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REVIEW

The impact of vaping on ocular health: a literature review

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Abstract

Purpose Vaping, or the use of electronic cigarettes, was initially introduced as a step toward smoking cessation, but has become an increasingly popular option for smokers. Though advertised as safer than conventional cigarettes, these devices have been found to contain carcinogenic chemicals, air pollutants, and heavy metals. The purpose of this article is to shed light on the known effects of vaping on the ocular setting and raise the discussion about additional potential effects that may call for further investigation.

Methods A comprehensive literature search was conducted for publications pertaining to the effects of vaping on the eye. Relevant studies and findings were summarized in this article.

Results It was found that aldehydes and free radicals present in electronic cigarettes may induce a disturbance in tear film stability, and vape flavorings may damage the lipid layer through peroxidation. Corneal staining has been shown to appear following exposure to e-cigarette vapor, with nicotine and acrolein potentially inducing an inflammatory response in corneal epithelial cells. In addition, nicotine has been shown to induce nystagmus, exert vasoconstrictive effects on ocular blood flow, and may interfere with retinal light-adapted vision. Vape-related explosions, though unpredictable, may also result in decreased visual acuity along with long-term ocular trauma.

Conclusion Research discussing both the short-term and long-term effects of vaping on the eye is limited. However, the potential harms of substances such as nicotine and aldehydes warrant additional investigation and increased education about the detriment that electronic cigarettes may inflict on sensitive organs.

Keywords Smoking · Vaping · Electronic cigarette · Nicotine · Ocular health

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Background

The electronic cigarette, first introduced to the global market in 2004, was designed to be a healthier alternative to conventional tobacco cigarettes and a step toward smoking cessation [1]. However, current trends suggest that electronic cigarettes may instead be perpetuating the normalization of smoking. The use of these devices, more commonly known as vaping, has become increasingly popular, growing from 7 million users to over 41 million users across the globe from 2011 to 2018 [2]. These battery-operated, compact cigarettes deliver nicotine through the heating and evaporation of a nicotine-containing e-liquid, granting individuals control over the flavor additives, temperature, and voltage. Their ease of use, the option for customization, and the access to a plethora of creative flavors have rendered electronic cigarettes appealing not only to adults, but also to youth. In fact, in the USA, younger generations are more likely to use electronic cigarettes than adults, with 10.5% of middle-school students, and 27.5% of high-school students, for a total of five million students, reported having vaped within the previous 30 days in 2019 [3]. These numbers continue to rise due to the attractive and robust advertising efforts of this multi-billion-dollar industry.

Given the multitude of health effects that traditional cigarettes have, a strong emphasis on investigating the deleterious health effects of electronic cigarettes has been a focus in recent times. Interestingly enough, the Flavor Extracts Manufacturers Association (FEMA) has approved flavors for electronic cigarettes for ingestion, but no parameters for their inhalation have been established [4, 5]. While it is true that there are significantly fewer toxins in electronic cigarettes as compared to traditional cigarettes, these devices have been found to contain carcinogenic chemicals, air pollutants, and heavy metals. One carcinogen that is produced through exhalation is secondhand aerosol (SHA). The US Department of Health and Human Services has found SHA to contain micro-particulate matter and volatile organic compounds, which can present health concerns for bystanders [6]. In addition, lung pathology, burn injuries, and respiratory illnesses have all been associated with the use of electronic cigarettes [7]. These adverse health effects and a growing youth clientele for these devices have launched initiatives to better understand the various impacts that vaping may have on sensitive organ systems, including the eye.

Tobacco cigarette smoking has long been associated with ocular conditions such as cataracts, diabetic retinopathy, macular degeneration, inflammation, and dry eye disease, amongst others [8]. Smoke has also been shown to cause instability in the tear film, to affect tear protein components, and to reduce goblet cell density [9–11]. However, there has been limited investigation into the potential effects of electronic cigarette use on the ocular setting, and to date, there have been only two published studies investigating the effects of vaping on the ocular surface. Given that individuals who vape tend to be younger, identifying ocular conditions associated with vaping may prove useful in identifying the possible long-term consequences of vaping to the eyes and visual acuity. This is especially important with regard to people who wear contact lenses or who may be interested in undergoing refractive surgery. This literature review compiles the most recent studies performed regarding implications on ocular health caused by electronic cigarette use, hopefully encouraging further investigation into both the short-term and long-term consequences of vaping on the eye (Fig. 1).

Methodology

Review of literature on ocular conditions associated with vaping

A literature search was conducted through PubMed, Harvard University Library Resources, Medscape, Countway Library of Medicine, JSTOR, and WorldCat databases to search for ophthalmic literature relevant to the use of electronic cigarettes. The 2020 World Health Organization, the 2019 Center for Disease Control (CDC), and the 2019 Food and Drug Administration (FDA) statistical reports for the use of electronic cigarettes in the USA were referenced.

Search parameters were set to include: “Electronic Cigarette Ocular,” “Electronic Cigarette Eyes,” “Electronic Cigarette Cornea,” “Vaping Ocular,” “Vaping Cornea,” “Electronic Smoking Ocular Effects,” “Vaping Ocular Effects,” “Electronic Smoking Ocular,” “Electronic Cigarette Dry Eye,” “Vaping Dry Eye,” “Vaping Eye Irritation,” “Electronic Cigarette Eye Irritation,” “Smoking Ocular,”

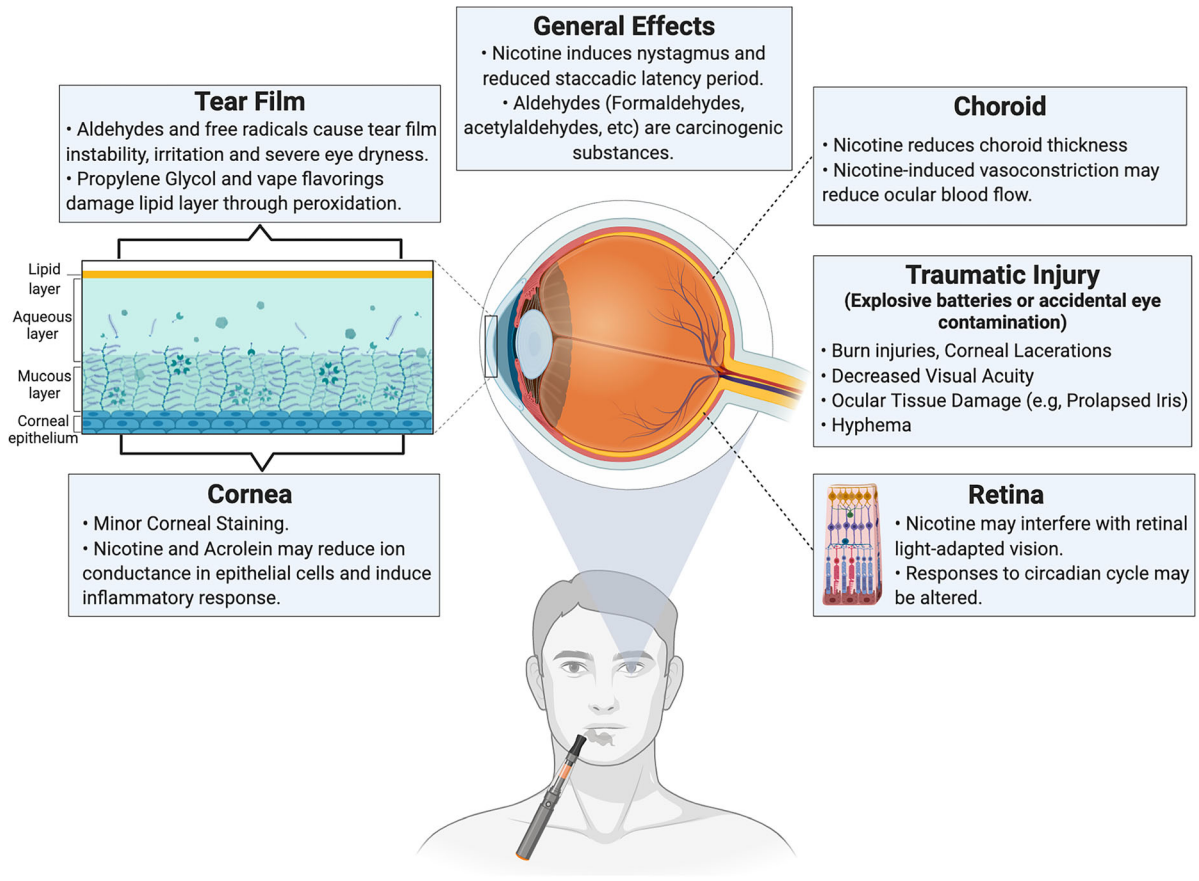

Fig. 1 Effects of vaping on the eye

"Smoking Eye Conditions," "Smoking Eye Irritation," "Smoking Cornea," "Smoking Tear Film," "Vaping Tear Film," "Electronic Cigarette Tear Film," "Electronic Cigarette Use Statistics," "Vaping Statistics," "US Vaping Statistics," "Youth Vaping," "US Youth Electronic Cigarettes," "Electronic Cigarette Market," "Vaping Trauma Eyes," "Electronic Cigarette Combustion Eyes," "Vaping Advertising," "Nicotine Ocular Effects," "Nicotine Retina," "Nicotinic Receptor Antagonist Ocular," "Dopamine Retina Function," "Dopamine Overexpression Ocular," "Nystagmus Nicotine," "Nicotine Eye Effects."

Resultant articles spanned the years 1950 to 2020. Out of 3,168 articles discussing the effects of smoking on the eye, 38 were thereby cited in our article following our exclusion criteria.

Inclusion and exclusion criteria

Our research methodology was predominantly secondary data analysis. We initially included 3168 papers relevant to ophthalmic effects of smoking, both tobacco and electronic. We used the research surrounding the harms of tobacco cigarettes as background material and as a general comparison to the harms of electronic cigarettes, but narrowed our scope to focus solely on electronic cigarettes. A flowchart of our inclusion/exclusion criteria can be found in Fig. 2. Of the 3168 papers originally included, 63 papers studied the effects of electronic cigarette toxins on different parts of the eye; we excluded papers irrelevant to smoking or toxins inside electronic cigarettes and papers that discussed smoking but did not illustrate its effects on the components of the eye. Of these 63 papers regarding electronic cigarettes, 39 papers were excluded due to either a lack of specificity

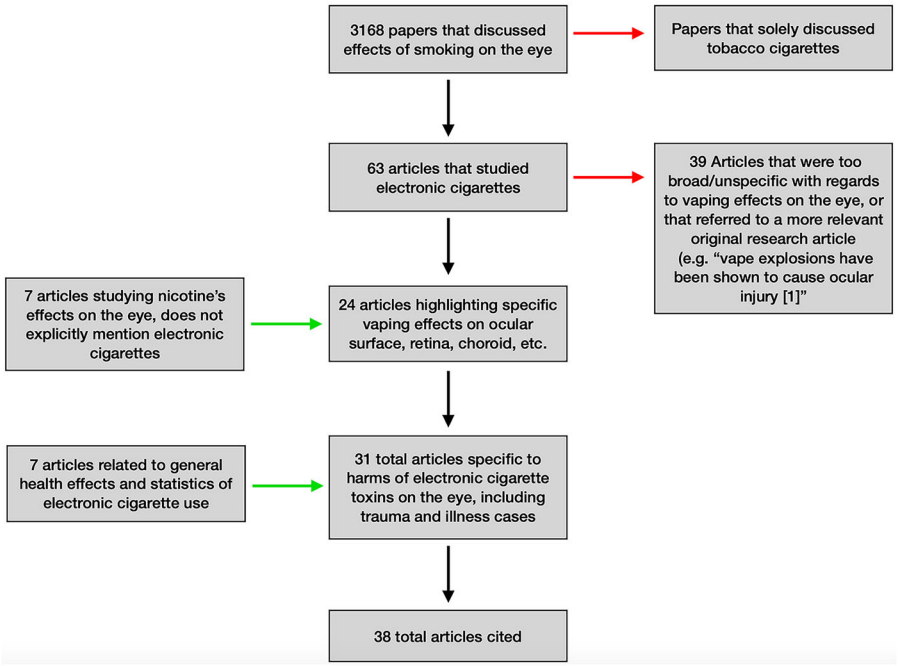

Fig. 2 Inclusion/exclusion criteria flowchart

of discussed effects, or because these articles cited original research articles that we found to be more relevant and detailed. Of the 24 remaining papers, 10 of them provided a strong discussion of the potential harmful effects of vaping on the ocular surface, specifically of the tear film and cornea. The other 14 papers included the effects of vaping beyond the ocular surface, including the retina and choroid, as well as more general effects of vaping on the eye, such as cases of ocular trauma caused by electronic cigarette use, as well as case reports of illnesses caused by exposure to electronic cigarette vapor. As there had been ample research exploring the effects of isolated nicotine on retinal and choroid function, we focused primarily on the potential effects that nicotine in electronic cigarette vapor may have on those functions, of which we cited seven additional papers. In addition to these 31 papers relevant to the specific effects of electronic cigarette toxins on ocular health, we cited seven articles surrounding general health effects and published statistics of electronic cigarette use, for a total of 38 cited articles. Though electronic cigarettes may present as a safer alternative to classical cigarettes, our aim was to highlight the dangers that vaping specifically poses to ocular health, as well as the lack of publications investigating these dangers.

Effects of vaping on the eyes

As vaping has been shown to affect various parts of the eye, we have written separate descriptions for each relevant anatomical component.

Tear film

Dry eye has long been associated with traditional smoking and has also recently been reported in users of electronic cigarettes as well. [12] A recent clinical study demonstrated that following the use of electronic cigarettes, vapers experienced "moderate-to-severe eye dryness" as well as a disturbance in tear film stability, as reflected by the reduction in tear breakup times and tear meniscus height [12]. In fact, the severity of dry eye displayed a correlation with vaping voltage, with higher voltages further aggravating dry eye symptoms. It has also been found that toxins found in electronic cigarettes, such as formaldehyde, acrolein, acetaldehyde, and free radicals, are released at higher concentrations with increased

voltage and temperature [13–19]. Exposure to toxic substances, namely free radicals and aldehydes, in electronic cigarette liquid or vapor, may be the cause for dry eye and tear film instability, as these toxins damage the lipid layer in the tear film via lipid peroxidation [20]. The production of free radicals, which are linked to both protein and lipid oxidation, are associated with the amounts of propylene glycol content and glycerin in electronic cigarette liquid. Thus, it is proposed that different flavoring agents in the vape fluid may have differing effects on the lipid layer of the tear film: flavors containing ethyl maltol (e.g., raspberry, watermelon, French vanilla) and linalool (e.g., spearmint and rainbow candy) may promote free radical production, while flavors containing ethyl vanillin (e.g., hazelnut) may inhibit free radical production [21]. Md Isa also noted that tear production, as determined by a Schirmer's reflex test, was higher among vapers than among nonsmokers, suggesting that either vapers may be compensating for jeopardized tear film integrity through increased tear production or that ocular irritation may be causing increased tear production [12].

However, a 2019 study of the effects of vaping on the ocular surface performed by Munsamy et al. negated the claim that glycol in electronic cigarettes causes dry eye, attributing discrepancies in results to the different methods of measurements in past studies [22]. They used noninvasive keratograph tear break up time (NIKBUT), rather than tear break up time to determine tear film stability following vaping. Furthermore, sample populations differed in total number and gender distribution: Munsamy et al. had a sample size of 64 vapers, consisting of both males and females with a mean age of 21 years, whereas Md Isa et al. had a sample size of 21 vapers and 21 nonsmokers in the control group, all male with a mean age of 22.7 ± 2 years [12, 22]. Distinct sample sizes, diversity among participants, and specific methodologies could all be contributing factors to these differing findings.

Cornea

While it has been found that traditional tobacco smoking may cause reduced corneal sensitivity, as well as a delay in corneal wound healing, discrepancies still exist among the effects that electronic smoking may have on the cornea. From their study, Munsamy et al. concluded that exposure to vapor from electronic cigarettes has no significant effect on corneal epithelial thickness and precorneal tear film. This evidence seems to suggest that tobacco cigarette smoke may have more detrimental effects on the ocular surface than electronic cigarette vapor [22].

On the other hand, when Md Isa et al. measured the grading of corneal staining in both vapers and nonsmokers following vaping, utilizing the National Eye Institute grading system, they noted that there were minor traces of corneal staining of the lowest degree in ten vapers and four nonsmokers [12]. Among the vapers, the corneal staining was identified inferiorly, with six of these vapers having bilateral corneal staining. Nonsmokers had corneal staining in various locations, possibly indicating that smoking may induce an inferior corneal staining pattern [22]. Their findings contrast those of Munsamy et al.

In addition, there is evidence to support that the use of electronic cigarettes may present danger to corneal epithelial cells. Vaping has been shown to jeopardize epithelial integrity in the lungs, as lung epithelial cells have been shown to undergo oxidative stress and release inflammatory cytokines in response to electronic cigarette vapor exposure [23, 24]. Lung epithelial cell proliferation and viability are also affected by flavored electronic cigarette liquids, with all flavors causing cytotoxicity of varying degrees [25]. E-cigarette vapor, unlike tobacco cigarette smoke, has been shown to affect ion conductance, reducing epithelial sodium channel activity in bronchial cells and eliciting an increase in cytoplasmic Calcium (Ca^{2+}) levels, the latter of which is caused by nicotine [26]. Both nicotine and acrolein, substances present in most e-cigarettes, may be responsible for affecting epithelial ion channels, as they induce damage through the formation of DNA adducts [27].

Choroid

Nicotine in electronic cigarettes may not only affect the ocular surface, but may alter ocular vasculature as well. Ocular blood flow has been demonstrated to be altered following the oral intake of nicotine, as signified by the significant decrease in choroidal thickness; there is strong evidence to suggest that choroidal thickness reflects the choroidal blood flow. This decrease in blood flow may potentially result from the vasoconstrictive effects of nicotine [28]. The

inhalation of nicotine through electronic cigarette vapor may exert similar effects on ocular blood flow and choroidal thickness.

Retina

There is increasing evidence to suggest that the nicotine present in electronic cigarettes may also adversely affect retinal function. In a study of the effects of isolated nicotine on the retina conducted by Varghese et al., nicotine was also shown to alter response properties in the retina through interactions with nicotinic acetylcholine receptors (nAChRs) [29]. NAChRs have been found in the inner plexiform layer in humans and on amacrine cells in various species, and it has been shown that the application of nicotine, a nicotinic agonist, onto amacrine cells indirectly induces the release of dopamine in the rabbit retina [30]. A proposed mechanism by which this occurs is as follows: nicotine may increase glutamate release from cone bipolar terminals, which in turn stimulates the release of γ-aminobutyric acid (GABA) from second-order neurons, leading to dopamine release [29]. In humans, dopamine modulates photoreceptor coupling and light-adapted vision in the retina, and its release normally follows a circadian rhythm regulated by light exposure; thus, nicotine-induced overexpression of dopamine may interfere with the ability of the retina to properly respond to the normal circadian cycle in a human [31].

General effects

Nicotine present in electronic cigarettes has also been shown to induce nystagmus, dizziness, and nausea in smokers through causing an imbalance of the vestibulo-ocular reflex; [32] it was found that the extent of nystagmus correlates with nicotine dosage [33]. In addition, ocular saccadic latency periods have been shown to decrease with increasing daily nicotine consumption [34].

While significant short-term impairment may not be induced through vapor, in cases of explosions, foreign bodies and flying debris may coat or even penetrate the ocular surface, causing severe corneal lacerations, ocular tissue damage, and ocular chemical burns. In a notable case, a patient suffered bilateral corneal burns due to an e-cigarette explosion, resulting in hyphema, prolapsed iris tissue, and a unilateral corneal laceration [35]. Vape explosions may result in decreased visual acuity along with long-term ocular trauma. In rare cases, eye irritation and corneal staining have also been found to result from accidental utilization of electronic cigarette liquid as eye drops due to the similarity in bottle shape and size [36, 37].

As previously noted, electronic cigarettes contain carcinogenic substances, with evidence indicating that they may cause eye cancer. A recently published case report described a patient with a history of long-term electronic cigarette use presenting with cancerous conjunctival intraepithelial neoplasia. The patient, in his early 20s, had reported vaping more than five times each day for five continuous years, but denied any traditional cigarette smoking. The authors suggested that the squamous neoplasia in the patient could likely be related to his chronic exposure to electronic cigarette vapor and advised that patients who present with squamous neoplasia should be assessed for a history of electronic cigarette use. [38]

Discussion and avenues for future investigation

Studies investigating links between ocular conditions and vaping are few, but nonetheless provide evidence that vaping may induce dry eye, reduce tear film stability, or reduce ocular blood flow, among other effects. These effects, along with tissue damage sustained from electronic cigarette explosions, present both short-term and long-term health risks that may impair visual acuity and may interfere with proper visual correction in the future, such as the wearing of contact lenses or undergoing LASIK. Further investigation into the effects that electronic cigarettes have on the eyes is of utmost importance, especially as there remains substantial uncertainty around the potential harms.

The two studies referenced in this article focused on short-term, immediate effects of vaping on the ocular surface; however, investigation into long-term ocular effects of vaping has yet to be conducted. The discrepancies between the results of the two publications with regard to vaping-induced dry eye warrant further investigation with larger sample sizes, including both male and female vapers with a broader age range. Conducting studies that follow adult vapers might also yield useful findings, as the studies now largely focus on young people.

While there has been no statistically significant evidence for the identification of major detrimental effects of vaping on the cornea, the finding that inferior corneal staining, although low-grade, presented in smokers following vaping calls for specific investigation into corneal staining patterns and the long-term severity of vaping-induced corneal staining.

Additional research regarding the inflammatory response of tear film components may provide an in-depth understanding of the mechanisms by which the toxic compounds present in vapor cause harm in the ocular setting. Furthermore, the short-term and long-term effects of nicotine on epithelial cell viability should be studied, as the ion conductance and inflammatory response in corneal epithelial cells may be affected in similar ways following vaping as in lung epithelial cells. In addition, a deeper investigation into the effects of nicotine on retinal light-adapted vision in human beings may present valuable findings with relevant implications for long-term visual acuity, vision disorders, and corrective procedures.

Conclusion

While electronic cigarettes may theoretically be a safer alternative to cigarettes, the current literature suggests that electronic cigarettes may pose a real threat to ocular health, and utmost caution in its use is advised. Because a vast percentage of the consumer population of vape devices comprise youth, the ocular issues described in these studies are especially pertinent to them. As ongoing research on this topic continues to expand and present new findings, a current course of action is increased education about the detriment that electronic cigarettes may inflict on sensitive organs and systems, including the eye, through e-liquid toxicity and battery explosions. Proper education of these risks may encourage smoking cessation, in turn promoting enduring ocular health.

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Declarations

Conflict of interest No authors have a conflict of interest related to this work.

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