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RESEARCH ARTICLE OPEN ACCESS

Comparative Assessment of Oral Health Findings Among E-Cigarette Users, Conventional Smokers, and Non-Smokers in Makkah City: A Cross-sectional Study

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Abstract:

Introduction: The rising popularity of electronic cigarettes (e-cigarettes) in Saudi Arabia has prompted concerns regarding their impact on oral health. This study compared oral health parameters among e-cigarette users, conventional smokers, and non-smokers.

Materials and Methods: A cross-sectional study was conducted on 90 participants at Umm Al-Qura University Dental Hospital, divided equally into three groups. Clinical assessments included salivary flow rate (SFR), decayed, missing, filled teeth (DMFT) index, plaque index, salivary potential of hydrogen (pH), gingival pigmentation, and gingivitis. Dry mouth and symptoms were assessed *via* validated questionnaires. (ANOVA) and Chi-square tests were applied ($p < 0.05$).

Results: E-cigarette users showed significantly lower SFR compared to non-smokers ($p < 0.01$; Cohen's d = 0.784) and a higher prevalence of gingivitis and dry mouth ($p < 0.01$). No significant differences were found in DMFT, plaque levels, pH, or gingival pigmentation. Most e-cigarette users perceived e-cigarettes as less harmful and more effective for smoking cessation.

Conclusion: E-cigarette use may negatively impact oral health by reducing salivary flow and consequently increasing the risk of gingivitis and dry mouth. These findings highlight the need for public health education and underscore the importance of further longitudinal and biochemical studies to clarify the long-term effects of e-cigarette use on oral health.

Keywords: Electronic cigarettes, Dry mouth, Smoking, Gingivitis, Vaping, Salivary flow rate.

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1. INTRODUCTION

E-cigarettes are battery-operated devices that vaporize a liquid solution typically containing nicotine, flavorings, and various chemicals for inhalation. Since their introduction in 2004, e-cigarettes have evolved considerably and have gained increasing popularity, particularly among younger populations [1, 2]. In the United States, about 20% of high school students and 5% of middle school students were reported to be using e-cigarettes in 2020 [3]. Similarly, in Saudi Arabia, e-cigarette use has been rising, especially among young adults, including those with a history of conventional cigarette smoking, although national data remain limited and aspects like attitudes, risks, and usage behaviors are still not well understood [4]. This trend is partly fueled by aggressive marketing campaigns promoting e-cigarettes as safer alternatives and smoking cessation tools, a concept first introduced by Chinese pharmacist Hon Lik [5].

While e-cigarettes are often considered less harmful than traditional tobacco products, their effects on oral health remain underexplored. Existing literature links e-cigarette use to oral health issues such as mucosal lesions, microbiome disruption, dental caries, and periodontal disease. Although nicotine may initially increase SFR, long-term exposure can damage salivary gland tissue, resulting in decreased SFR and xerostomia. Additionally, e-cigarette aerosols may cause inflammation in periodontal tissues and promote colonization by pathogenic bacteria such as *Veillonella* sp. and *Porphyromonas gingivalis*, which are strongly associated with periodontal disease. Laboratory studies suggest e-cigarette aerosols may also reduce enamel hardness and increase microbial adhesion, biofilm formation, and potentially carcinogenic effects [6-10].

Moreover, e-cigarette use has been linked to increased colonization by *Streptococcus mutans*, higher DMFT scores, and greater salivary viscosity and oral pigmentation [11, 12]. Salivary pH is another important indicator, as decreased pH can promote enamel demineralization and elevate the risk of caries [13]. Similarly, gingival pigmentation, commonly associated with conventional tobacco use, may serve as an early visible marker of soft tissue changes due to e-cigarette exposure, though this relationship remains underinvestigated.

Despite these findings, few studies have evaluated the clinical oral health implications of e-cigarette use in Middle Eastern populations. To our knowledge, no previous study has comprehensively assessed oral health parameters among e-cigarette users in Saudi Arabia using a structured clinical protocol. This study aims to fill that gap by comparing e-cigarette users, conventional smokers, and non-smokers in terms of nicotine concentration, caries experience, gingival pigmentation, SFR, salivary pH, and dental plaque, integrating both objective clinical assessments and self-reported questionnaire data.

2. MATERIALS AND METHODS

2.1. Study Design

This cross-sectional study was conducted to evaluate the potential impact of e-cigarette use on oral health. Participants (n = 90) were categorized into three groups: non-smokers (n = 30), exclusive e-cigarette users (n = 30), and exclusive conventional cigarette smokers (n = 30).

2.2. Study Setting and Period

The study was conducted at Umm Al-Qura University Dental Hospital, between 19/07/2024 and 25/12/2024.

2.3. Sample Size and Justification

A convenience sample of 90 participants was selected from the outpatient clinics of Umm Al-Qura University Dental Hospital. The sample size was determined based on previous studies with similar objectives and methodologies, ensuring sufficient power to detect clinically relevant differences. The sample size was determined to provide preliminary insights into the relationship between e-cigarette use and oral health parameters.

2.4. Sample Collection

A convenience sample of 90 participants from Umm Al-Qura University Dental Hospital was selected, comprising both males and females. Individuals under 18 years of age and those who reported any systemic diseases, such as diabetes, autoimmune disorders, or immunosuppressive conditions, were excluded from the study.

2.5. Questionnaire

Data on demographic characteristics, self-reported oral symptoms, smoking habits, nicotine content in e-cigarette liquids, and specifically dry mouth were assessed based on participants' self-reports using a binary yes/no question. All data were collected using validated questionnaires [14-18]. Trained examiners administered the questionnaire to participants in the dental hospital clinics.

The questionnaire used in this study was adapted from the World Health Organization Oral Health Survey – Basic Methods, 5th Edition (2013), a widely recognized and validated tool for assessing oral health status and behaviors in population-based studies [19].

The questionnaire's content validity was ensured by deriving questions from the WHO tool and reviewing them with a panel of oral health experts to confirm their relevance and cultural appropriateness [20].

Face validity was assessed through a pilot study involving 20 participants who provided feedback on clarity and interpretability.

Test-retest reliability was evaluated by administering the questionnaire to the same group after a two-week interval. The resulting Cohen's kappa coefficient was 0.78, indicating substantial agreement, and the full questionnaire, which includes items related to smoking habits, nicotine concentration, self-reported dry mouth, and oral hygiene behaviors, has been submitted as a supplementary file [21].

2.6. Clinical Examination

An inter-class correlation coefficient test was used to assess inter-examiner agreement. Under the supervision of a consultant in periodontics, the examiners underwent calibration on five cases before the study, which were subsequently excluded from the sample. Only inter-examiner reliability was tested through this 5-case calibration process; intra-examiner reliability was not formally assessed, and these five cases were excluded from the sample. Furthermore, the examiners were blinded to the patients' smoking status. Participants were examined across various parameters at the dental clinics of Umm Al-Qura University. They were categorized into three groups: non-smokers, exclusive e-cigarette users, and exclusive conventional smokers.

2.6.1. Caries Assessment

The prevalence of caries was assessed using a DMFT chart [22].

2.6.2. Gum Pigmentation

It was noted as either present or absent [11].

2.6.3. SFR

Stimulated salivary flow was measured by asking participants to chew sugarless gum for five minutes and collect saliva in a calibrated tube. The total volume of saliva collected was then measured in milliliters and divided by five to calculate the flow rate per minute [23].

2.6.4. Saliva pH

It was measured using a saliva-check buffer; the measured pH values were categorized as follows: acidic (<6.8), neutral (6.8–7.4), and alkaline (>7.4) [24].

2.6.5. Dental Plaque Measurement

Plaque levels were assessed using the Silness and Löe Plaque Index (PL.I) on six designated teeth: 16, 12, 24, 36, 32, and 44 [25].

2.6.6. Conventional Smokers

Individuals who reported smoking tobacco products daily or almost daily for a minimum of 6 months [26].

2.6.7. E-cigarette Users

Individuals who reported exclusive use of e-cigarettes for a minimum of 6 months, with no concurrent use of conventional tobacco during this period (2).

2.6.8. Gingivitis

It was diagnosed based on clinical signs of gingival inflammation, including gingival redness and swelling, bleeding on probing (BOP), and no attachment loss or periodontal pocketing [27].

2.7. Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board at Umm Al-Qura University, Faculty of Dental Medicine. The Biomedical Research Ethics Committee has evaluated and examined the above-mentioned research proposal and has found it to be in accordance with the specifications and conditions of the ethics of scientific research. (Approval No. HAPO-02-K-012-2024-02-2006). Informed consent was received from each participant, and those who declined participation were excluded from the study [14-18].

2.8. Statistical Analysis

Mean and 95% confidence intervals were reported for the following variables: DMFT, Plaque Index, and SFR. One-way Analysis of Variance (ANOVA) was used to assess whether there were significant differences between the groups. Tukey's post hoc test was conducted if a significant difference was detected. Counts and percentages were reported for pH and gum pigmentation. Attitudes among non-smokers, conventional smokers, and e-cigarette users were also assessed using counts and percentages. Additionally, we evaluated oral symptoms reported by participants, specifically gingivitis and dry mouth, using counts and percentages. The Chi-square tests were conducted to assess the dependency between categorical variables. A significance level of 0.05 was established for all tests, and analyses were performed using Stata SE 18.

3. RESULTS

This study included 90 subjects; 37 were females, and 53 were males. Table **1** presents data comparing oral findings among non-smokers, smokers, and e-cigarette users. The mean DMFT score for the total sample size was 15.58 (95% CI: 14.15–17.02), with smokers showing the highest mean at 17.13 (95% CI: 14.80–19.46) compared to the other groups; however, the differences were not statistically significant among the groups (p = 0.20). Regarding plaque, the total mean was 1.47 (95% CI: 1.34–1.61), with e-cigarette users having the highest mean (1.57, 95% CI: 1.33–1.80) compared to the other groups, though the difference is not statistically significant (p = 0.62). For the SFR, non-smokers had the highest mean (1.92, 95% CI: 1.78–2.07) compared to the other groups; a statistically significant difference in SFR was observed among groups (p < 0.01). Cohen's d for non-smokers *versus* smokers was about 0.585, suggesting a medium effect size. In contrast, the d value for non-smokers compared to e-cigarette users is approximately 0.784, indicating a large effect size. According to conventional interpretation, a Cohen's d value of 0.2 indicates a small effect, 0.5 a medium effect, and 0.8 or above a large effect. These benchmarks help contextualize the clinical importance of differences between groups.

Regarding pH, a higher percentage of alkaline pH was observed in non-smokers (43.14%) compared to smokers (29.41%), but this difference was not statistically significant (p = 0.08). Similarly, gum pigmentation was present in 40% of the total sample, with no statistically significant difference across groups (p = 0.19).

Table 1. Statistics of oral health variables by smoking status and E-cigarette use.

Variable	Total	Non-Smoker	Smoker	E-Cigarette	*p*-value
-	Mean (95% CI)	-	-	-	-
DMFT Score [α]	15.58 (14.15–17.02)	13.96 (11.82–16.10)	17.13 (14.80–19.46)	15.66 (12.59–18.74)	0.20
-	Mean (95% CI)	-	-	-	-
Plaque Index	1.47 (1.34–1.61)	1.412 (1.17–1.64)	1.453 (1.18–1.72)	1.57 (1.33–1.80)	0.62
-	Mean (95% CI)	-	-	-	-
SFR [β]	1.41 (1.28–1.54)	1.92 (1.78–2.07)	1.37 (1.13–1.60)	0.94 (0.80–1.07)	<0.01**
pH*	n (%)	-	-	-	-
Alkaline	51 (56.67%)	22 (43.14%)	15 (29.41%)	14 (27.45%)	0.08
Acid	39 (43.33%)	8 (20.51%)	15 (38.46%)	16 (41.03%)	-
Gum Pigmentation	n (%)	-	-	-	-
Absent	54 (60.00%)	22 (40.74%)	16 (29.63%)	16 (29.63%)	0.19
Present	36 (40.00%)	8 (22.22%)	14 (38.89%)	14 (38.89%)	-

Note: [α] DMFT: decayed, missing, and filled teeth.
[β] SFR: salivary flow rate milliliter per minute.
*pH: potential of hydrogen.
** $p<0.01$.

Table 2. Attitudes among non-smokers, conventional smokers, and E-cigarette users.

Variable	Non-Smoker		Smoker		E-Cigarette		*p*-value
-	Agree n (%)	Disagree n (%)	Agree n (%)	Disagree n (%)	Agree n (%)	Disagree n (%)	-
Smoking e-cigarettes is less dangerous than smoking conventional cigarettes.	10 (33.33%)	20 (66.67%)	12 (40.00%)	18 (60.00%)	29 (96.67%)	1 (3.33%)	<0.01**
Smoking e-cigarettes is less addictive than smoking conventional cigarettes.	9 (30.00%)	21 (70.00%)	15 (50.00%)	15 (50.00%)	20 (66.67%)	10 (33.33%)	0.02*
Smoking e-cigarettes is an effective means to achieve smoking cessation.	11 (36.67%)	19 (63.33%)	16 (53.33%)	14 (46.67%)	30 (100.00%)	0 (0.00%)	<0.01**

Note: ** $p<0.01$
* $p<0.05$.

Table 3. Gingivitis and dry mouth by smoking status and E-cigarette use.

-	Total	Non-Smoker	Smoker	E-Cigarette	*p*-value
Gingivitis	n	n (%)	n (%)	n (%)	-
No	37	10 (27.03%)	21 (56.76%)	6 (16.22%)	<0.01**
Yes	53	20 (37.74%)	9 (16.98%)	24 (45.28%)	
Dry mouth	-	-	-	-	-
No	70	30 (42.86%)	19 (27.14%)	21 (30.00%)	<0.01**
Yes	20	0	11 (55.00%)	9 (45.00%)	

Note: ** $p<0.01$.

Attitudes of non-smokers, conventional smokers, and e-cigarette users regarding the dangers and addictiveness of e-cigarettes, as well as their effectiveness for smoking cessation, are shown in Table **2**. A significantly higher proportion of e-cigarette users (96.67%) reported that e-cigarettes are less dangerous than conventional cigarettes, compared to 40% of smokers and 33.33% of non-smokers. This difference is statistically significant ($p < 0.01$). In terms of addictiveness, 66.67% of e-cigarette users agree that e-cigarettes are less addictive than conventional cigarettes, while agreement is lower among non-smokers (30%), with a statistically significant difference ($p = 0.02$). Additionally, all e-cigarette users reported that e-cigarettes are an effective smoking cessation method, in contrast to 36.67% of non-smokers. This difference is also statistically significant ($p < 0.01$).

In Table **3**, findings of gingivitis and dry mouth were presented, categorized by smoking status. Out of a total of 90 participants, 53 had gingivitis, with 37.74% being non-

smokers, 16.98% smokers, and 45.28% e-cigarette users. A statistically significant association was found between smoking status and gingivitis ($p < 0.01$). Regarding dry mouth, 20 participants experienced dry mouth, with 0% being non-smokers, 55.00% smokers, and 45.00% e-cigarette users. This difference was statistically significant ($p < 0.01$).

4. DISCUSSION

This study investigated the effects of e-cigarette use on oral health parameters in Makkah City, Saudi Arabia, examining SFR, dental caries, plaque accumulation, salivary pH, and gingival pigmentation. The findings reveal notable patterns that warrant further attention from both researchers and public health professionals [8].

E-cigarette users demonstrated a marked reduction in SFR compared to non-smokers. This aligns with literature suggesting that, while nicotine may initially stimulate salivary glands, chronic exposure leads to glandular dysfunction through inflammatory pathways, resulting in reduced secretion over time. Nicotine's vasoconstrictive and neurotoxic properties likely impair salivary gland activity and tissue perfusion, contributing to xerostomia. A clinical cutoff of <1.0 mL/min is considered indicative of hyposalivation, a condition associated with increased risk of dental caries, mucosal irritation, and periodontal disease. This threshold underscores the clinical relevance of the observed SFR reduction in e-cigarette users. Lower SFR compromises the oral cavity's ability to regulate pH, clear debris, and inhibit microbial overgrowth, thus increasing the risk of dental caries and periodontal disease [8, 28].

Although DMFT scores and plaque accumulation were higher among e-cigarette users, these findings were not statistically significant. Nonetheless, prior research supports the idea that e-cigarette aerosols can facilitate bacterial adhesion and biofilm formation due to the viscosity and chemical composition of e-liquids. Specific agents such as propylene glycol and flavoring compounds may alter the oral microbiota in favor of cariogenic organisms such as *Streptococcus mutans*. Furthermore, evidence suggests that enamel hardness may decrease following prolonged exposure to e-cigarette use, exacerbating susceptibility to decay. However, given the non-significant results in our cohort, these interpretations should be approached cautiously and confirmed through larger longitudinal studies that control for usage duration and frequency [6, 9, 12].

Slight decreases in saliva pH among e-cigarette users were also observed, though they were not statistically significant. Acidification of the oral environment is clinically relevant, as it promotes demineralization and favors acidogenic bacterial species. These changes may be linked to acidic flavor additives in e-liquids or the metabolic byproducts of altered microbial communities. Additionally, increased gingival pigmentation in e-cigarette and tobacco users, while not statistically significant, suggests that prolonged exposure to vaporized chemicals could result in melanin deposition or localized tissue responses [11, 13].

Importantly, the study identified a significant association between e-cigarette use and symptoms of dry mouth and gingivitis. These findings can be attributed to several mechanisms associated with vaping. E-cigarette aerosols contain substances such as nicotine, propylene glycol, and various flavoring agents, which may induce oxidative stress and inflammatory responses in gingival tissues. Additionally, propylene glycol acts as a humectant that can lead to mucosal dehydration, further contributing to xerostomia and gingival irritation [28, 29].

Variations in nicotine concentration and flavoring agents among e-cigarette products may explain differences in oral health outcomes. To the best of our knowledge, no prior study has comprehensively examined how differences in nicotine strength or e-liquid composition affect specific oral health parameters, which may contribute to the variability observed in our findings.

Regarding the lack of statistical significance in some results, it is crucial to consider potential confounding variables that may have influenced the outcomes, such as dietary habits, oral hygiene practices, and the frequency or duration of vaping or smoking among participants. Controlling for these factors in future studies will enhance the reliability of findings.

The perception of e-cigarettes as safer alternatives to tobacco remains prevalent among users. Many respondents cited stress relief, flavor preference, and cost-effectiveness as primary reasons for use. Notably, a substantial portion of participants believed that e-cigarettes are medically approved for smoking cessation, or were uncertain of their health risks. These misconceptions highlight a pressing need for public health interventions. Dental professionals are well-positioned to address these gaps by educating patients on the oral health implications of vaping and dispelling myths about its safety. Tailored communication strategies, including chairside counseling and educational materials, could play a pivotal role in shifting user beliefs and reducing harm [4, 10, 24, 30].

4.1. Study Limitations

When evaluating these findings, several limitations need to be taken into account. First, the cross-sectional design of the study limits the ability to establish causal relationships between e-cigarette use and specific oral health outcomes. Without longitudinal data, it is not possible to conclude whether e-cigarette use leads to or results in changes in oral health outcomes.

Second, the reliance of the study on self-reported data regarding e-cigarette use frequency and oral health symptoms may introduce recall bias, social desirability bias, and incorrect information due to participants misunderstanding or misreporting. These biases can result in significant effects on the validity of the study findings.

Third, the proportionately small and probably homogeneous sample size limits the generalizability of the results to larger populations. Larger and more diverse cohorts are required to reach stronger conclusions about

these findings and guarantee their applicability to different demographic groups.

A fourth limitation is the absence of biochemical validation to determine the actual exposure levels to e-cigarette nicotine. Biomarkers such as Cotinine levels in saliva, plaque, serum, or urine would enable more precise assessments of e-cigarette exposure levels and strengthen the reliability of the findings.

Fifth, the study did not provide an assessment of the minor salivary glands, which have an important role in mucosal health and local immunity. Providing these assessments could clarify the local effects of e-cigarettes on oral tissues. Sixth, the buffering capacity of saliva, which is also an important factor in resisting pH changes and protecting against dental caries, was not tested. The absence of these assessments limits the ability to determine the functional changes in salivary physiology that may be associated with e-cigarette use. Seventh, the study did not assess participants' oral hygiene behaviors such as brushing frequency and flossing, which may act as potential confounding factors influencing oral health outcomes. The lack of this information limits the ability to fully interpret the associations between e-cigarette use and oral health findings.

Future research should adopt longitudinal designs with more extensive and diverse populations to clarify the long-term oral health impacts of e-cigarette use. Moreover, further studies should include clinical and biochemical analysis of saliva and plaque samples to explore the microbiological and inflammatory changes associated with e-cigarette exposure.

CONCLUSION

This cross-sectional study provides preliminary evidence that e-cigarette use was associated with higher rates of gingivitis, reduced salivary flow rate (SFR), and dry mouth symptoms. While these associations were statistically significant, the cross-sectional design limits the ability to infer causality. Healthcare providers should educate patients about the potential oral health implications of e-cigarette use. Future research, including longitudinal and interventional studies, as well as investigations into salivary biochemistry, is recommended to better understand the long-term effects of e-cigarettes on oral health.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: M.T.: Study conception and design; O.A.: Data collection; H.A.: Data curation; R.A.: Analysis and interpretation of results; M.A.: Methodology; A.A., A.A.Q., A.S.: Investigation; D.N.: Writing the paper. All authors reviewed the results and approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the Institutional Review Board at Umm Al-Qura University, Faculty of Dental Medicine. (Approval No. HAPO-02-K-012-2024-02-2006).

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

Informed consent was received from each participant, and those who declined participation were excluded from the study.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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