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Health effects of nicotine products on oral tissues: Prevention approaches

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Abstract. The study aimed to analyse the impact of smoking and modern nicotine release systems on the state of the oral cavity, addressing the stratification of risk factors for the development of dental pathologies, determining the possibility of complications and introducing preventive programmes for dentists to minimise the harmful effects of this habit. PubMed, Scopus, Web of Science, and Google Scholar sources were analysed to conduct the research. E-cigarettes, traditional cigarettes and tobacco heating systems were determined to have a negative impact on the oral cavity, causing risks of leukoplakia, gingivitis and periodontal disease. Smoking traditional cigarettes causes significant destructive changes, including deep periodontal pockets (68%), loss of tissue attachment (42%) and gingival leukoplakia (85.1%). E-cigarettes, although less harmful, cause mucosal irritation, and dysbiosis and increase the risk of periodontal disease by 1.43 times compared to non-smokers. Tobacco heating systems show lower toxicity, but the risk of inflammation and tissue destruction remains. The results show that smoking cessation has a positive impact on dental health. A year after smoking cessation, there was a 1.5 mm reduction in the depth of periodontal pockets and a 1.2 mm improvement in tissue attachment. This confirms the importance of combating addiction for the prevention of dental diseases. Recommendations for physicians include history analysis, recording nicotine use patterns, applying the 5A principle of a patient's tobacco use history, providing cessation information, assessing their readiness to quit, assisting with the cessation process, and providing follow-up support through regular contact. Informing patients about the risks associated with all forms of tobacco and promoting complete cessation should be prioritised. However, if it is not possible to quit smoking, it is necessary to visit the dentist regularly, stop smoking during periodontal disease treatment or dental implants, carefully follow the rules of oral hygiene with the use of rinses and abrasive pastes, and seek professional help in a timely manner. Such measures help reduce the risk of dental pathologies and contribute to the long-term maintenance of oral health

Keywords: periodontitis; squamous cell carcinoma; leukoplakia; caries; smoking; electronic cigarettes

INTRODUCTION

Tobacco smoking remains one of the most popular negative habits. Smoking traditional cigarettes, e-cigarettes and tobacco heating systems negatively impact oral health, which can cause cancer, tooth decay, periodontitis, as well as microbiome and salivary disorders. The spread of alternative ways of consuming nicotine is a cause for concern due to insufficient research on their health effects and potential harm to young people. The research relevance is determined by the need for effective control over new types of tobacco products and raising public awareness of their risks.

According to the World Health Organisation (WHO) [1], tobacco use causes more than 8 million deaths each year, of

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which 1.3 million were attributed to second-hand smoke. Approximately 80% of tobacco users lived in low- and middle-income countries, where the tobacco epidemic was most severe. In 2003, WHO member states adopted the Framework Convention on Tobacco Control, which has become a key instrument in tackling this global problem. In the spring of 2023, the WHO, together with the Ministry of Health of Ukraine and the International Institute of Sociology in Kyiv, conducted a new survey aimed at studying tobacco consumption habits among the adult population of Ukraine [2]. The survey found that the prevalence of smoking and the use of new tobacco products among adults remained almost unchanged. In particular, 27.4% of respondents (44% of men and 13.7% of women) reported use of any tobacco or nicotine products. Of these, 23% are daily users (37.5% of men and 11.1% of women).

A survey conducted by Kyiv International Institute of Sociology [3] revealed a downward trend in tobacco consumption in Ukraine from 32% in 2022 to 27% in 2024. The highest level of consumption is observed among young people aged 18-29. The popularity of heated tobacco products is growing: 45% of young people use them. Most respondents supported anti-tobacco measures, including bans on advertising, visible packaging and flavours, and increased excise taxes, which help to reduce the popularity of traditional cigarettes. The findings confirmed that smoking remains an important issue, especially due to the growing popularity of tobacco heating systems.

The first barrier for tobacco combustion products to reach the lungs is the oral mucosa (OME). According to the American Lung Association, cigarette smoking produces more than 7,000 chemical compounds, 69 of which are classified as carcinogens [4]. These substances are associated with the development of oral diseases, including cancer, which is the eighth leading cause of cancer-related deaths in the world. According to the Centres for Disease Control and Prevention [5], the use of tobacco products, including cigarettes and smokeless tobacco, significantly increases the risk of developing oral diseases. Smoking is associated with higher levels of tooth decay: 40% of smokers aged 20-64 have untreated tooth decay, compared to 20% of those who have never smoked. In the older age group (65 years and older), these figures are even worse: 43% of smokers have completely lost their teeth. Smoking is also a key risk factor for oral and upper respiratory cancers, which underscores the need for medical intervention to combat this problem.

Tobacco combustion products, including aerosols, contain carcinogenic substances that can initiate oxidative stress and damage to epithelial cells, potentially leading to malignant transformation. Abuse of tobacco-containing products is associated with mucosal diseases (MD), such as leukoplakia, keratosis, erythroplakia and nicotinic stomatitis, especially in areas of contact with chewing tobacco or snus. According to G.D.G. Da Silva & T.N. Pinheiro [6], 3-6% of leukoplakias have a high risk of malignancy, which highlights the importance of timely detection of these conditions in smokers or tobacco users.

The association between smoking and periodontal disease was confirmed by numerous clinical and epidemiological studies by G.V. Popa *et al*. [7], which show that tobacco combustion products can affect the clinical manifestations and progression of the disease. The study established that cigarettes are one of the key risk factors for the development and severity of periodontal disease. In the United States, the prevalence of periodontitis is about 40%, and among smokers, the disease is at least 50% more common than among non-smokers. Studies have also shown that smokers show less pronounced improvement in symptoms after non-surgical treatment of periodontitis compared to non-smokers.

The results of the study by A.C. Devlin & P.A. Fee [8] demonstrated that the risk of dental implant failure is significantly increased in patients who smoke. In the group that consumed less than 10 cigarettes per day, the failure rate was higher than in non-smokers ($p = 0.046$; 95% CI: 1-1.64). At the same time, patients who smoked more than 10 cigarettes per day showed an even higher failure rate compared to those who consumed lower doses ($p < 0.001$; 95% CI: 1.31-2.17). These data confirm that an increase in the number of cigarettes smoked directly correlates with an increase in the rate of implant failure. E. Jonas *et al*. [9] found that tobacco smoking is associated with sialolithiasis and changes in the rheological characteristics of saliva. Factors such as the presence of *Streptococcus mutans*, poor oral hygiene and a diet rich in carbohydrates are central to the development of caries. According to a study by M.A. Khan *et al*. [10], smoking is associated with an increase in the number of cariogenic microorganisms, including *S. mutans*. Nicotine disrupts the balance of the oral microflora, creating conditions for colonisation by this pathogen, which, together with a reduced saliva buffering capacity, contributes to caries.

Smokers are at an increased risk of oral diseases. Given the popularity of tobacco heating systems, vapes and tobacco pouches in Ukraine, their impact on dental health needs to be assessed, as they are often considered less harmful, even among dentists. Objective of the study: to assess the impact of smoking on oral health, identify the risks of complications and justify the implementation of anti-smoking programmes to reduce the negative impact of smoking on oral tissues. Tasks of the study: to compare the impact of smoking classic cigarettes and modern tobacco heating systems on the state of the oral cavity; to develop recommendations for dentists to avoid oral diseases among smokers.

MATERIALS AND METHODS

The study was conducted using a theoretical literature review. The comparison of the incidence of oral diseases, such as gingivitis, stomatitis, and leukoplakia, among users of classic cigarettes and modern nicotine systems, was emphasised. The analysis was based on scientific articles, clinical trials, meta-analyses and retrospective reviews available in international databases such as PubMed, Scopus, Web of Science and Google Scholar. The following keywords were used in the literature search: oral diseases, tobacco impact on oral health, electronic cigarettes, tobacco heating systems, keratosis, leukoplakia, caries, periodontitis, periodontal disease, oral cancer, smoking, and smoking prevention.

Following the research topic, 103 scientific papers were selected that reflected the relevance of the problem. The following inclusion criteria were used to ensure the relevance and scientific reliability of the data: by type of study, the list of references included original articles containing

data from clinical, epidemiological or laboratory studies, systematic reviews and meta-analyses, and retrospective and prospective studies. Clear criteria were established for including articles in the review that met the standards of systematic reviews. The period of publication was prioritised: papers published between 2021 and 2024 were included in the analysis. This ensured that the materials were up-to-date and in line with modern scientific approaches. However, articles published before 2020 were included in the analysis if they were of high scientific value if they contained unique data, fundamental findings, or the results of large-scale research that are still relevant.

In addition, the level of evidence was an important criterion: preference was given to randomised controlled trials, meta-analyses and systematic reviews, as well as clinical trials with a high degree of confidence. The type of study population was also considered. The review included studies that analysed the health status of adults or adolescents who used tobacco products or modern nicotine release systems. The criterion of data completeness was also important: only those publications that contained detailed research results, a formed abstract, and were relevant to the research topic were considered. Another important factor was language accessibility. The analysis included papers written in English and Ukrainian, which were used to address relevant and accessible materials for analysis. The relevance of the study was also assessed following the topic: only those publications that covered oral diseases in smokers or users of modern nicotine systems were considered.

The study examined the impact of different ways of consuming nicotine, including classic cigarettes and modern tobacco release systems, on the condition of periodontal tissues, oral mucosa, saliva pH and the intensity of plaque formation. The carcinogenic status of smokers, including the number of carcinogenic microorganisms and changes in the acid-base balance of saliva, which affect the risk of caries and periodontal disease, was studied. Particular attention was devoted to the prediction of the development of re-implantation in patients who consume nicotine in various forms. The effectiveness of individual oral hygiene products, their adaptation to the needs of smokers, and the frequency of informing patients by dentists about the risks of nicotine consumption for oral health and prevention measures were also studied.

RESULTS AND DISCUSSION

The impact of tobacco smoking and heating systems on the occurrence of salivary gland disorders and inflammatory disorders of the oral cavity

Smoking habit is a significant risk factor for periodontal diseases, caries, re-implantation and other pathologies that significantly reduce the quality of life of patients. Smoking not only deteriorates hygiene but also affects the acidity of saliva (pH), changes the microflora and promotes the formation of plaque, which creates the preconditions for the progression of inflammatory processes. Therefore, the study of changes in oral tissues caused by tobacco products is important for the development of effective preventive and therapeutic measures.

Research data confirm the significant impact of smoking on the clinical condition of the oral mucosa and hygiene indicators. For instance, in the group of smokers with more than five years of experience, the mean value of bacterial plaque was 35.68 ± 12.45, which was twice as high as in non-smokers (16.32 ± 6.61) [11]. Plaque in smokers had a mean value of 2.24 ± 1.02, while in the control group, it was 0.94 ± 0.68. The gingival bleeding index was also significantly higher in smokers (42.86 ± 14.93) compared to non-smokers (19.54 ± 7.89) (Table 1). Smoking contributed to the progression of gingivitis and plaque accumulation, creating conditions for the development of periodontitis. Gingivitis, which is an initial reversible inflammation of the gums, became chronic in smokers and was complicated by poor oral hygiene. Thus, monitoring of hygiene among smokers is a mandatory measure to prevent the progression of diseases.

Table 1. Descriptive characteristics for groups of non-smokers and smokers by age categories

Age category (years)	Bacterial plaque (NS, %)	Bacterial plaque (S, %)	Gingival bleeding during probing (NS, %)	Gingival bleeding during probing (S, %)
18-25	8.66	12.02	14.16	16.42
26-35	19.75	14.41	17.35	21
36-45	25.25	21.03	25.09	21
46-55	31.26	29.24	30	37.5
56-65	36.78	36.56	44.16	43.93
>65	43.45	52.14	53.14	52.14

Notes: NS – non-smokers; S – smokers
Source: compiled by the authors based on [11]

Other studies confirm the link between smoking duration and its harmful effects. In adolescents who smoked regularly, there was a high prevalence of inflammatory changes in the periodontium, which correlated with the duration and intensity of the habit ($r = 0.79$ and $r = 0.75$, respectively) [12]. Poor oral hygiene ($r = 0.71$) increased the risk of developing pathologies. Smoking led to a decrease in the elasticity of the mucous membranes, changes in pH and microcirculation, which intensified the destructive processes. A study of the impact of new tobacco devices that heat but do not burn (HNB) on patients' oral cavities revealed a decrease in the impact of biomarkers associated with tobacco harm. Compared to conventional cigarettes, the use of HNB devices reduced levels of 12 major BoEs, including nicotine, by an average of 30-50% ($p < 0.05$). Despite the negative effects, modern alternatives such as HNBs show reduced toxicity, but the risk of inflammatory reactions remains.

Despite the reduction in overall toxic exposure, BoE analysis showed that some biomarkers associated with the

risk of inflammatory reactions in oral tissues remained elevated [13]. Compared to abstinence, HNB 4 users had higher BoEs, which may indicate a risk of chronic mucosal irritation. The results highlighted the need for further independent research to assess the long-term effects of HNB on oral tissues, as the involvement of the tobacco industry in most existing studies limits their objectivity. Comparing HNB to traditional smoking, there is some harm reduction, but abstinence remains the best way to stay healthy.

E-cigarettes also affect the oral cavity. An analysis of the oral cavity of patients who used e-cigarettes revealed changes in the microbiome compared to non-vapers [14]. E-cigarette users showed an increased content of unclassified *Veillonella* species and an increase in alpha diversity among dual users (vaping and regular smoking). Beta diversity also varied depending on the way nicotine products were used. A link was found between the dual use of tobacco products and the presence of pathogenic microbes that may contribute to the progression of periodontal and oral mucosal diseases. Thus, the use of e-cigarettes is not safe and requires careful analysis.

An analysis of the oral health of female smokers revealed significant changes in salivary calcium levels and gingival bleeding index (GBI) compared to non-smokers [15]. In a study of 26 smokers and 37 non-smokers, the mean salivary calcium levels of female smokers were significantly lower than those of non-smokers. At the same time, the average BOP in the smoking group was significantly higher ($p < 0.05$). There was a positive correlation between salivary calcium and BOP among smokers. The longer the duration of smoking, the more the calcium levels decrease and the more the gingival bleeding increases. The overall dietary calcium intake was not statistically different between the groups, but the low salivary calcium levels may have been caused by nicotine, which reduces its concentration. These findings highlighted the importance of preventing smoking among women and educating them about its negative effects on the oral cavity. Comparing these findings with subsequent studies of the effects of alternative nicotine delivery methods, similarities in impairment can be noted, but the mechanisms of change are different.

Significant changes in oral health were observed in young smokers of traditional cigarettes, e-cigarettes and heated tobacco products [16]. The concentration of sphingolipids and ceramides in saliva was reduced in all groups of smokers compared to non-smokers, indicating a lipid imbalance. The levels of malondialdehyde and 4-hydroxynonenal were highest in traditional smokers, indicating increased oxidative stress. E-cigarette and HNB users showed lower levels of these indicators in stimulated saliva. Thus, although the level of oxidative stress is lower in e-users, lipid imbalance and possible oral health consequences remain a common concern for all forms of nicotine consumption.

The study of the impact of heat-treated tobacco products on oral health requires attention due to the growing popularity of these products as an alternative to conventional cigarettes [17]. At the same time, their benefits compared to traditional cigarettes remain controversial due to the lack of long-term studies. A study [17] showed that smokers are still at risk of developing various oral diseases when using HNB products such as IQOS, albeit to a lesser extent compared to traditional smoking. However, research indicates a growing interest in these products among young people and non-smokers, which may help attract new smokers. At the same time, the study observed that IQOS attempts were more popular among younger smokers (25.1%) compared to traditional cigarettes (19.3%) and less so among e-cigarettes (29.1%).

The clinical condition of the oral cavity after exposure to e-cigarettes was characterised by changes that included dry mouth, mucosal irritation and an increased risk of gum disease [18]. There were also changes in the microbiome, which demonstrated a potentially pathogenic orientation compared to the microbiome of non-smokers. *In vitro* studies demonstrated that the effect of e-cigarette components on cells was less pronounced than tobacco smoke but had the potential for long-term tissue changes. Epidemiological data indicated the need for further clinical trials to assess long-term effects. In summary, despite some benefits, e-cigarettes and HNB products share a common risk to oral health that requires preventive measures. These findings are consistent with previous studies of e-cigarettes that also show significant oral health effects, but the difference in mechanisms and potential consequences between different nicotine delivery methods is of interest for further comparative analysis. Prolonged exposure to tobacco led to a significant deterioration in the condition of the oral cavity, manifested in the form of pathologies such as periodontitis, leukoplakia and caries. In patients with long-term tobacco use, an increase in the depth of periodontal pockets was detected in 68% of cases, loss of clinical gingival attachment in 42%, and mucosal leukoplakia in 34% [19]. These pathological changes tended to be localised in the cheeks, gums and tongue, which is consistent with general clinical observations.

An analysis of the state of periodontal tissues of patients after tobacco exposure revealed a significant deterioration in their functional state. Tobacco smoking contributed to the progression of periodontitis, loss of tissue attachment and increased risk of tooth loss. The analysis determined that smoking cessation was accompanied by a gradual decrease in the negative impact on periodontal tissues [20]. After several years of tobacco cessation, the risk of periodontitis decreased, and the effectiveness of non-surgical treatment increased. Positive changes were observed in patients who stopped smoking and received individualised recommendations for prevention and treatment. This confirms the need to focus on smoking cessation programmes as an effective method of reducing the risk of periodontal disease.

Accordingly, the results of smoking cessation programmes indicate a significant potential for improving oral health, even in patients with a history of long-term smoking. The state of the patient's oral cavity after tobacco exposure indicated the progression of periodontal disease, in particular, an increase in the depth of periodontal pockets (PD) and loss of tissue attachment (CAL). Participants in a smoking cessation programme [21] showed a marked improvement in these parameters after 12 months: a 1.5 mm reduction in PD depth and a 1.2 mm improvement in CAL. A reduction in plaque and gingival inflammation was observed, indicating a positive impact of smoking cessation on periodontal health. This emphasises the importance

of smoking cessation for maintaining periodontal tissue health and supporting overall oral health [21].

After using electronic nicotine delivery systems (ENDS), including e-cigarettes and vapes, patients experienced a proliferation of symptoms such as dry mouth, mucosal irritation, ulcers, inflammation, and dysbiosis [22]. Exposure to ENDS was associated with oxidative stress and DNA damage in oral epithelial cells, which was confirmed by *in vitro* studies. Some components of ENDS liquids, including formaldehyde and acetaldehyde, were found to be carcinogenic, increasing the risk of developing oral malignancies. In addition, prolonged use of these devices contributed to changes in the oral microbiome, which could lead to periodontal disease. Cases of oral cancer have been reported in ENDS users without other traditional risk factors, such as tobacco smoking. Despite the absence of traditional risk factors, such as smoking, ENDS use appears to be potentially carcinogenic, suggesting that it is necessary to investigate the long-term effects of ENDS use on oral health.

Thus, tobacco smoking has a significant negative impact on oral health, including bacterial plaque levels and gum bleeding. Smokers have an average plaque level twice as high and a gum bleeding index 20% higher than non-smokers. Statistical analysis confirms that 68% of smokers experience an increase in the depth of periodontal pockets, and 42% have a loss of tissue attachment, which is accompanied by significant risks of gum disease. The use of alternative tobacco products, such as tobacco heating devices, reduces the toxic effects on the oral cavity, but the risk of inflammation remains, which requires additional research and preventive measures. Compared to classic smoking, e-cigarettes cause less tissue irritation and have a less pronounced effect on the depth of periodontal pockets. However, both types of nicotine products contribute to pathogenic changes in the oral microbiome. In addition, the cessation of both classic cigarettes and electronic products demonstrates a significant improvement in oral health parameters: a 1.5 mm reduction in periodontal pocket depth and a 1.2 mm improvement in tissue attachment one year after quitting. This underscores the importance of preventive measures and active anti-addiction efforts to reduce the negative impact of tobacco products.

The impact of tobacco on the occurrence of leukoplakia and oral cancer

An analysis of the clinical condition of the oral mucosa among tobacco users showed a high incidence of potentially malignant diseases [23]. A study involving 4,500 people found that submucosal fibrosis (OSMF), mucositis from chewing tobacco and squamous cell carcinoma (OSCC) were the most observed conditions among people in Group A (chewing tobacco) and Group C (combined chewing and smoking). Group B (smoking only) was dominated by smoker's palate lesions. The prevalence of OSCC and OSMF increased significantly with increasing frequency and duration of tobacco use. Lesions were more common in men, as smoking was not recorded in women in this study. A statistically significant correlation was found between increased tobacco use and the risk of lesions ($p < 0.05$). The findings emphasised the need to inform the population about the harmful effects of tobacco use to prevent mucosal pathologies.

Among the population of Hazaribagh, the impact of tobacco on oral tissues was characterised by a high frequency of mucosal lesions [24]. Among the tobacco users, the most common lesion was tobacco pouch keratosis, followed by OSMF, lichenoid reaction, nicotinic stomatitis or melanosis, leukoplakia, erythroplakia and oral cancer (Table 2). According to the results, most lesions were associated with smokeless tobacco use (74.7%), compared to smoking (25.2%). The findings may provide a basis for preventive measures aimed at reducing the prevalence of tobacco-related oral lesions. These results are consistent with the above data on the significant impact of smokeless tobacco on the mucous membrane, which indicates the need to inform the population about the possible risks.

Table 2. Types of mucosal lesions associated with tobacco habits

Type of lesion	Percentage
Erythroplakia	50%
OSMF	17%
Lichenoid reaction	15%
Proliferative ulcerative changes (carcinoma)	3%
Tobacco keratosis	2%
Hyperkeratosis / smoker's palate	13%

Source: compiled by the authors based on [24]

The clinical condition of the oral cavity after tobacco exposure was manifested in a significant proportion of patients as leukoplakia, which was confirmed histopathologically [25]. Among 5,720 examined patients with oral mucosal diseases in Northern Poland, 416 were diagnosed with leukoplakia. The highest incidence of the disease was observed in the 41-60 age group (46.6%), where 85.1% of patients were active smokers, of whom 86.2% were men. Among women, the highest prevalence of smoking (86.8%) was found in the 21-40 age group. The homogeneous form of leukoplakia was the most common (95%) and was mostly localised on the buccal mucosa. Lesions on the gums, alveolar rims and lower part of the tongue were less common. A statistically significant correlation between tobacco smoking and leukoplakia was confirmed. The results emphasised the importance of early diagnosis of leukoplakia by dentists and the need to eliminate smoking as a key risk factor.

Patients exposed to tobacco had a high incidence of squamous cell carcinoma, including gingival cancer [26]. In 46.9% of patients included in the retrospective study, gingival cancer was diagnosed, while other sites were less commonly affected. The average age of patients with

gingival cancer was 74.2 years, which was significantly higher than the average age of patients with tumours in other sites (63.9 years). Most gingival lesions were observed among men (60%), while the gender ratio in patients with other forms of cancer was more even. Patients who combined tobacco and alcohol use accounted for 26.7% of those with gum cancer, all of whom were men. The data confirmed a significant association between tobacco use and an increased risk of squamous cell carcinoma. The findings emphasised the need for timely diagnosis and implementation of preventive measures for patients with risk factors.

Clinical analysis of the oral tissues of patients exposed to tobacco showed significant changes [27]. In most cases, OSCC was observed, with a higher incidence among men with a history of smoking and among women who used chewing tobacco products. The most common lesions were located on the tongue in women, while in men, cancer was detected in the retromolar region and on the tonsils. The age of diagnosis in women was significantly younger (46 years) than in men (57 years). This indicates a difference in cancer development patterns depending on gender and type of tobacco used, which allows for detailed prevention strategies for different groups of patients.

A clinical analysis by L. Amato *et al*. [28] of the oral cavity of patients who used tobacco products showed significant changes in the tissues. E-cigarette smokers developed localised mucosal lesions, the development of a villous black tongue, and an increased frequency of dry mouth. Allergic reactions, carcinogen formation and an increased risk of developing oral cancer were also observed. Cough, irritation and headache were common complaints. In patients with a long history of smoking, bone resorption increased, and chronic inflammatory processes developed. These observations support the findings of other studies that indicate the need for further research on the long-term effects of e-cigarettes. In summary, the impact of tobacco on the development of leukaemia and oral cancer is significant, particularly in patients who are regular tobacco users. Studies have shown that out of 5,720 patients, 416 were diagnosed with leukoplakia, including 85.1% of smokers, which indicates a close link between smoking and the onset of pathologies. In the group of patients with gum cancer, which was detected in 46.9% of cases, smokers accounted for 60%, which confirms the importance of timely diagnosis and preventive measures for people at high risk.

Periodontal diseases are caused by tobacco or electronic heating systems

A study by R. Nazaryan *et al*. [29] of the clinical state of the oral cavity in patients who used tobacco revealed significant changes in dental health indices. In adolescents with 1-3 years of smoking experience, an increase in the level of inflammatory processes in periodontal tissues was observed according to the papillary-marginal-alveolar index, which reached 36 ± 2.04%. The simplified index of oral hygiene exceeded the value of the control group, indicating a deterioration in the hygienic state. The biophysical properties of oral fluid, such as elasticity and pH, demonstrated a negative effect of tobacco smoke, which contributed to the development of periodontal disease. This suggests that smoking is a major risk factor for gum health, as it changes the oral microenvironment, creating conditions for disease progression.

The effect of tobacco smoke on the health of patients' gums was studied by B. Liu *et al*. [30]. The authors noted that the risk of developing periodontitis was significantly increased. In particular, the incidence of this disease among people exposed to tobacco smoke reached 56.57%. The likelihood of developing periodontitis was almost twice as high in patients exposed to tobacco smoke compared to those who were not (OR 1.96; 95% CI, 1.67-2.31). At the same time, a protective role of adequate zinc intake was found to reduce the risk of periodontitis (OR 0.86; 95% CI, 0.76-0.98). Exposure to tobacco smoke interacted with zinc deficiency, contributing to the progression of the pathology. The antagonistic effect of this interaction emphasised the importance of maintaining optimal zinc levels in the diet to prevent periodontal disease. Optimising the diet to ensure adequate zinc levels and reducing tobacco smoke exposure were considered effective preventive measures to prevent disorders in the oral cavity. These results highlight the importance of maintaining optimal micronutrient levels in the diet to minimise the effects of smoking on periodontal health.

A study by S. Al Kawas *et al*. [31] on the effect of different types of tobacco on the subgingival microbiome and periodontal health showed significant changes in the microflora in smokers. Compared to nonsmokers, cigarette, Medwakh and hookah smokers showed a significant increase in the relative abundance of pathogens such as *Prevotella denticola*, *Treponema*, *Streptococcus mutans*, *Veillonella dispar*, *Streptococcus sanguinis* and *Tannerella forsythia*. This was associated with an increased risk of developing periodontal disease, even in the absence of clinical manifestations or in mild disease. Among 40 patients in a dental clinic in the United Arab Emirates, subgingival plaques were analysed using Oxford Nanopore sequencing technology. The results indicated a pronounced microbiome dysbiosis that contributes to the progression of periodontitis. The detected microbiological changes can be used as a prognostic marker to assess the risk of developing severe periodontal disease among smokers. This emphasises the importance of further studying the effects of smoking cessation to stabilise the microbiome and prevent periodontal disease. Changes in the microbiota show how smoking, even without severe symptoms, can lead to oral pathologies.

The clinical condition of the oral cavity of patients after tobacco exposure was characterised by significant changes in tissues due to the toxic effects of tobacco smoke components, when using tobacco heating systems such as IQOS [32]. Patients showed signs of periodontal inflammation, deterioration of the mucous membrane and reduced elasticity, as well as changes in saliva pH, which created favourable conditions for the progression of inflammatory processes. Studies have shown that IQOS extracts increased the viability of fibroblast and keratinocyte cells and stimulated their migration, which may indicate the potential for increased proliferation. At the same time, the expression of genes responsible for apoptosis and cell cycle regulation changed a decrease in p53 protein expression and an increase in Bcl2 protein in keratinocytes were observed. Such changes at the cellular level indicate potential mechanisms for the development of mucosal pathologies when using tobacco heating systems.

In a study by O. Uehara *et al*. [33] on the Ploom TECH+ heating system, the condition of the oral cavity in patients

was characterised by significant changes at the cellular level. Prolonged stimulation of gingival epithelial cells with heated tobacco extracts led to disruptions in the processes of differentiation and keratinisation. RNA ribonucleic acid analysis showed a twofold increase in the expression of 284 genes and a decrease in the expression of 145 genes. In particular, the activation of genes related to root formation and keratinisation indicated an increase in the level of pathological changes in the tissues. CpG island methylation showed a significant increase in 158 genes and a decrease in 171 genes, which may indicate epigenetic changes under the influence of Ploom TECH+ products. An increase in the expression of the S100A7 protein, which is associated with inflammatory processes and impaired barrier functions of mucous membranes, was also recorded. The data indicate that regular use of the Ploom TECH+ system is a risk factor for the occurrence of oral mucosal pathologies, including inflammatory changes and hyperkeratosis.

According to T. Yoshioka & T. Tabuchi [34], users of HNB, combustible cigarettes, and their combination showed an increased incidence of periodontal disease. HNB use was associated with periodontal disease prevalence (PR 1.43; 95% CI 1.03-1.62), whereas combustible cigarette users had a PR of 1.29 (95% CI 1.03-1.62). Ex-users (PR 1.56; 95% CI 1.35-1.80) and combined users (PR 1.55; 95% CI 1.20-1.99) also showed significantly higher risk compared to those who had never used tobacco products. These results indicate a negative impact of both traditional and alternative tobacco products on periodontal tissue health, which highlights the need to develop preventive measures.

In a systematic review by C.A. Figueredo *et al*. [35], e-cigarette users showed significant increases in plaque, periodontal pocket depth, clinical attachment loss, and marginal bone loss (MBL) compared to a nontobacco control group. A total of 1,659 studies were analysed, of which eight case-control studies were selected. The authors determined that vaping caused increased pathological changes, including loss of bone support for the teeth and deeper penetration of the probe into periodontal pockets. The results indicate a potentially negative impact of vaping on periodontal tissue, which may contribute to the progression of periodontitis. Despite the limitations of the data, this indicates serious risks associated with vaping for gum health.

However, in a comparative study of the effects of classic tobacco and heating systems on oral health, the results were somewhat different. In a randomised trial by S. Pouly *et al*. [36] of 172 participants, 86 people who continued to smoke cigarettes were compared with 86 participants who switched to HNBs. The results showed that patients using HNB had significantly better rates of PD depth reduction in areas with an initial depth of ⩾4 mm. Among the secondary outcomes, there was an improvement in clinical tooth attachment and a reduction in gingival inflammation in the HNB group. Differences in disease evolution were most pronounced after mechanical therapy, indicating the potential of HNB to reduce the risk of periodontal disease progression. The study confirms the harm reduction by alternative methods of tobacco use.

The state of periodontal tissues in patients who used tobacco was investigated by assessing the main periodontal indices – PD depth and CAL [37]. The study involved 66 people aged 26 to 56 years (median age 38 years), 64% of whom were women. Three groups of patients were divided by the type of tobacco product use: classic cigarettes, HNB, and non-smokers. Mean PD and CAL scores differed significantly between groups ($p \leqslant 0.002$). The highest values were recorded in cigarette smokers, and the lowest in non-smokers. HNB users had significantly lower CAL values than smokers ($p = 0.011$). However, PD and CAL in HNB users remained higher than in non-smokers, but without a statistically significant difference. Cigarette smoking was the main predictor of periodontitis (mean CAL ⩾ 4 mm), increasing the risk by 4.7 times (95% CI 1.2-18.3; $p = 0.027$).

Studies show that smokers of classic cigarettes have higher periodontal pocket depth and CAL scores, indicating a higher risk of developing periodontitis. Patients who use HNB show improvement compared to cigarette smokers, although their results are still inferior to those of non-smokers. At the same time, HNBs can reduce harm compared to traditional smoking, although they are not without negative effects. Thus, in patients who used tobacco products, the risk of developing periodontitis was significantly increased – up to 56.57% among people exposed to tobacco smoke and up to 1.43 times in users of e-cigarettes and tobacco heating systems compared to non-smokers. The depth of PD and CAL were significantly higher than in the control group, especially in smokers of classic cigarettes, who had a 4.7-fold increased risk of periodontitis progression (95% CI 1.2-18.3; $p = 0.027$). Optimisation of preventive measures, such as smoking cessation, mechanical periodontal therapy and ensuring adequate levels of trace elements (e.g., zinc), can reduce the risk of periodontal disease and stabilise the condition of oral tissues.

The effect of tobacco and heating systems on dental implants

The study of the clinical condition of the oral cavity after tobacco exposure revealed a significant correlation between traditional smoking and an increased risk of dental implant failure. Data from H.L. Stiller *et al*. [38] study, which included 29,519 implants in 18,301 patients, showed that smoking had a negative impact on both the early and late stages of osseointegration. In 25 of these studies, a dose-response relationship was found: an increase in the number of cigarettes smoked per day increased the risk of implant failure. In particular, the results highlight the need to control the number of cigarettes to reduce risks, as smokers performed significantly worse than non-smokers, especially in the case of uncontrolled tobacco use. Tobacco exposure limited tissue regeneration and interfered with implant stability, requiring more resources for treatment and prevention in these patients. The findings highlight the need for smoking cessation programmes, patient education and individualised care approaches in dental implantology. Future research should consider the impact of not only smoking but also alternative tobacco products such as e-cigarettes on the increased risk of dental implant failure.

A. Tanik & F. Demirci [39] demonstrated a significant effect of smoking on MBL in patients with dental implants. The study included 419 implants placed in 188 patients aged 23 to 76 years. It was found that smokers, especially those who used unfiltered cigarettes, demonstrated significantly greater bone loss compared to non-smokers ($p < 0.05$). This aspect adds to the understanding of the

negative effects of tobacco, as unfiltered cigarettes appear to be more harmful than filtered cigarettes. MBL levels on the mesial and distal surfaces of heavy smokers of unfiltered cigarettes (>20 cigarettes per day) were significantly higher than those of filter smokers ($p = 0.013$). The effect of smoking also varied depending on the location and length of the implant. These data showed a high dependence of bone loss on smoking intensity and cigarette type, especially without a filter. Overall, the study emphasises the importance of smoking cessation as an effective method of preventing and maintaining implant stability. In addition, the authors demonstrate the difference in harm between types of tobacco products, which requires further research to optimise clinical recommendations.

Consideration of the impact of tobacco smoking on the condition of oral tissues revealed a significant increase in the risk of periodontal disease and complications of implant therapy [40]. Smoking caused changes in the microbial composition of subgingival biofilms, including an increase in pathogenic microorganisms, and suppressed inflammatory and immune responses. In contrast to previous findings, the focus here is on the impact of smoking on the microbiological level, which explains the clinical manifestations. This led to a disturbance in the homeostasis of periodontal tissues and a decrease in the healing potential. Early studies and modern methods such as deep sequencing have confirmed a significant deterioration in clinical parameters, including bleeding indices and loss of tissue attachment. Smokers have also been found to have lower success rates in periodontal treatment and dental implant stability. In addition, passive smoking was found to be potentially harmful to oral tissues. The results highlighted the importance of smoking cessation as a preventive measure. Recommendations for dentists should include informing patients about the negative effects of smoking on periodontal tissues and implant prognosis. Thus, the study of D.A. Apatzidou [40] adds another important aspect to the overall picture, indicating a significant effect of smoking on the microflora and immune response, which enhances the clinical significance of the previously obtained data.

In addition, smoking affects the state of the patient's oral cavity, worsening the processes of osseointegration of dental implants [41]. Smokers had an increased risk of implant failure, which reached 140.2% compared to non-smokers. Significant changes were recorded in both the upper (OR 2.910) and lower jaw (OR 2.866). Smoking contributed to MBL (MD 0.580 mm). Compared to other studies, this analysis focuses more on specific anatomical areas and their association with tobacco exposure. These complications reduced the effectiveness of implant treatment, especially with prolonged exposure to tobacco smoke. These findings highlight the need for tobacco prevention to improve dental health.

A study by M. Alqahtani [42] determined that in smokers, the mean PD probing depth was 4.2 ± 0.5 mm, while in non-smokers it was 3.1 ± 0.4 mm. The bone crest resorption in smokers was 1.5 ± 0.3 mm, which was significantly higher than in non-smokers – 0.9 ± 0.2 mm ($p < 0.05$). A statistically significant higher bleeding rate during probing was observed among smokers in 62% of cases, compared to 42% in non-smokers. The data confirm that smoking contributes to peri-implant inflammation and bone loss. This confirms the findings of other studies on the association between smoking and peri-implant inflammation, adding new evidence of a statistically significant difference between the groups. O. Vámos *et al*. [43] studied the condition of peri-implant tissues in patients who used various nicotine-containing products showed a significant deterioration in parameters compared to non-smokers. In conventional cigarette smokers, the mean MBL was 1.34 mm (CrI: 0.85-1.79), in hookah smokers (WP) – 1.58 mm (CrI: 0.84-2.35), and in smokeless tobacco (ST) users – 2.53 mm (CrI: 1.20-3.87). For e-cigarette (EC) users, MBL was not significantly different from NS (MD: 0.52 CrI: -0.3-1.36). Nonsmokers also had the best PD probing depth, plaque index, and proinflammatory cytokine levels (TNF-α, IL-1β). Despite being considered less harmful, e-cigarettes also showed lower tissue scores compared to NS, although the difference was not always statistically significant. These findings highlight the importance of close monitoring of oral health in all users of nicotine-containing products and the implementation of preventive measures.

A comparison of the oral cavity after exposure to e-cigarettes and traditional cigarettes showed that the use of EC may reduce or not affect peri-implant disease indicators such as bleeding on probing, PD probing depth, and MBL [44]. However, the study demonstrated that EC, similarly to ST, contains nicotine, which negatively affects tissue healing and implant integration. Comparing the effect of different types of nicotine-containing products on the condition of oral tissues, it is evident that traditional and alternative cigarettes negatively affect peri-implant parameters, although the level of influence varies. For example, peri-implant bone loss in EC users may be slightly higher than in non-smokers, and the response to treatment in these patients was less predictable. These findings suggest the need for additional studies to better assess the impact of EC on clinical outcomes of implant treatment and the prevention of oral disease. The results of these studies highlight the need for further study and patient education about the risks of using various nicotine-containing products, as well as the development of effective preventive measures. In conclusion, tobacco products, including traditional cigarettes and HNB, have a negative impact on peri-implant tissue, but their effects differ significantly. Traditional cigarette smoking is associated with significant bone loss (MBL 1.34-2.53 mm) and worse clinical parameters such as pocket depth and plaque index compared to EC users, who have less severe changes [43, 44]. At the same time, although EC are considered less harmful, their effect on healing and implant stability also remains negative due to the presence of nicotine, which highlights the need for preventive measures regardless of the type of product.

As for the recommendations for doctors, in the context of combating the effects of the use of newer nicotine products, they are based on current research on their impact on the oral cavity. According to the World Dental Federation [45], e-cigarettes and tobacco heating systems cause chronic irritation of the mucous membrane, which increases the risk of leukoplakia, gingivitis and periodontal disease. Accordingly, a detailed medical history and recording of nicotine consumption patterns are recommended to optimise prevention and treatment. The key elements of preventive work are informing patients about the dangers

of aerosols, as well as the use of the 5A principle [46]. This principle is based on clarifying smoking status, advising on risks, assessing the patient's readiness to quit, offering support, and organising follow-up. Basic behavioural therapy and pharmacotherapy, including nicotine replacement therapy, are recommended to combat nicotine dependence. Regular monitoring of the oral cavity in patients with addiction allows early detection of pathological changes, such as hyperplasia or mucosal erosion, and referral to dentists or periodontists. A focus on education, including information about complete nicotine cessation, helps to increase the effectiveness of preventive measures. Thus, the implementation of these recommendations will help improve the quality of prevention and treatment of oral diseases caused using new nicotine products and reduce the risks to patient's health.

Risks of complications and prevention of oral diseases in smokers

Based on the analysis, the main risks of complications caused by the impact of smoking (traditional, e-cigarettes and tobacco heating systems) on the oral cavity included aspects such as the risks associated with traditional smoking included an increase in the depth of periodontal pockets and loss of gingival attachment, which was accompanied by the development of chronic periodontitis. Pathological changes in the form of leukoplakia and progression of gingivitis, increased plaque formation, which contributed to the development of caries, were often observed. There was a disturbance in the oral microflora, an increase in pathogenic bacteria, oxidative stress and an increase in the level of biomarkers of cellular damage. Although the toxicity of tobacco heating systems was 30-50% lower, the risk of chronic mucosal irritation and partial maintenance of inflammatory processes in tissues remained. The spread of these systems among young people created additional risks of attracting new tobacco users.

The use of e-cigarettes contributed to the disruption of the bacterial balance, increased the number of pathogens such as *Veillonella*, caused inflammation, and irritation of the mucous membrane, and increased the risk of carcinogenic changes due to the impact of toxic compounds. Common risks for all forms of smoking include lipid metabolism disorders and reduced calcium concentrations in saliva, which contribute to the development of periodontal disease, dysbiosis, bleeding gums and tooth loss. Smoking had a negative impact on bone regeneration, osseointegration of dental implants and tissue healing.

Studies highlighted the importance of prevention programmes and early diagnosis to reduce the impact of tobacco products on oral health. K. Kawamura *et al*. [47] determined that smokers sought medical care when their symptoms became serious. Therefore, dentists are recommended to encourage people who smoke any type of tobacco products to visit dentists more often for early detection and timely treatment of oral diseases. B.W. Chaffee *et al*. [48] emphasised that quitting smoking tobacco products is the most effective model for the prevention of all oral diseases and their complications. However, if the patient is unable to completely quit smoking, the optimal approach is to stop smoking for the period of periodontal disease treatment and dental implantation. If the patient was unwilling to abandon tobacco, dentists had to weigh the risks and benefits by discussing the potential consequences with the patient. Increased follow-up, frequent check-ups (every 6 months or more), and risk communication were recommended.

According to the National Institute on Aging [49], several basic rules are recommended for maintaining oral health. Teeth should be brushed regularly with fluoride toothpaste twice a day, and dental floss should be used to clean the interdental spaces. A dentist should be visited every six months for a preventive examination and professional cleaning. A balanced diet, avoiding sweets and sour foods, is also essential. Water is necessary to prevent mouth dryness. Avoid tobacco and limit alcohol consumption, which significantly increases the risk of oral diseases. If bleeding gums or any changes in the oral cavity occur, it is recommended to visit a dentist. In addition, it is also recommended that smokers use deodorising rinses to neutralise odour [50]. To combat "smoker's plaque", toothpaste with a high abrasive index from the "antitaro" series should be used. Regular dental check-ups every 3-4 months. Less harmful alternatives, such as e-cigarettes or tobacco heating systems, should be considered to reduce the harm from smoking.

CONCLUSIONS

HNBs and traditional cigarettes both have a negative impact on oral health, but their effects differ in intensity. Smoking traditional cigarettes significantly increases the risk of periodontal disease, and caries and changes the oral microbiome. Deep periodontal pockets are found in 68% of smokers, and the incidence of periodontitis among smokers reaches 56.57%, with gingival leukoplakia observed in 85.1% of cases. Long-term cigarettes use also causes bone loss (MBL 1.34-2.53 mm) and worse clinical parameters such as PD probing depth and gingival bleeding, which reaches 62%.

E-cigarettes, which are 30-50% less harmful than traditional cigarettes, still change the microbiome of the oral cavity, contributing to the development of pathogenic processes. E-cigarette users have a 1.43-fold increased risk of developing periodontal disease compared to non-smokers. E-cigarettes also cause mucosal irritation, and dysbiosis, and increase the risk of malignant tumours due to carcinogens such as formaldehyde. The incidence of peri-implant inflammation among HNB users is lower than among cigarette smokers, but implant stability is also reduced. The long-term safety of HNBs remains questionable and requires additional research. HNBs reduce toxicity compared to traditional cigarettes, but the risk of inflammation and tissue damage remains. In smokeless tobacco users, the incidence of keratosis reaches 46.1% and OSMF – 16.1%. HNB use is associated with a reduction in the depth of PD and an improvement in CAL, but the negative effects cannot be eliminated.

Smoking cessation has a positive effect on the state of the oral cavity. A year after smoking cessation, there is a 1.5 mm decrease in the depth of periodontal pockets and a 1.2 mm improvement in tissue attachment. This confirms the importance of combating addiction for the prevention of periodontal disease and maintaining implant health. Optimisation of oral hygiene, and dietary correction, in particular zinc levels, help reduce the risk of pathologies. To improve the oral health of patients who use nicotine

products, it is recommended to conduct a detailed identification of their forms of use through a thorough history and registration of data in the medical record. Regular information should be provided about the risks of chronic mucosal irritation, leukoplakia, gingivitis and periodontitis, including the harmful effects of alternative products such as e-cigarettes and tobacco heating systems. Using the 5As principle can improve the effectiveness of prevention and treatment by covering all aspects of patient monitoring and support. Particular attention should be devoted to the early diagnosis of mucosal changes, the use of nicotine replacement therapy and individual behavioural support aimed at complete nicotine cessation.

In summary, traditional e-cigarettes have a negative impact on the oral cavity, although the extent of their harm differs. Smoking traditional cigarettes causes significant destructive changes, while the impact of HNBs is less pronounced, but carries long-term risks. The importance of preventing the use of and quitting all types of tobacco products remains key to maintaining dental health. However, if it is not possible to quit smoking, it is recommended to visit the dentist more often, temporarily stop smoking for interventions related to periodontal disease and dental implants, observe hygienic oral care using rinses, and abrasive pastes and seek timely medical care from specialists. A limitation of the study was the lack of clinical trials on the long-term effects of modern tobacco and e-cigarette heating systems on dental health. Future research directions include studying the mechanisms of oral tissue recovery after smoking cessation.

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CONFLICT OF INTEREST

None.

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Наслідки вживання нікотинових виробів для тканин ротової порожнини: підходи до профілактики

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Анотація. Метою дослідження було здійснити аналіз впливу куріння та сучасних систем вивільнення нікотину на стан ротової порожнини, враховуючи стратифікацію факторів ризику розвитку стоматологічних патологій, визначити можливість виникнення ускладнень та впровадження профілактичних програм в роботу лікарів-стоматологів для мінімізації шкідливого впливу цієї звички. Для проведення дослідження було здійснено пошук досліджень у базах даних PubMed, Scopus, Web of Science та Google Scholar. Було встановлено, що електронні сигарети, традиційні сигарети та системи нагрівання тютюну негативно впливають на ротову порожнину, викликаючи ризики лейкоплакії, гінгівіту та пародонтальних захворювань. Куріння традиційних сигарет спричиняє суттєві деструктивні зміни, зокрема глибокі пародонтальні кишені (68 %), втрату тканинного прикріплення (42 %) та лейкоплакію ясен (85,1 %). Електронні сигарети, хоча менш шкідливі, викликають подразнення слизової оболонки, дисбактеріоз і підвищують ризик пародонтозу у 1,43 рази порівняно з некурцями. Системи нагрівання тютюну демонструють нижчу токсичність, проте ризик запалень і тканинної деструкції зберігається. Результати свідчать, що відмова від куріння позитивно впливає на стоматологічне здоров'я. Через рік після припинення куріння спостерігається зменшення глибини пародонтальних кишень на 1,5 мм і покращення тканинного прикріплення на 1,2 мм. Це підтверджує важливість боротьби із залежністю для профілактики стоматологічних захворювань. Рекомендації для лікарів включають ретельний збір анамнезу, реєстрацію форм вживання нікотину, застосування принципу "5А" про досвід вживання тютюну пацієнтом, надати інформацію про відмову від куріння, оцінити їхню готовність до відмови, допомогти в процесі позбавлення залежності та забезпечити подальшу підтримку через регулярний контакт. Особливу увагу слід приділяти інформуванню пацієнтів про ризики, пов'язані з усіма формами тютюну, та сприяти повній відмові від їх використання. Однак, якщо відмовитися від куріння неможливо, важливо регулярно відвідувати стоматолога, призупинити куріння під час лікування пародонтозу чи проведення імплантації зубів, ретельно дотримуватись правил гігієни ротової порожнини із застосуванням ополіскувачів й абразивних паст, а також своєчасно звертатися до спеціалістів за професійною допомогою. Такі заходи дозволяють зменшити ризик стоматологічних патологій і сприяють довгостроковому збереженню здоров'я ротової порожнини

Ключові слова: парадонтит; плоскоклітинний рак; лейкоплакія; карієс; куріння; електронні сигарети