 15 years and older.[2] The data obtained showed that, in 2017, 15% of Canadians aged 15 years and older had tried an e-cigarette, as had 23% of youth (15–19 years), 29% of young adults (20–24 years) and 13% of adults (≥ 25 years). More males (19%) than females (12%) had used an e-cigarette. E-cigarette use in the past 30 days was reported by 3% of Canadians aged 15 years and older, 6% of youth, 6% of young adults and 2% of adults. Among those who had used an e-cigarette in the past 30 days, 65% were current smokers, 20% were former smokers and 15% had never smoked. Of those who had never smoked, 58% were youth and 33% were young adults.

The CTADS also found that, among Canadians aged 15 years and older who had an e-cigarette in the past 30 days, 43% reported using a fruit-flavoured one, 22% tobacco flavoured and 14% candy/dessert flavoured. Most youth (69%) and young adults (62%) reported using a fruit flavour. In contrast, among adults (≥ 25 years), 33% reported using a fruit flavour and 29% reported using tobacco flavour. Of Canadians who had tried an e-cigarette, 64% reported that the last e-cigarette they used contained nicotine, 24% reported it did not contain nicotine and 12% were uncertain. Of current or former smokers, 32% reported using e-cigarettes as a cessation aid in the past 2 years.

The Canadian Student Tobacco, Alcohol and Drugs Survey, conducted in 2016–2017, showed that the prevalence of having tried an e-cigarette had increased to 23% from 20% in 2014–2015. In the past 30 days, 10% of students had used an e-cigarette, an increase from 6% in 2014–2015. Prevalence of e-cigarette use in the past 30 days was higher among males (12%) than females (8%) and higher among those in grades 10–12 (15%) than for students in grades 7–9 (5%).[2]

Among students who used an e-cigarette in the past 30 days, 57% had done so in the last 3 days, while 11% reported daily use. Daily use of e-cigarettes in the past 30 days was higher among males (14%) than females (5%); 17% were current smokers, 12% were former smokers, 35% were experimental smokers or puffers and 36% indicated that they had never smoked a cigarette. Of students in grades 7–12, 13% had tried both cigarettes and e-cigarettes. Of students who had tried both cigarettes and e-cigarettes, 54% tried CCS first, while 35% first tried an e-cigarette. The prevalence of trying an e-cigarette first was higher among students in grades 7–9 (39%) than in grades 10–12 (34%).[2]

Comparative Health Effects of CCS and E-Cigarettes

E-cigarettes are seen as a potentially safer smoking alternative to regular cigarettes.[20,25] Several experimental and smoker-derived studies suggest that e-cigarettes can indeed be seen as a harm reduction strategy for those engage in CCS. Nevertheless, some caution is needed to avoid giving the impression that e-cigarettes are harmless, especially for young people who have never used CCS.

Experimental Studies: Endothelial cells, exposed to extracts from combustible cigarettes or from e-cigarettes showed greater inhibition of cell migration from the former, suggesting that e-cigarettes do not delay wound healing processes, compared with combustible cigarettes.[10] Human gingival epithelial cells exposed to cigarette smoke showed a much greater toxic effect compared with those exposed to e vapours. Indeed, cell growth was almost absent with CCS compared with e vapours; this was supported by high cell death with CCS but not with e-cigarettes.[26-28] Exposure of human lung epithelial carcinoma cells A549 to either e-cigarette liquids or collected aerosols produced no meaningful toxic effects compared with CCS.[29] Exposure of neonatal mice to e vapours during the first 10 days of their life resulted in modestly impaired lung growth, alveolar cell proliferation and lower total body weight.[30] In a murine asthma model, exposure to e vapours increased airway inflammation, including an increase in eosinophil levels of Th1-cytokines (IL-4, IL-5, IL-13), OVA-specific IgE and hyperresponsiveness.[31]

Clinical Studies: In a clinical study,[32] 110 out of 350 smokers

switched to e-cigarettes for 120 days. These participants had an oral examination and completed a self-administered questionnaire on variations in certain aspects of general health and their need to use CCS. Clinical examinations at various times showed a reduced plaque index among most of the participants who had used CCS for less than 10 years. Switching from CCS to e-cigarettes also resulted in plaque index reduction for participants who used CCS for more than 10 years. In addition, bleeding index improved with the use of e-cigarettes. The self-assessment questionnaire revealed that about 71% of e-cigarette users felt an improvement in general health. Less than a third of participants felt no clear change in health status, either positive or negative. Only 2 participants indicated a worsening of their general health. Although not comparing CCS and e-cigarette users at the same time, this study indicated oral health improvements from switching from CCS to e-cigarettes.

In another clinical study,[33] 105 participants were enrolled and randomly divided into 3 groups: (i) exclusively commercial e-cigarette use, (ii) dual-use of commercial e-cigarettes and their usual cigarette brand and (iii) discontinued use of all tobacco and nicotine products. Biochemical analysis showed a significant reduction in detrimental urinary biomarkers with the use of e-cigarettes only. Dual users exhibited a 7–38% reduction in 8 of 9 urinary biomarkers. All e-cigarettes users showed a significant decrease in exhaled CO. This observation was also supported by Adriaens and others,[34] who studied 30 participants who were smokers for at least 3 years, smoked at least 10 cigarettes a day, had no intention of quitting smoking in the following 3 months and were willing to try several less harmful alternatives. This study showed e-cigarette use over a short time significantly reduced exhaled CO, compared with CCS. These studies suggest that partial or complete substitution of CCS with e-cigarettes reduced the exposure of smokers to hazardous products and improved health.

E-cigarettes have also been reported to promote smoking cessation. In a Malaysian study[35] that included 146 participants who were dual users and 69 who were sole e-cigarette users, 20.5% of previous cigarette smokers who switched to e-cigarettes quit smoking. This study suggests that quitting smoking could be easier if smokers use e-cigarettes only, compared with dual use.

A recent study[36] of 210 smokers randomized to 3 groups (70 to nicotine e-cigarettes, 70 nicotine free placebo e-cigarettes and 70 to a control group) confirmed the efficacy and safety of e-cigarettes over a short period, which led to a high cessation rate. However, the majority of available studies related to the use of e-cigarettes were generated from self-reported perceptions, which may not identify clinical manifestations or modifications that occur in the oral cavity of e-cigarettes users. In addition, reported safety was based on short-term use of e-cigarettes. As such, the effects of the various chemicals in e-cigarettes, and their variable levels, on the oral cavity are still not known.

Concerns Regarding E-Cigarette Use

Concerns regarding e-cigarettes pertain to the battery, PG, VG, the flavours and the availability of high concentrations of nicotine. The literature includes clinical cases of e-cigarette explosions and fire causing damage to users; however, none have been reported in Canada.[37-39] These incidents may be a result of mishandling devices or batteries or use of unregulated "mechanical mod" devices that can result in battery failure. The nicotine carrier solvents in vaping solutions may also be of concern and may have adverse effects for e-cigarette users.

Some flavours used in e-cigarette liquids have been reported to be toxic. Clapp and Jaspers[40] suggested that e-cigarette users, with an estimated consumption rate of 3 mL of e-cigarette liquid a day, would be exposed to a level of diacetyl exceeding the 5 parts per billion limit established by the National Institute for Occupational Safety and Health and the Centers for Disease Control and Prevention (CDC).

The adverse effect of diacetyl-rich e-cigarette liquid has also been confirmed by in vitro studies. Bronchial epithelial cells exposed to vaped flavoured liquids showed cell toxicity that was dependent on the level of diacetyl in the liquid.[41] Diacetyl is not the only e-cigarette chemical raising health concerns, as benzaldehyde has also been shown to be potentially harmful.[42]

In addition, the presence of flavour in nicotine rich liquid may alter nicotine's pharmacokinetics and user behaviour. Indeed, in a study involving young adult e-cigarette smokers, subjective reward value was reportedly higher with flavoured nicotine rich e-cigarettes versus unflavoured products. Participants were found to work harder for puffs of flavoured e-cigarette than unflavoured ones. Furthermore, the participants took twice as many flavoured e-cigarette puffs than unflavoured ones. The authors concluded that flavouring enhanced the standard nicotine reward, leading to potential abuse in young adult smokers.[43]

E-cigarette safety and harm is still a matter of debate. In the United Kingdom, e-cigarettes are regulated for safety and quality. They are considered safe, because they do not produce tar or carbon monoxide as CCS does. However, the regulation still warns that e-cigarettes are not risk free.[44] The CDC recently warned of possible health impairment from e-cigarettes because of an association with mysterious lung diseases among certain e-cigarette users.[45]

E-Cigarettes May Promote Periodontal Disease: In a clinical study46 involving 3 groups (33 cigarette smokers, 31 e-cigarette users and 30 never-smokers), full-mouth plaque index and a probing depth > 4 mm were significantly higher among combustible cigarette smokers, followed by e-cigarette users, compared with non-smokers. Gingival pain was also reported more often by combustible cigarette smokers than by e-cigarettes users. However, although periodontal inflammation and self-perceived oral symptoms were

higher with CCS, e-cigarettes also contributed to adverse periodontal health for their users.

These clinical studies suggest close e-cigarette/oral periodontium interactions, which may lead to poor oral health (**Table 1**). Further studies are needed to validate these observations and determine the leading causes of these e-cigarette adverse effects, as well as the mechanisms involved in the periodontal damage. Future studies should answer the question: to what extent are e-cigarette–oral periodontium interactions associated with periodontal disease?

E-Cigarettes May Promote Dental Caries: PG and VG give e-cigarette liquids their high viscosity. As a result, aerosols from these liquids are likely to adhere to exposed surfaces, such as the soft and hard tissues in the oral cavity, as well as dental implants. This interaction may, in turn, facilitate bacterial adhesion leading to oral infections, such as caries (**Table 1**). In addition, dental caries can be promoted by added flavours supplemented with sugars.[58] Sucrose, sucralose and sugar alcohol are known additives to e-cigarette liquids that enhance taste and fragrance.[59,60]

A recent study[58] showed that e-cigarette aerosols increased the adhesion of *Streptococcus mutans* to enamel and promoted biofilm formation. Indeed, enamel exposed to flavoured e-cigarette aerosols showed decreased hardness, compared with that exposed to unflavoured controls. This bacteria-initiated enamel demineralization was associated with high levels of esters (ethyl butyrate, hexyl acetate and triacetin) found in e-cigarette liquids. Because commercial e-cigarette liquids contain several additives at various levels, including sucrose, sugar substitutes and acids, interactions with teeth could vary from one liquid to another.[59,61]

Table 1. *Potential adverse effects on the oral cavity attributed to the use of e-cigarettes.*

Area of Effect	*Impact*	*Reference(s)*
General Oral Health	Poor Oral Health	47
	Increased gingival bleeding	48
	Increase in dry mouth/ irritated mouth	49, 50
	Gingival ulcers	51
	Increase in inflammation/ pro-inflammatory cytokines	52, 53
Periodontal disease	Increased gingival bleeding and periodontal pockets	53–55
	Increased plaque index	54, 56
Caries	Oral microbiome changes	57
	Tooth infection	58
Tooth structure	Increased incidence of cracked or broken teeth	48

Additional studies are warranted to inform both users and dental professionals on the prevention of e-cigarette-induced caries. Indeed, a specific research question would be: what is the extent to which e-cigarette aerosols increase dental caries incidence among users?

E-Cigarettes May Have Adverse Effects on Teeth and Tooth-Supporting Tissue: With e-cigarette use, the aerosol comes into direct contact with the teeth and may negatively affect tooth structure. Cho[48] examined the association between e-cigarette use and several oral symptoms among adolescents and revealed a significantly increased risk of damage to the teeth with vaping (**Table 1**). Indeed, 11.4% of those using e-cigarettes self-reported a cracked or broken tooth in the last 12 months, 18.5% reported having experienced gingival pain and/or bleeding and 11.0% reported tongue pain, with and without inside cheek pain.

These observations are supported by an *in vitro* study[62] conducted with bovine enamel specimens exposed to aerosols from e-cigarettes, using various liquid flavours (neutral, menthol and tobacco) and nicotine content (0, 12, and 18 mg). The study demonstrated that aerosols with various nicotine contents and flavours altered enamel colour and reduced luminosity; flavoured liquids caused greater colour change.

These findings suggest that e-cigarettes have negative effects on tooth structure and esthetics. Additional *in vivo* research is needed to validate such observations and to answer the question: to what extent does smoking e-cigarettes affect the structure of teeth and their supporting tissues?

Effect of E-Cigarettes on Dry Mouth and Other Forms of Irritation: In a study[63] based on reports by e-cigarette users for the last 30 days and with reported 30-day e-cigarette use, it was shown that those who spent more on e-cigarettes were more likely to report chest pain (9.9%), to notice blood when brushing their teeth (17.1%), to have sores or ulcers in their mouth (8.3%), and to have more than one cold (6.8%), than those with no spending on e-cigarettes. These data support another study[51] in which e-cigarettes users reported sensitive teeth, mouth ulcers, headaches and cold symptoms. In a prospective proof-of-concept study[64] monitoring modifications in the behaviour of smokers who switched to e-cigarettes, the most frequently reported adverse events were throat/mouth irritation (35.6%), dry throat/mouth (28.9%), headache (26.7%) and dry cough (22.2%). These findings suggest that e-cigarettes may have negative effects on oral health by increasing mouth irritation, dry mouth and ulceration.

Further studies are required to validate these observations and to answer the question: what is the extent to which e-cigarette smoking is associated with dry mouth and other forms of irritation: among those who switch from CCS to e-cigarettes and among e-cigarette users who never engage in CCS?

Conclusions

Smoking is a global public health issue. Tobacco smoking is responsible for local and general health problems, which can be prevented by cessation. Although complete smoking cessation is the best outcome, the powerful addictive properties of nicotine represent an enormous obstacle, even for those with a strong desire to quit smoking.

Various nicotine replacement strategies have been developed, including e-cigarettes. Several self-reported and randomized studies suggest that e-cigarettes are a harm-reduction strategy that may improve the oral and general health of smokers and may contribute to smoking cessation. However, additional long-term clinical and user-based studies are needed to validate these observations. It is also important to note that a harm-reduction strategy is irrelevant for e-cigarettes users who never engage in CCS. For the latter population, evidence of the adverse effects of e-cigarettes on oral health is needed to inform policy, programs and practices.

Recommendations and Knowledge Gaps

Based on the available literature, it is possible to recommend the use of e-cigarettes as a temporary alternative for harm reduction and as an aid to smoking cessation. For those who have never engaged in CCS, but use e-cigarettes, oral health professionals may need to explain to these patients and their parents that the use of e-cigarettes is not harmless. To advise their patients appropriately, oral health professionals are encouraged to learn more about e-cigarette constituents and their possible effects on oral health.

Oral health professionals may need to document observed modifications in the oral cavity of their patients, such as saliva thickening, unusual oral ulcers and the frequency of caries. It could be useful to record associated e-cigarette use, type of liquid used, flavours preferred and nicotine concentration.

Overall, although available studies suggest that e-cigarettes are safer than combustible cigarettes, they may not be as safe as believed, as most of these studies are based on self-reported perceptions. More evidence is needed to better understand the safety of e-cigarette use or the harm they cause in the short and long term.

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