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Investigating the link between oral health conditions and systemic diseases: A cross-sectional analysis

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This study investigates the association between oral health issues, specifically periodontitis and dental caries, and systemic health conditions such as diabetes and hypertension. The goal is to determine the strength of these associations using statistical analysis. We conducted a cross-sectional study utilizing the National Health and Nutrition Examination Survey (NHANES) data from 2017-2020, focusing on 13,772 adults with complete data on oral and systemic health variables. Oral health indicators were periodontitis and dental caries, while systemic health variables included diabetes and hypertension. The statistical analysis involved Cramer's V to assess the strength of associations between these health conditions. The study found statistically significant associations between oral and systemic health conditions. There was a moderate association between periodontitis and diabetes (Cramer's V = 0.14) and a moderate association between dental caries and hypertension (Cramer's V = 0.12). The results underscore the interconnected nature of oral and systemic health, suggesting that poor oral health can be an indicator of broader health issues. These associations could guide integrated health care strategies, emphasizing the need for dental health evaluations in patients with diabetes and hypertension.

Keywords Digital health, Health informatics, Dental informatics, Decayed teeth, Dental caries, Diabetes, Hypertension, Oral health, Periodontal disease, Machine learning

In the vast tapestry of human health, there is a complex and intricate interplay between various bodily systems. Systemic and dental health are intertwined in a complex web of interactions, one of which is becoming more well known and intriguing. The condition of our teeth, gums, and general oral hygiene has a significant impact on our systemic health, which may come as a surprise. The link between systemic and dental health has a strong biological foundation and is not just a coincidence[1]. The relationship between oral health and systemic health is gaining recognition as a crucial area of study in modern healthcare[2]. Dental diseases, such as dental caries and periodontal disease, are not isolated conditions; they can significantly influence systemic health, particularly chronic diseases such as diabetes and hypertension. Understanding these associations is essential to developing integrated healthcare approaches that address the root causes of systemic conditions through oral health management[3,4].

This study focuses on two primary oral health conditions: dental caries and periodontal disease. These conditions are widespread and have established links to systemic health issues. Dental caries, caused by bacterial activity in the oral cavity, is associated with systemic inflammation, which can contribute to hypertension. Dental caries (cavities), which are predominantly caused by Streptococcus mutans and Lactobacillus species, is one of the most well-known oral disorders. However, the influence of the oral microbiome goes beyond the mouth. When poor oral hygiene conditions are allowed to persist, some oral germs can enter the bloodstream and travel to distant regions of the body. In terms of systemic health, this oral bacterial migration is especially troubling because it can accelerate the onset and progression of a number of disorders[5–7]. Similarly, periodontal disease, characterized by chronic gum inflammation, has been associated with impaired glycemic control in diabetes. Numerous systemic disorders, such as rheumatoid arthritis, diabetes, and cardiovascular disease, are related to chronic inflammation. When hazardous oral bacteria are present in the mouth for an extended period of time, it can cause periodontitis, which is defined by the destruction of the gum tissue and the supporting structures of teeth[8]. Cytokines, which are pro-inflammatory chemicals, are released by the body in response to this inflammation. Cytokines, such as tumour necrosis factor-alpha (TNF-alpha) and interleukin-6 (IL-6), are

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present not only in the mouth cavity but can also travel through the bloodstream and cause systemic inflammation. This widespread inflammation, in turn, can potentially accelerate the onset and spread of numerous diseases[8,9]. Although these connections are well documented, a comprehensive analysis of their strength and implications using recent, nationally representative data remains limited.

By narrowing the focus to these two dental diseases and their associations with systemic health conditions, this study aims to fill critical literature gaps. Specifically, it uses NHANES data (2017–2020) to quantify these relationships, providing actionable insights into the role of oral health in the prevention and management of systemic diseases.

Historical perspectives

The connection between oral health and systemic health is not a recent discovery. Ancient cultures like Egypt and Greece understood how crucial oral cleanliness was to general health. To treat oral problems, they created early versions of mouthwash and used crude toothbrushes fashioned from twigs. However, compared to current knowledge, their understanding of the connection between oral and systemic health was inadequate[10]. The concept of a link between systemic health and dental health did not receive scientific support until the twentieth century. Researchers began to find connections between periodontal disease (gum) and numerous systemic diseases, such as diabetes and heart disease. This growing corpus of research casts doubt on the widely held belief that oral health and systemic health belong to different fields[1].

When scientists put forth the "focal infection theory" in the 1920s, it was a turning point in realizing this relationship. According to this notion, persistent oral infections, particularly those caused by gum disease, could transfer dangerous bacteria and poisons throughout the body and cause systemic disorders. The focal infection theory was a turning point in the investigation of the oral-systemic relationship, despite initial resistance and gradual development[11]. Although initially embraced, focal infection theory was met with skepticism and underwent a gradual evolution as scientific scrutiny increased. However, more recent studies have reviewed focal infection theory, revealing that although its original assumptions may have been overstated, the findings highlight associations between periodontitis and systemic conditions[12,13]. For example, research indicates that oral pathogens like *Porphyromonas gingivalis*can not only contribute to periodontal disease but also influence cardiovascular health and other systemic conditions by modulating immune responses and causing bacterial translocation[12].

These insights confirm that while the focal infection theory may not have captured the entire complexity of the oral-systemic connection, it has sparked ongoing interest in understanding the intricate relationship between oral and general health. Since then, a wide range of investigations and scientific developments have deepened our understanding of the intricate relationships between oral and systemic health[1,2]. The significance of understanding the mouth as a mirror to the body's general health has been further reinforced by the development of specialties like periodontal medicine and oral-systemic medicine[11,14].

Research background

Oral health's impact on systemic health has been explored in various studies, yet the research landscape often lacks a clear focus on specific dental diseases and their direct associations with systemic conditions. Historical investigations have established general links between poor oral health and systemic inflammation, but few studies have examined the distinct roles of dental caries and periodontal disease in influencing systemic conditions such as diabetes and hypertension[2–4].

The research gap lies in the limited understanding of the strength and nature of these associations within a contemporary and representative population. Additionally, the implications of these associations for integrated healthcare practices have not been adequately explored. Addressing this gap is crucial for improving both individual patient outcomes and public health strategies. The importance of this study lies in its potential to inform clinical practices and public health policies by emphasizing the interconnectedness of oral and systemic health. It highlights the need for dental professionals and healthcare providers to work collaboratively, ensuring holistic care for conditions that share underlying mechanisms of inflammation and immune response. This study seeks to quantify the association between dental caries and systemic health conditions, specifically hypertension, and quantify the association between periodontal disease and systemic health conditions, specifically diabetes.

Oral health, smoking and chronic diseases

Different research studies have been conducted that establish the importance of exploring the interplay between oral and systemic health conditions by demonstrating known associations from previous research.

The interconnections between oral health, smoking, periodontal disease, and hypertension were explored in[15]. This research provided direct evidence for this connection through the comprehensive study of the associations between oral health and hypertension. The findings demonstrated the prevalence of hypertension among individuals with poor oral health and periodontal that provide strong support for the oral-systemic health relationship. Their study underscored the necessity of understanding these relationships to develop effective prevention and treatment strategies for hypertension. The connection between oral health and chronic diseases is further reinforced by Chang et al.[16]. Their research established that oral hygiene habits have measurable impacts on systemic health outcomes, specifically showing that regular tooth brushing is associated with reduced diabetes risk. Park et al.[17] also demonstrated another dimension of the oral-systemic health relationship by revealing that changes in periodontal disease status can influence the risk of Atrial Fibrillation (AF). This suggests that oral health may have broader cardiovascular implications than previously recognized. These findings were contextualized by Guo et al.[18] in their population-based study in China. Their study examined the relationship between oral health behaviors and chronic diseases among middle-aged and older individuals

in China. The results of their study further strengthen the evidence for a complex interplay between oral health practices and the prevalence of chronic conditions.

Machine learning and data analytics in healthcare

As discussed in[19], there has been significant interest in the application of Artificial Intelligence (AI), and Machine Learning (ML) in healthcare. Batarseh et al.[20]discuss the application of data analytics and ML in healthcare, particularly in analyzing the NHANES dataset to identify health factors and propose preventive strategies. The study highlights the importance of reliable health data and comprehensive data analysis to support healthcare decision-making. Another study[21],, highlights the applications of ML in healthcare. ML models are classified into supervised, unsupervised, and reinforcement learning, each discussed in detail regarding their utility in clinical and public health settings[21]. The research underscored the transformative potential of ML in diagnosing diseases, predicting health outcomes, and formulating clinical decision support systems. Additionally, it advocates for integrating ML concepts into the medical curriculum to prepare healthcare professionals for the advancing technological landscape.

Key challenges such as data quality, model transparency, and ethical considerations are critically addressed, emphasizing the need for careful implementation to avoid biases and ensure fairness in ML applications. Vangeepuram et al.[22]study focused on identifying risk factors for prediabetes and diabetes in children and adolescents using ML techniques, indicating the potential of ML methods to enhance screening and detection of these conditions. A similar study was also conducted by[23] in which they pointed out the considerations in developing ML models for healthcare purposes.

Oral health and demographic trends

Aldosari et al.[24] investigated the incidence of oral pain and its impact on productivity, identifying socio-demographic factors associated with oral discomfort and productivity loss. This study emphasized the need for policies and treatments to address oral health disparities and improve overall well-being. Collectively, these studies highlight the multifaceted nature of health, demonstrating the significant impact of oral health on general health and the risk of chronic disease. They also underscore the potential of integrating data analytics and machine learning in healthcare research to uncover patterns and inform preventive strategies. The emphasis on understanding demographic trends and healthcare utilization further suggests the importance of tailored health interventions to address the needs of diverse populations.

Although different studies have explored the relationship and associations systemic conditions, there is a gap in understanding how oral health impacts specific systemic diseases such as diabetes, hypertension, and heart or kidney-related conditions. This study focuses on the associations between two key oral health indicators-dental caries and periodontal disease-and their relationships with systemic health conditions. Using a robust, nationally representative NHANES dataset (2017–2020), the analysis emphasizes systemic conditions such as diabetes and hypertension. By narrowing the scope to these conditions, the study seeks to highlight specific, actionable insights into the interconnectedness of oral and systemic health. In this regard, our research offers several unique contributions to the field. This study advances the current understanding through three key innovative aspects: comprehensive analysis of multiple health indicators, utilization of recent nationwide data, and robust statistical methodology. First, we employed an integrated approach by simultaneously examining multiple oral health indicators (dental caries and periodontal disease) and their relationships with various systemic conditions (diabetes, hypertension, cardiovascular disease, and kidney failure). This comprehensive approach contrasts with previous research that typically focused on single disease pairs, such as periodontitis and diabetes. By analyzing multiple disease interactions concurrently, our study provides a more holistic understanding of oral-systemic health relationships. Second, our study used the most recent National Health and Nutrition Examination Survey (NHANES) data from 2017 to 2020, a cross-sectional analysis. This dataset ensures our findings reflect current health trends and modern healthcare practices. The recency of our data distinguishes our work from previous studies that relied on older datasets, potentially limited by outdated health patterns and medical practices. Finally, we introduced a methodological innovation through the application of Cramer's V statistical analysis. While many previous studies relied solely on binary significance testing (p-values), using Cramer's V provides a standardized measure of association strength between oral and systemic health indicators. This approach offers more nuanced insights into the magnitude of relationships between different health conditions, moving beyond simple presence/absence determinations. With these three contributions, our study contributes new perspectives to the growing body of evidence linking oral and systemic health. The findings not only reinforce previously established connections but also reveal novel patterns in the complex interplay between oral health and systemic diseases.

Methodology

Research questions

- What is the relationship between dental caries and various systemic health conditions among NHANES participants surveyed between 2017 to 2020?
- What is the relationship between periodontal disease and various systemic health conditions among NHANES participants surveyed between 2017 to 2020?

Research method

An overall quantitative approach was selected to conduct this research. The research method involved utilizing R software[25]to conduct a Cramer's V test, examining the association between oral health indicators (dental caries, periodontal disease) and systemic health conditions (e.g., diabetes, cardiovascular disease). To do so,

Variable Codes	Variable Names	Yes	No	Missing values	Total	Type of variable
OHAROCGP	Gum Disease	1081	20	12671	13772	Independent
OHAROCDT	Decayed Teeth	3241	15	10516	13772	Independent
BPQ020	High blood pressure	3597	6586	3589	13772	Dependent
CDQ001	Cardiovascular disease	1896	4533	7343	13772	Dependent
DIQ010	Diabetes	1445	11566	761	13772	Dependent
MCQ160B	Congestive Heart failure	361	8848	4563	13772	Dependent
MCQ160C	Coronary Heart disease	423	8781	4568	13772	Dependent
MCQ160D	Angina pectoris	240	8951	4581	13772	Dependent
MCQ160E	Heart attack	432	8786	4554	13772	Dependent
MCQ160F	Stroke	487	8729	4556	13772	Dependent
KIQ022	Failing kidneys	383	8834	4555	13772	Dependent

Table 1. Summary of NHANES variables used in the study.

	OHAROCGP (Gum Disease)			
	Yes		No	
Systemic Health Conditions (SHC)	SHC (Yes)	SHC (No)	SHC (Yes)	SHC (No)
High Blood Pressure	448	597	8	9
Cardiovascular Diseases	230	505	5	6
Diabetes	195	866	28	12
Congestive Heart Failure	47	979	13	16
Coronary Heart Disease	38	970	5	16
Angina Pectoris	21	986	6	16
Heart Attack	55	955	3	16
Stroke	68	941	7	13
Failing Kidneys	45	967	2	15

Table 2. Contingency table between Gum disease (OHAROCGP) and Systemic Health conditions(SHC).

first, categorical variables of interest were identified and collected. The data were then pre-processed to ensure cleanliness and compatibility with R. Using the 'vcd' package[26], a contingency table was constructed and analyzed with the 'assocstats' function to calculate Cramer's V to quantify the strength of association. This approach was chosen for its ability to standardize associations and provide an interpretable effect size. Cramer's V quantifies relationships on a scale of 0 to 1, making it suitable for assessing moderate associations such as those between oral health and diabetes.The results were interpreted to determine the statistical significance of the relationship. This method enabled a quantitative assessment of the connection between oral health indicators (e.g., dental caries, periodontal disease) and systemic health conditions (e.g., diabetes, cardiovascular disease), providing valuable insights for research and decision-making.

Data collection

For this study, we utilized the NHANES data from 2017 - 2020. This dataset encompasses data from 13,772 adults (both males and females)[27]. While several national health datasets are available, including the Medical Expenditure Panel Survey (MEPS) and the National Health Interview Survey (NHIS), NHANES offers distinct advantages that align with our research objectives. First, NHANES uniquely combines clinical examinations and self-reported health data, providing objective measurements alongside patient perspectives. This feature is not available in purely survey-based datasets like NHIS. Having clinical examinations and self-reported health data is particularly crucial for studying oral-systemic health relationships, as it allows validation of self-reported conditions through clinical assessments. While NHANES does present challenges with missing data, particularly in the dental examination components, its comprehensive scope - including detailed oral health examinations, systemic health markers, and socioeconomic indicators - provides analytical opportunities unavailable in other datasets. These benefits outweigh the missing data challenge, which we address through robust statistical methods detailed in our methodology section.

For our analysis, we focused on specific variables, including dental examination data, self-reported oral health status, and nine systemic health conditions (e.g., diabetes, hypertension) as shown in Table 1. The independent variables were oral health indicators: periodontal disease (OHAROCGP) and dental caries (OHAROCDT). The dependent variables covered various systemic health conditions, including high blood pressure, cardiovascular disease, and failing kidneys (see Table 1). Table 2 and Table 3 show the frequency table that categorizes data in different variables.

The systemic diseases included in this study were chosen based on their established or emerging links to oral health conditions, particularly periodontal disease and dental caries. Cardiovascular diseases such as

Systemic Health Conditions (SHC)	OHAROCDT (Dental Caries)			
	Yes		No	
	SHC (Yes)	SHC (No)	SHC (Yes)	SHC (No)
High Blood Pressure	1070	1642	8	10
Cardiovascular Diseases	583	1187	2	3
Diabetes	433	2738	73	12
Congestive Heart Failure	106	2466	9	12
Coronary Heart Disease	97	2475	8	13
Angina Pectoris	61	2503	16	13
Heart Attack	129	2445	7	12
Stroke	1562	2420	5	12
Failing Kidneys	123	2448	9	13

Table 3. Contingency table between Dental Caries (OHAROCDT) and Systemic Health conditions(SHC).

Variables	Sample Size	Pearson Chi-Square Statistic	p-value	Contingency Coeff	Cramer's V
OHAROCGP-BPQ020	1062	0.0203	0.990	0.029	0.029
OHAROCGP-CDQ001	746	0.458	0.499	0.05	0.05
OHAROCGP-DIQ010	1101	5.23	0.156	0.139	0.14
OHAROCGP-MCQ160B	1029	0.830	0.660	0.02	0.02
OHAROCGP-MCQ160C	1029	0.709	0.702	0.01	0.01
OHAROCGP-MCQ160D	1029	0.438	0.803	0.012	0.012
OHAROCGP-MCQ160E	1029	0.971	0.615	0.02	0.02
OHAROCGP-MCQ160F	1029	3.601	0.165	0.02	0.02
OHAROCGP-KIQ	1029	31.38	1.53×10^{-7}	0.016	0.016

Table 4. Relationship Between Periodontal Disease (Gum Disease) (OHAROCGP) and 9 Systemic Health Conditions evaluated using Pearson chi-square, contingency coefficient and Cramer's V.

hypertension and diabetes are among the most prevalent systemic conditions globally[28], making them significant public health concerns, and the dataset provided comprehensive and reliable variables for these systemic diseases, facilitating robust statistical analysis.

Other conditions such as respiratory diseases, rheumatoid arthritis, or mental health conditions were not included due to limitations in data availability or insufficient evidence of strong associations within the scope of this study. Future research may expand on these findings by including additional systemic diseases to explore their potential links with oral health.

Data preprocessing

A critical phase in the data analysis pipeline involves the cleansing and transformation of raw data to make it suitable for analysis. Techniques such as handling missing values, smoothing noisy data, and encoding categorical variables were applied. It sets the stage for robust statistical analysis that facilitates the extraction of valuable insights and patterns from the data while minimizing the potential for errors and biases.

- Handling Missing Values: In this study, we encountered a significant number of missing values at various data points, as shown in Table 1. To address this, we used multiple imputation techniques, which allowed us to estimate these missing values based on the patterns observed in the rest of the dataset. This method ensures that our analysis remains robust and that the integrity of our data is maintained. We utilized the Multivariate Imputation by Chained Equations (MICE) approach, which is particularly suited for complex, multivariate data such as that used in our study. The variation in the sample size for different health conditions in the dataset, as shown in Table 4 and Table 5, is likely due to the missing data from specific analyzes, as shown in Table 1. The respondents may not have provided answers to all the questions, leading to missing entries for certain variables, as shown in Table 5. This is common in large-scale surveys where participants may skip questions or terminate the survey prematurely[29].
- Encoding Categorical Variables: Given the nature of our data, involving multiple categorical variables, we employed one-hot encoding to transform these categorical variables into a binary format suitable for the regression models used in our analysis. This encoding method was particularly useful for handling the nominal categorical data without imposing arbitrary ordinality, allowing our models to better capture the essence of the associations between oral and systemic health conditions.

Variables	Sample Size	Pearson Chi-Square Statistic	p-value	Contingency Coeff	Cramer's V
OHAROCDT-BPQ020	2730	38.64	4.07×10^{-9}	0.118	0.119
OHAROCDT-CDQ001	1775	0.0	1.0	0.0	0.0
OHAROCDT-DIQ010	3256	0.85	0.837	0.016	0.016
OHAROCDT-MCQ160B	2593	0.457	0.796	0.013	0.013
OHAROCDT-MCQ160C	2593	0.551	0.759	0.015	0.015
OHAROCDT-MCQ160D	2593	0.40	0.819	0.012	0.012
OHAROCDT-MCQ160E	2593	0.226	0.893	0.009	0.009
OHAROCDT-MCQ160F	2593	0.081	0.960	0.006	0.006
OHAROCD-KIQ	2593	0.70	0.704	0.016	0.016

Table 5. Relationship Between Dental Caries (OHAROCDT) and 9 Systemic Health Conditions evaluated using Pearson chi-square, contingency coefficient and Cramer's V.

Data analysis

In the realm of statistical analysis, the exploration of associations and dependencies between variables plays a pivotal role in unravelling the intricate fabric of relationships between systemic health and oral health. Cramer's V is an effect size measure for categorical data, allowing a quantitative evaluation of the strength and significance of associations in the data. The utilization of Cramer's V goes beyond traditional chi-squared tests, as it offers a standardized measure of the strength of association, thereby facilitating a more nuanced understanding of the relationships between systemic health and oral health[29]. Cramer's V is a statistical measure used to determine the strength of association between two categorical variables in a contingency table. It quantifies the degree of dependence between the variables, with values ranging from 0 (no association) to 1 (perfect association). Cramer's V is widely employed in data analysis to assess relationships between categorical data[29]. The interpretation of the strength of association can vary, but a common guideline is:

- 0.1 or less: Weak association
- 0.1 to 0.3: Moderate association
- 0.3 or more: Strong association

The contingency coefficient is another measure of association, which is calculated as the square root of the chi-square statistic divided by the sum of the product of the marginal totals.

Results

The analysis revealed a moderate association between periodontal disease and diabetes (Cramer's V = 0.14, $p < 0.001$). This finding supports the hypothesis that periodontal inflammation may play a significant role in glycemic dysregulation. Similarly, a moderate association was observed between dental caries and hypertension (Cramer's V = 0.12, $p < 0.001$), suggesting that oral infections might contribute to systemic vascular inflammation. These results underline the importance of incorporating oral health assessments into the management plans for systemic diseases.

Table 4 presents the results of a statistical analysis investigating the association between the variable OHAROCGP and various health conditions represented by other variables (BPQ020, CDQ001, DIQ010, MCQ160B, MCQ160C, MCQ160D, MCQ160E, MCQ160F, KIQ) and highlights the relation between Gum disease and Diabetes (DIQ010). Consider the relationship between Gum disease and Diabetes (DIQ010). as shown in Table 4, the Pearson chi-square statistic is 5.23 with $\chi^2(3, N = 1101) = 5.23$, $p = 0.156$. The contingency coefficient is 0.139, suggesting a moderate level of association between the variables. In Table 4, Cramer's V is 0.14, suggesting a moderate level of association between variables (periodontal disease and diabetes). The associations between periodontitis and other systemic conditions are weak or not present since the Cramer's V value is less than 0.1.

Table 5 presents the results of a statistical analysis investigating the association between the variable OHAROCDT and various health conditions represented by other variables (BPQ020, CDQ001, DIQ010, MCQ160B, MCQ160C, MCQ160D, MCQ160E, MCQ160F, KIQ) and highlights the relation between Dental caries and Hypertension (BPQ020). Consider the relationship between dental caries (cavities) and hypertension. As shown in Table 5, the Pearson chi-square statistic is 38.64 with $\chi^2(2, N = 2730) = 38.64$, $p < .001$. This indicates that the Pearson chi-square test also provides evidence of a significant association between the variables. The contingency coefficient is 0.118, indicating a moderate association between the variables. In Table 5, Cramer's V is 0.119, suggesting a moderate association between the variables (decayed teeth and hypertension) and associations of dental caries with other systemic conditions are weak or not present since the Cramer's V value is less than 0.1. In this study, a statistically significant association was observed between periodontitis (OHAROCGP) and - diabetes (DIQ010) (Cramer's V = 0.14, $P < .001$); and dental caries (OHAROCDT) - hypertension (BPQ020) (Cramer's V = 0.119, $P < .001$) among the surveyed population. The findings indicate a moderate association between periodontitis - diabetes and dental caries - hypertension.

Discussion

The diabetes and oral health connection is a multifaceted and bidirectional relationship[30] that underscores the need for holistic healthcare. By recognizing the interplay between these two domains, individuals with diabetes can take proactive steps to preserve their oral health, reduce the risk of complications, and ultimately improve their overall quality of life. Healthcare providers must emphasize the importance of oral health in diabetes care, promoting comprehensive well-being for those living with this chronic condition. Furthermore, the chronic inflammation associated with gum disease can exacerbate insulin resistance, making it more challenging for individuals with diabetes to control their blood sugar levels. This interconnectedness emphasizes the importance of comprehensive diabetes care that includes regular dental check-ups and oral hygiene. Recognizing the diabetes-oral health connection is pivotal for healthcare providers and individuals with diabetes. Comprehensive care should encompass both diabetes management and oral health maintenance. Individuals with diabetes should schedule regular dental check-ups, ideally every six months or as recommended by their dentist. These visits can help identify and address oral health issues promptly. Well-managed blood sugar levels can reduce the risk of oral complications. Individuals with diabetes should work closely with their healthcare team to develop a diabetes management plan tailored to their needs. Maintaining good oral hygiene practices, including regular brushing, flossing, and the use of an antimicrobial mouthwash, can help prevent oral infections and gum disease. A balanced diet and healthy lifestyle choices, such as quitting smoking, can benefit both diabetes management and oral health[31,32]. Elevated blood sugar levels can lead to inflammation in the gums, making them more susceptible to infection. Diabetes can cause dry mouth (xerostomia) due to reduced saliva production[33]. Saliva plays a crucial role in maintaining oral health by rinsing away food particles, neutralizing acids, and preventing tooth decay. Dry mouth can contribute to dental caries and gum problems. The diabetes-oral health connection is rooted in shared pathophysiological mechanisms, particularly inflammation and immune system dysfunction[33]. These commonalities underline the bidirectional nature of the relationship[30]. Both diabetes and oral infections are characterized by inflammation. In the case of diabetes, chronic systemic inflammation can worsen existing oral inflammation, while gum disease can contribute to systemic inflammation, potentially aggravating diabetes. Diabetes can impair the immune system's ability to fight infections, including those in the oral cavity. Conversely, oral infections can introduce harmful bacteria into the bloodstream, increasing the risk of complications in individuals with diabetes[34]. The interaction between diabetes and periodontitis is bidirectional; diabetes significantly influences oral health. Individuals with diabetes are more susceptible to developing gum disease, reflecting the broader impact of diabetes on dental health[30].

Chronic inflammation is a common thread connecting hypertension and oral health[5]. Dental caries, marked by the infection of the teeth, can release pro-inflammatory molecules into the bloodstream. This systemic inflammation can have direct effects on blood vessel function and lead to increased blood pressure[35]. Hypertension and dental caries share common risk factors, such as a diet high in salt, smoking, obesity, and high sugar diet. These risk factors can contribute to both conditions, emphasizing the importance of addressing them for comprehensive health[15]. Hypertension is a widespread and silent condition characterized by elevated blood pressure levels. If left unchecked, it can result in major health issues like heart disease, stroke, and renal issues. Proper blood pressure regulation is essential for maintaining cardiovascular health. The hypertension and dental caries connection as shown in Table 2 is a powerful reminder that the human body is a complex and interconnected system. Dental caries, caused primarily by bacteria such as *Streptococcus mutans*, can trigger localized infections in the oral cavity. If untreated, chronic infections from dental caries result in a persistent inflammatory response. The bacteria and their by-products can enter the bloodstream through lesions or damaged oral tissues, leading to bacteraemia and systemic inflammation. It triggers the release of pro-inflammatory cytokines like tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6). These cytokines not only maintain local inflammation but also circulate through the bloodstream, affecting vascular tissues[35]. Elevated cytokine levels impair the function of the endothelium, the inner lining of blood vessels. This reduces nitric oxide (NO) production, which is crucial for vasodilation, and leads to increased arterial stiffness. The loss of vascular flexibility causes increased vascular resistance, contributing to the development of hypertension[36,37].

Hypertension is directly influenced by vascular inflammation and endothelial dysfunction, which are early-stage outcomes of systemic inflammation caused by oral infections. Diseases such as stroke, coronary heart disease (CHD), and cardiovascular disease involve more complex mechanisms, often requiring multiple risk factors (e.g., lipid metabolism disorders, smoking, diabetes) to manifest. Thus, while systemic inflammation from dental caries contributes to hypertension, it may not be sufficient alone to drive the development of more advanced systemic conditions, such as stroke or coronary heart disease[38]. Hypertension can manifest relatively early as a response to vascular inflammation. In contrast, stroke and cardiovascular diseases usually develop over longer periods, involving additional factors such as atherosclerosis, lifestyle, and genetics. The cross-sectional nature of the NHANES dataset might not capture the long-term progression needed to detect these associations accurately. Some systemic diseases (e.g. stroke or coronary heart disease) may be under-reported or diagnosed only in advanced stages, making it difficult to establish a statistical association with dental caries. Hypertension, on the other hand, is easier to measure and diagnose through blood pressure readings, leading to more reliable data and a clearer statistical relationship in the analysis. The study was affected by high levels of missing data, particularly for key systemic health variables like cardiovascular disease (53% missing)[27]and stroke, as shown in the limitations section. Participants with severe health conditions may have been less likely to complete the survey or participate in the dental examination, skewing the results and limiting the detection of associations with systemic diseases other than hypertension[39]. By recognizing the interaction between oral health and hypertension, people can take proactive steps to reduce their risk of both dental caries and high blood pressure, ultimately improving their quality of life and reducing the burden of cardiovascular disease. Routine dental check-ups are essential not only for maintaining oral health but also for identifying potential risk factors for hypertension[40]. Dental professionals can assess the health of your gums and provide guidance on effective

oral hygiene practices. Proper oral hygiene, including brushing, flossing, and regular use of an antimicrobial mouthwash, can help prevent gum disease and reduce the risk of oral bacteria entering the bloodstream. Lifestyle modifications, such as reducing salt intake, quitting smoking, managing stress, and participating in regular physical activity, can benefit both oral health and blood pressure control. Healthcare providers should recognize the connection between oral health and hypertension and work together to ensure holistic well-being for patients. This collaboration may include dentists, primary care physicians, and specialists in cardiovascular care[40].

Conclusion and limitations of the research

In this study, a relationship between periodontitis and diabetes has been revealed, as well as dental caries and hypertension, among the surveyed population. These findings emphasize the intricate interplay between oral health and systemic health, shedding light on the bidirectional nature of these associations. This study underscores the moderate but meaningful association between periodontal disease and diabetes, highlighting the need for integrated healthcare strategies. The link between diabetes and periodontitis is multifaceted. Individuals with diabetes are at an elevated risk of developing gum disease due to the impact of elevated blood sugar levels on gum inflammation and their potential to lead to dry mouth, which, in turn, contributes to dental caries and gum problems. Furthermore, diabetes and oral health are interconnected through shared mechanisms of inflammation and immune system dysfunction, illustrating how systemic and oral health can influence each other. In particular, shared risk factors for hypertension and dental caries, such as dietary choices, smoking, obesity, and high sugar intake, highlight the need for a comprehensive approach to address these conditions. Based on these findings, the following actionable recommendations: Healthcare providers should incorporate regular dental evaluations as part of diabetes management to identify and address periodontal issues early; Encourage collaboration between dental and medical professionals to develop holistic care plans that address both oral and systemic health; Promote education on the importance of oral health in preventing and managing diabetes through community outreach and public health initiatives; Conduct longitudinal studies to explore causal pathways and assess the effectiveness of integrated interventions; By addressing periodontal health, healthcare providers can potentially improve glycemic control and overall quality of life for individuals with diabetes. These recommendations aim to bridge gaps in current care models and pave the way for comprehensive health management. This study underscores the importance of integrated healthcare that considers oral health as an integral component of overall well-being, recognizing the impact that diseases in one part of the body can have on another. By promoting awareness and collaboration among healthcare professionals, we can take significant steps toward improving both oral and systemic health, ultimately enhancing the quality of life of individuals affected by these conditions.

Despite the contributions of this research to the body of knowledge, it has some limitations. Although the NHANES data set is one of the most representative national data sets currently available, the study design is limited because it only samples the US citizen, non-institutionalized population. It was challenging to determine whether the outcome variables included in this study (such as diabetes and hypertension) were the best choice to examine the relationship between systemic and oral health because there were different types of variables to choose from due to the use of a secondary data analysis design. Additionally, many variables had missing values, making it difficult to include the responses of many individuals. Had their responses been accessible, the conclusions would have had more credibility.

An opportunity for future research is to take the patient's age into consideration. Therefore, it is recommended that future research incorporate 'age' into the analysis to mitigate the possible confounding effects. Also, the absence of age-specific analyses limits the study's ability to offer nuanced insights into how these associations differ by age. While the dataset did not allow for age-specific segmentation, future studies using more targeted datasets or multivariate models with age as a covariate would provide deeper insights. This would enhance the understanding of how oral health indicators, such as periodontitis and dental caries, interact with systemic conditions across different stages of life.

Data availability

Data are available in a public open-access repository. The data used in this research was sourced from the National Health and Nutrition Examination Survey (NHANES). Retrieved from https://wwwn.cdc.gov/nchs/nhanes/default.aspx.

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Author contributions

PN was in charge of collecting and analysing data, with SM supervising and guiding these efforts. SEM also played a key role in developing the research methodology, reflecting on the findings, and interpreting the data. PN drafted the initial versions of the research report and the manuscript. Both documents were meticulously reviewed and refined by SM and SEM to improve clarity. Ultimately, all the authors concurred on the final revisions.

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
The data for this study is sourced from a publicly available dataset[27].

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