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Diabetes and Oral Health: Evidence, Mechanisms, and Clinical Implications

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ABSTRACT

Diabetes mellitus is a chronic metabolic disorder with wide-ranging systemic consequences, including profound effects on oral health. Accumulating evidence demonstrates a bidirectional relationship between diabetes and oral diseases, particularly periodontal disease, whereby poor glycaemic control exacerbates oral pathology and chronic oral inflammation adversely affects metabolic regulation. This review synthesizes current evidence on the epidemiology, mechanisms, and clinical implications of diabetes-related oral health complications. It examines the spectrum of oral manifestations associated with diabetes, including periodontal disease, gingival and periodontal infections, xerostomia, dental caries, altered oral microbiota, microvascular dysfunction, and impaired wound healing. Key pathophysiological mechanisms such as hyperglycaemia-induced immune dysregulation, advanced glycation end-product accumulation, oxidative stress, inflammatory cytokine networks, and vascular impairment are explored to elucidate the biological basis of these associations. The review further highlights the impact of periodontal disease and its treatment on glycaemic control, underscoring the clinical relevance of oral health in diabetes management. Special populations, including children, adolescents, and pregnant individuals, are discussed alongside public health, health literacy, and access-to-care considerations. Finally, the paper emphasizes the need for integrated medical-dental care models, routine oral health screening in diabetes care, and interprofessional collaboration. Addressing oral health as an integral component of diabetes management is essential for improving clinical outcomes, reducing systemic inflammation, and enhancing overall quality of life.

Keywords: Diabetes Mellitus, Oral Health, Periodontal Disease, Glycaemic Control, and Integrated Care.

INTRODUCTION

Diabetes mellitus (DM) is recognized as one of the leading public health crises of the modern world. The World Health Organization (WHO) estimates roughly 420 million people are affected internationally, and by 2030, this figure will rise to an estimated 552 million people [1-8]. The link between diabetes and oral health has been acknowledged for many years. The diagnosis and management of diabetes in patients are often accompanied by a cascade of oral health complications [9-10]. These complications may be related directly to the pathophysiological changes of diabetes itself or to the effects of diabetes-related therapies. An oral-systemic connection is evident in which there is a bidirectional effect between glycemic control and the oral cavity [11-15]. Oral manifestations of diabetes are seen as the sixth complication of the disease, of which periodontal disease is the most evident and examined complication [16-20]. These consequences are influenced by a multitude of both local and systemic factors; nevertheless, the degree of oral complications observed in diabetic patients is directly correlated to the adequacy of the patient's metabolic control. A comprehensive overview of the association between diabetes and oral health, their implications, proposed explanatory mechanisms, and contemporary clinical strategies to mitigate these oral abnormalities is outlined in this study [21-24].

Overview of Diabetes Mellitus

Diabetes mellitus (DM) is a chronic polyendocrine disorder characterized by hyperglycemia, stemming from β-cell impairment and/or reduced insulin response [25-28]. Its multifactorial etiology encompasses genetic and

environmental determinants, such as nutritional factors, infections, and epigenetic influences [29-34]. The International Diabetes Federation estimates that around 537 million adults aged 20-79 years worldwide had diabetes in 2021 and projects an increase to 643 million by 2030 and 783 million by 2045. Type 1 (T1D) is an autoimmune diabetes that results in absolute insulin deficiency and accounts for approximately 5-10% of cases, with onset typically occurring before adulthood [35-38]. Type 2 (T2D) is a heterogeneous disorder characterized by significant genetic and epigenetic predisposition and involves relative insulin deficiency and/or resistance [39-45]. It accounts for about 90% of diabetes cases and is usually diagnosed in adulthood, although the prevalence of pediatric and adolescent T2D is rising. Diabetes can also develop in pregnant individuals and is referred to as gestational diabetes mellitus [46-49].

Oral Health Outcomes Associated with Diabetes

Diabetes is associated with a range of oral health-related issues, including periodontal disease, gingival and periodontal infections, xerostomia, increased caries risk, and microvascular complications affecting oral health [50-55]. These manifestations have been linked to poorer blood glucose control and can compromise diabetes management. Periodontal disease remains the most significant oral complication and is acknowledged as the sixth complication of diabetes [56-60]. Periodontal disease affects a substantial proportion of individuals with diabetes and is correlated with the extent of glycemic control [61-64]. Studies indicate that individuals with diabetes are 2.5 times more likely to experience periodontal disease when compared to non-diabetics, with advanced periodontitis being more prevalent. Destructive periodontal disease has been identified as a major local risk factor for individuals with diabetes [65-70].

Periodontal Disease

Diabetes has significant implications for oral health, with periodontal disease being the most prevalent diabetes-related oral disease and a complication that worsens glucose control [71-76]. However, periodontal status is rarely assessed in diabetes care, and diabetes history is often not elicited when patients present with periodontal disease.

A bidirectional relationship exists between diabetes and periodontal disease [77-82]. Diabetics have a greater risk of periodontal disease and experience more rapid disease progression, leading to increased tooth loss, abscess formation, and complications during periodontal surgery. Conversely, diabetes can be a complication of periodontal disease, even in the absence of a pronounced systemic disease history [83-87]. Periodontal disease can disrupt glycemic control, with improved glycemic control succeeding periodontal treatment. The presence of oral bacterial infections has also been linked to metabolic syndrome, and oral pathogens can be detected in atherosclerotic plaques, potentially acting as a cofactor in atherogenesis[88-89]. Periodontal disease emerges as a major oral complication of diabetes, exacerbated by poor metabolic control. This chronic inflammatory condition of supporting periodontal tissues is driven by the accumulation of plaque, calculus, and other dental biofilms on tooth surfaces [90-93]. Susceptible individuals experience plaque-induced gingivitis and periodontitis, which can extend to dehydration, swelling of tissues, and tooth loss if left untreated. In diabetes, ongoing tissue impairment, benign neoplastic lesions, and primary and secondary candidiasis increase the risk of periodontitis [94-98].

Gingival and Periodontal Infections

The inflammatory responses observed in gingival and periodontal infections are increased in diabetes mellitus 4. Even in the absence of periodontitis, individuals with diabetes display greater inflammatory responses than their non-diabetic counterparts [99-102]. The chronic inflammatory response triggered by diabetes is implicated in cardiovascular disease development. There is an association between chronic inflammatory states and the progression of severe periodontitis [103-108]. The microbial flora of dental plaque is known to play a key role in the development of periodontal disease. Plaque within periodontal pockets of gingivitis contains primarily gram-positive species, while anaerobic gram-negative pathogens such as Actinobacillus actinomycetemcomitans, Porphyromonas gingivalis, and Prevotella intermedia dominate deeper pockets. The continued presence of supra- and subgingival dental plaque on teeth or prosthetics maintains the inflammatory process. The presence of P. gingivalis and other periodontal pathogens is greater in the dental plaque of type 2 patients than in that of healthy individuals [109-110]. In patients with diabetes, increased glucose levels lead to an increase of gram-positive and non-fermentative species, such as Staphylococcus epidermidis, Pseudomonas aeruginosa, and Acinetobacter baumannii, in the oral cavity and on subgingival surfaces [5]. Patients with type 2 diabetes exhibit a distinct subgingival microbial composition different from both healthy individuals and patients with type 1 diabetes. Elevated concentrations of inflammatory markers such as sICAM−1, IL−1β, and TNF−α in periodontal tissues reflect increased microbial load and cytokine expression [2]. The microorganisms present in such patients are capable of inducing a wide range of pro-inflammatory cytokines. Diabetes promotes a hyperinflammatory response to different periodontal pathogens. Infected diabetic patches rouse a greater influx of neutrophils, macrophages, and T helper type 1 cells, resulting in increased tissue destruction. Bacterial proteases, lipopolysaccharides, and other toxins released during plaque accumulation degrade tissue and induce bone resorption[7]. Hyperglycaemia prevents normal intracellular signalling in neutrophils and alters phagocytic and bactericidal functions. In diabetic

individuals, both local and systemic immune pathways function at diminished capacity, eventually leading to diminished control over local periodontal pathogens and, therefore, augmented periodontal tissue destruction [9].

Xerostomia and Salivary Changes

Diabetes mellitus is associated with a number of oral health problems, including alterations in salivary flow and composition, leading to xerostomia or dry mouth [5]. Patients may experience not only persistent dryness but also other symptoms such as changes in taste sensation. Diabetic patients with xerostomia may have reduced salivary flow related to poor metabolic control, elevated HbA1c, and increased fasting blood glucose and other risk factors, including the use of certain medications [6]. Xerostomia can have a number of detrimental effects on overall oral health, and the condition appears to be associated with greater caries incidence, periodontal disease, discomfort due to denture use, and impaired speech [9]. The salivary gland parenchyma may undergo structural and functional alterations in individuals with diabetes, resulting in a decrease in salivary flow [3]. Neuropathy affecting salivary glands, the presence of advanced glycation end products, and blood vessel impairment due to diabetes-related angiopathy may also contribute to diminished salivary secretion [5]. Decreased salivary flow can lead to hyposalivation and eventually asialia, or an almost complete absence of salivary output [1].

Caries Risk and Microbial Shifts

In diabetic subjects, the hazard of demineralization, particularly of the tooth's surface, may be heightened, a phenomenon closely interlinked with hydration [7]. When salivary concentrations of glucose, which exist above baseline levels, also prevail, the count of cariogenic species is prompted to rise. Notably, the cariogenic role of these species manifests through local acid production that extends into biofilm [8]. Furthermore, dental biofilms taken from people with diabetes harbor an overabundance of microorganisms from categories known to influence caries[9]. Strong partners, both in disease and the public domain, exhibit varied salivary compositional features depending on whether the host is diabetic[10].

Microvascular and Healing Considerations

Diabetes mellitus is a chronic metabolic disorder that is characterized by hyperglycemia due to a deficit of insulin secretion, action, or both [2]. It causes microvascular and macrovascular complications, which include diabetic parodontopathy. There is a strong association between diabetes and periodontal disease that has been attributed to damaging alterations of microcirculation in the periodontium and oral mucosa [9]. Hyperglycemia determines the excessive production of reactive oxygen species, which induces oxidative stress. Oxidative stress increases protein glycation and oxidation, which are factors associated with atherosclerosis and microangiopathic phenomena. Characteristic manifestations of microcirculatory damage at the oral mucosa level are tissue atrophy and an increase in periodontal disease, which is also partially caused by the excessive glucose concentration in the sulcular fluid [7]. The alterations at the microcirculation level can be in vivo analyzed by videocapillaroscopy, which allows the examination of capillaries' morphology and dynamics, including diameter, crossing, and density[6]. These parameters may have predictive value from the clinical point of view. However, no in vivo study has so far demonstrated an explicit connection between the variations of periodontal microcirculation and diabetic pathology. Capillaroscopic examination should be carried out on the oral mucosa, which is an accessible site for the study of patients [9]. Individuals with type 2 diabetes have been found to show macrovascular, microvascular, and metabolic complications related to increased glucose levels in different biological fluids, such as plasma, serum, and urine [6]. The periodontium is also accessible to capillaroscopy. Based on the considerations mentioned above, a study was carried out to identify and analyze microcirculatory variations at the periodontal mucosa in a population of subjects with type 2 diabetes [3].

Pathophysiological Mechanisms Linking Diabetes and Oral Health

Diabetes is a global health concern, and its prevalence is expected to rise significantly in the coming decades. Diabetes mellitus comprises a group of metabolic disorders characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both [3]. There are two major forms: type 1 diabetes, in which pancreatic β-cells are destroyed, leading to insulin deficiency, and type 2 diabetes, known for multifactorial aetiologies, including a combination of insulin resistance and defective insulin secretion, which often co-presents with obesity [15]. The concentration of glucose in the blood is maintained within narrow limits through a feedback mechanism coordinated by hormones such as insulin, glucagon, somatostatin, and catecholamines. Prolonged dysregulation triggers diabetes-associated pathophysiological changes, such as microvascular complications affecting the retina and kidney, peripheral vascular insufficiency, cardiovascular pathophysiology, delayed wound healing, and impaired immune response [11]. Such complications magnify patient risk for oral health-related issues and amplify attacks on dental and periodontal structures [4]. Glycemic control begun upon initial diagnosis and consistently pursued plays a significant role in mitigating these complications and, thus, is of pivotal importance. Therefore, the oral cavity should act as a crucial point of focus for health inspections, assessments, and feedback regarding the plight of the diabetic patients and their intimate relationship with evolving diabetes care [12]. Pathological transformations also encounter the oral cavity at various stages and

magnitudes during various oral and systemic events associated with uncontrolled high-risk diabetes and later-stage pre-diabetes [10].

Hyperglycemia and Advanced Glycation End-Products

Elevated levels of glucose and advanced glycation end-products (AGEs) are hallmarks of diabetes, responsible for several complications [3]. At normal glycemic levels, glucose is low enough that endogenous AGE formation catalyzed by glucose at free amino groups of proteins, lipids, and nucleic acids occurs relatively slowly [11]. AGEs can also be formed from other sources, including nicotine, pyrraline, methylglyoxal, oxo-dehydroglucose, and lead, among others, through non-enzymatic processes like Amadori rearrangement and caramelization (Chopra et al., 2022)[12]. The body has several systems for degrading these products, and AGEs can improve the biological properties of proteins, extend the half-lives of glycosylated proteins, and act as viability signals for cells [16]. Tissue concentrations of AGEs rapidly increase under elevated glucose levels, becoming detrimental (Chopra et al., 2022). For instance, it was demonstrated in a study in T1DM^1 that AGEs accumulate in lamina propria and corneal epithelium, causing approx[13]. 1.5- and 2-fold increases in skin fluorescence in T2DM. Sources of extracellular AGEs include proteins infiltrating from plasma and glycosylated/non-glycosylated proteins, their half-lives being considerably expanded under hyperglycemic conditions (Chopra et al., 2022)[11]. AGEs stimulate various receptors (e.g., RAGE), triggering inflammation, apoptosis, vascular leakage, and accelerating the development of diabetic complications. Hyperglycemia-induced DAG synthesis activates PKC isozymes in vascular cells, thereby also promoting inflammation and other mechanisms through other compounds and pathways [2]. Fluorophotometric measurements in another study of T1DM indicated that the eye-glucose barrier can be breached by AGEs (Chopra et al., 2022). Accordingly, AGEs contribute to hyperglycemia-induced early ocular complications in DM. AGEs produced in inflamed periodontal tissues were shown to be responsible for systemic elevation of AGEs in individuals with or without diabetes (Chopra et al., 2022)[3]. Individuals exhibiting periodontitis have higher AGE levels in serum, saliva, gingival crevicular fluid, tissue, and combined diabetes/periodontitis involvement leads to greater systemic AGE elevations than either condition alone[5].

Inflammatory Pathways and Cytokine Networks

Glycemic imbalance produces important changes in the immune system that affect host responses to infection and enhance tissue destruction [2]. Systemic effects of diabetes, including impaired immune response, altered salivary function, and impaired wound healing, promote the onset, severity, and progression of oral diseases, including infections and periodontal disease [12]. Immuno-inflammatory mediators, such as cytokines, are produced in the diabetic host in response to multiple stimuli, including microbiota dysbiosis in the oral cavity, and induce tissue damage and bone resorption in multiple organs. Periodontal pathogens contribute to the pathogenesis of diabetes through diverse inflammatory pathways [5]. Confirmatory evidences include sustained elevations of specific immunological components related to diabetes observed after oral infection, which, in turn, induces modifications of the oral biofilm conducive to other opportunistic infections [9]. The pandemic of diabetes mellitus (DM) is affecting millions of people worldwide. Since the beginning of the 21st century, China has overtaken the USA to become the country with the most people with diabetes. DM is a heterogeneous group of disorders characterized by hyperglycemia due to defects in glucose homeostasis [13]. Type 1 DM is characterized by insufficient insulin production, whereas Type 2 DM, the most prevalent form, may have an initially normal or even high-serum insulin level but is accompanied by [2] the lack of efficiency of the secreted hormone to elicit a physiological response, [1] increased production of insulin combined with altered insulin clearance, or [3] the action of various biological pathophysiological processes responsible for the eventual depletion of the original insulin supply [15].
Metabolic syndrome, a disease that affects the majority of Type 2 DM patients, is associated with Pre-Diabetes and progresses from Insulin Resistance to overt clinical stages where a variety of bioactive lipids accumulate, triggering further downstream inflammation [5]. The disease is characterized by high blood sugar levels due to a lack of insulin, insulin resistance, or other causes, and has a wide range of tissue and organ complications, such as cardiovascular disease, nephropathy, retinopathy, neuropathy, and poor wound healing [13].

Salivary Alterations and Oral Microbiome

Long-term hyperglycemia in diabetes leads to the development and progressive accumulation of advanced glycation end-products (AGEs), generation of reactive carbonyl precursors, and post-translational protein modifications that induce morphological, structural, and functional changes in salivary glands, notably the parotid gland [13]. These changes impair salivary secretion; alter the concentration of specific proteins, electrolytes, nitric oxide (NO), and other metabolites; and induce increased dehydration, viscosity, and lability of saliva [7]. Consequently, saliva substitutes, moisturizers, and stimulants that are commonly prescribed for xerostomia provide only partial relief [8]. Within the oral cavity, diabetic hyperglycemia alters the composition of the salivary microbiome, salivary metabolites, and the pH of saliva. At both the systemic and local levels, diabetes influences the immune and inflammatory response; increases the risk of infection through alterations of the plasma and salivary proteomic profiles; and modifies the bioavailability of key signalling molecules such as reactive oxygen species (ROS) and nitric oxide (NO) [14]. These effects, combined with a reduced pH and increased

viscosity of saliva, may promote the transition from health to disease following infection of vital organs and tissues, including the oral cavity [13].

Vascular and Wound-Healing Impairments

Impaired vascular integrity and compromised wound healing are common consequences of diabetes mellitus. Endothelial dysfunction plays a pivotal role in vascular complications and leads to macrovascular and microvascular diseases such as retinopathy [11]. Diabetes increases the risk of infection and prolongs the healing process due to immune dysfunction, including abnormalities and impaired chemotaxis of neutrophils. In patients with diabetes, dental treatment often results in delayed healing, with defects in neutrophil activation, fibroblast migration, proliferation, and angiogenesis [15]. Advanced glycation end-products accumulate in gingival tissues, potentially contributing to tissue injury by interfering with matrix-cell interactions [12].

Bidirectional Relationships: Oral Health Impact on Glycemic Control

The interrelationship between periodontal disease and diabetes has been described as bidirectional. Clinical and epidemiological studies demonstrate not only that poorly controlled diabetes increases the risk of periodontal disease, but also that periodontal therapy can significantly lower glycated hemoglobin (HbA1c) levels [16]. Individuals with diabetes exhibit higher frequencies of periodontal disease, gingival inflammation, and oral complications than those without [17]. Societal frameworks employed for diabetes care present relevant diagnostics and therapeutics for examination of these relationships [2]. Periodontal treatment reduces HbA1c levels by an average of 0.38% over periods ranging from 1.5 to 24 months, achieving significance in most studies. The relationship between oral infections and systemic inflammation may represent a crucial pathway for the influence of oral health on diabetes [6]. Periodontopathic bacteria and their extracellular products can enter the bloodstream and stimulate production of interleukin (IL)-1β and IL-6, which induce hepatic production of fibrinogen and C-reactive protein (CRP) [7].

Influence of Periodontal Therapy on HbA1c

Periodontitis is a chronic inflammatory disease that affects the supporting tissues of the teeth. It is characterized by periodontal pocket formation, gingival recession, and loss of connective tissue attachment to root surfaces. Diabetic patients have a higher prevalence and severity of periodontal diseases than nondiabetic individuals [2].
Diabetes is still a major problem in the world [17]. It is a noncommunicable disease that has high prevalence and mortality [11]. Periodontal disease is also a major concern for the world currently. It affects a large population throughout the world. Many studies have been done to assess the effect of diabetes on periodontal disease. Markedly elevated levels of glycosylated hemoglobin A1c (HbA1c) provide evidence of poor glycemic control [3]. According to the American Diabetes Association (ADA), HbA1c can be used to measure the 3-month average of carbohydrate intake and metabolic control in patients. It represents a significant measure in the progression of diabetes. Strict control of glucose levels is essential in establishing a healthy life [5]. Diabetes can enhance susceptibility to various infections and can impede the healing of wounds in diverse sites of the body, including the oral cavity. Diabetic patients have a higher prevalence of oral diseases and infections; periodontal disease appears to have a close association with diabetes among all of these problems [7]. Periodontal disease affects not only the oral cavity but can also reflect the overall health status of the patient; that is, periodontal disease can be considered as a manifestation of systemic disease[4]. Periodontal disease might adversely affect the control of glucose levels. The association between periodontal disease and diabetes has suggested that periodontal treatment is likely to have an effect on the glycemic control of diabetic patients [18, 19].

Impact of Oral Infections on Systemic Inflammation

Periodontal pathogens that penetrate the bloodstream during gingival inflammation can impact distant tissues involved in energy homeostasis [21]. This influence constitutes a relevant mechanism for the bidirectional connection between diabetes and periodontitis [20]. In type 2 diabetes, prolonged hyperglycemia alters metabolic pathways and activates the formation of advanced glycation end products (AGEs). Such compounds elevate the secretion of proinflammatory mediators by immune cells and compromise the functionality of macrophages, dendritic cells, and neutrophils, causing further tissue damage [22]. Increased circulating levels of proinflammatory substances such as tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and C-reactive protein (CRP) by the host lie at the heart of the relationship between diabetes and periodontal disease [23]. These factors aggravate metabolic control, intensify microvascular complications, and render type 2 diabetes more difficult to manage [21].

Clinical Assessment and Risk Stratification

Regular screening for oral health problems should be considered an integral component of diabetes care [22, 23]. Periodontal disease and other oral health disorders negatively impact the quality of life in diabetic individuals. Further, the presence of oral disease could contribute to poor glycemic control, increased systemic inflammatory burden, and heightened cardiovascular disease risk [16]. The American Dental Association endorses the consideration of whether a person has, or is at risk of developing, a dental disease or condition as one of the six key clinical conditions that constitute indicators of overall health. Consequently, oral health status should be included

in the assessment of persons with diabetes [2]. Periodontal involvement or candidiasis may be taken as indicators of poorly controlled diabetes during initial or subsequent visits. Individuals with diabetes are known to be at increased risk of oral health problems stemming from abnormal salivary function, poor oral hygiene practices, and a high dietary intake of fermentable carbohydrates [4]. Periodontal health status, number of remaining teeth, oral hygiene practices, salivary function, and frequency of dental visits therefore represent appropriate screening indicators for the identification of oral disease risk, the understanding of diabetes-related oral complications, and, ideally, the initiation of interprofessional collaboration or referral[6]. The presence of advanced periodontal disease and excessive tooth loss following periodontal disease is also associated with increased cardiovascular disease risk both in the general population and in populations characterized by a high prevalence of diabetes [7].

Screening for Oral Health in Diabetes Care

Diabetes has been shown to exacerbate oral diseases, including periodontal disease, especially in individuals with poor glycemic control [1]. The ability of oral diseases to negatively impact glycemic control adds a further dimension to the interrelationship between diabetes and oral health, making screening for oral health and the provision of goal-oriented oral health care critical in diabetes management [16]. Such screening should be performed at the time of initial diagnosis and at subsequent routine health care visits.

Diagnostic Indicators and Monitoring

In addition to the oral health complications associated with diabetes mellitus, underlying factors contributing to these adverse outcomes have been identified [3]. One means of detecting such changes involves the monitoring of specific biomarkers in saliva and blood [3]. When assessing paraclinical evolution or the efficacy of anti-diabetic therapy, monitoring blood levels of glycated hemoglobin (HbA1c) represents a standard procedure [6]. The concentrations of this hemoglobin derivative furnish information about glucose variability over previous weeks and enable the definition of hyperglycemia-based metabolic control, being an indirect indicator of periodontal condition [1]. Following the first months of diabetes treatment, the objective for HbA1c improvement is hence determined. The relative reduction sought for this marker can be used to classify patients into different metabolic control categories, taking into account the level of glycemic control before diabetes therapy was introduced [6]. Periodontal pathologies have also been correlated to the presence of salivary indices linked to the glycemic status of individuals, notably salivary glucose [6].

Inter-professional Collaboration and Care Pathways

Healthcare professionals play a vital role in screening for oral health conditions in patients with diabetes. Numerous studies have explored how and when oral health is focused on within diabetes care [24]. One study reported that primary care physicians seldom ask about the oral health of patients with diabetes. This is partly attributed to a perception that such inquiries are not relevant and a view that patients already receive any necessary oral healthcare [23]. Dental health services, on the other hand, largely lack specific protocols for analyzing diabetes hazards. Consequently, diabetes has little impact on the assessment of oral health, despite the existence of considerable evidence indicating a connection [22]. Many dental health providers do not routinely question patients about diabetes, and even those who conduct glucose testing report discrepancies in the condition's influence on treatment [21]. Patients with diabetes are often unaware of the association between their condition and oral health. They seek more information about how periodontal treatment can improve glycaemic control, desire assistance in managing their disease, and value discussions with healthcare professionals about both the disease itself and oral hygiene [19]. Integrating topics related to diabetes and oral health into a patient's overall wellness can improve motivation. Attention to oral health can enhance patient engagement in diabetes treatment programmes [18]. Patients are also concerned that appropriate management of gum disease may reduce ongoing complications due to dental treatment. Greater awareness about the relationship connecting diabetes and oral health could help patients make educated decisions about both [17].

Management and Intervention Strategies

The management and intervention strategies reported emphasize preventive methods and treatment alternatives that target both diabetes and its oral health ramifications. Individuals suffering from tooth loss and those who self-assess their oral health unfavorably face a heightened risk of ischemic stroke, additional vascular disorders, and increased mortality rates [25]. Hence, individualized wellness and health agendas aimed at curtailing obesity emergence or progress are warranted, given obesity's established links to diabetes and other chronic conditions [26]. Certain periodontal therapies, including non-surgical periodontal treatment (NSPT) augmented with adjunctive photodynamic therapy and doxycycline, effectively reduce glycated hemoglobin (HbA1c) levels in non-smoking patients who also present periodontal disease [11]. Gaseous ozone treatment further benefits patients experiencing both diabetes and periodontitis [12]. Moreover, access to oral healthcare remains notably limited for residents of assisted living facilities, reinforcing policy advocacy's importance [11]. Educational strategies such as role-playing pharmaceutical consultations serve to enhance health professionals' knowledge and motivation surrounding diabetes, while interventions introducing dental hygienists to palliative care promote both career development and improvement of patients' quality of life [10]. Risks to oral hygiene frequently arise among

college students, highlighting the necessity for dedicated awareness campaigns targeting this demographic [19]. More generally, preventive approaches addressing both environmental and genetic determinants, thereby preventing and arresting the onset of diabetes, its complications, and concomitant oral health issues, constitute a primary line of action [8]. Comprehensive diabetes management and treatment orbited around glycemic control and systemic factors substantially mitigate the risk of oral conditions [14]. Health practitioners, especially general medical doctors and nurse practitioners, thus bear crucial responsibilities in both the clarification of oral health's implications in diabetes and the constituent engagement of patients in therapeutic strategies [17].

Preventive Dentistry in Diabetes

Patients with diabetes are at heightened risk for oral health complications, yet information on appropriate dental care remains insufficiently integrated into diabetes care [13]. Although certain diabetes medications can exacerbate periodontal disease, other medicines such as metformin, glucagon-like peptide-1 receptor agonists, and sodium-glucose co-transporter-2 inhibitors exert an overall prophylactic effect [5]. Consequently, dental health professionals should employ teaching and counselling strategies focusing on self-care and on the management of specific complications, including dry mouth, oral candidiasis, dysgeusia, and periodontal disease. Referral pathways for diabetes prevention and management should furthermore be enhanced and strengthened [1, 16].

Periodontal Therapy and Glycemic Outcomes

Severe periodontal disease represents a significant oral health complication for individuals with diabetes mellitus. As evidenced by clinical improvements following therapy, active periodontal disease may negatively impact glycemic control [18]. Widths of keratinised gingival tissue, probing depth, and clinical attachment levels in patients with type 2 diabetes and periodontal disease improve after nonsurgical periodontal therapy. Improvements in clinical and glycemic parameters are apparent as early as three months post-treatment [27]. Bacteriological studies and records of diabetes history prior to the onset of periodontal disease suggest the systemic impact of periodontal infection [20].

Patient Education and Self-Care

The provision of information about diabetes-related oral complications, specific sugary dietary risk factors, dietary replacements for sugary products, tobacco cessation assistance for periodontal health, smoking addiction and periodontal disease awareness, and clarifications regarding early-periodontally-influenced diabetes was consistently substandard [2]. Public health initiatives and instructional programs that stress the necessity of oral examinations, the oral impact of diabetes on both esthetics and quality of life, and the need for interprofessional assistance could greatly benefit affected populations [28]. Adherence to prescribed pharmacological treatment regimens and the link between temporal control of blood glucose and the prevention of complications merit patient educational emphasis. Periodontal disease impacts diabetic control [29]. Educational programs that address the reciprocal effects of diabetes and periodontal health may enhance compliance with proper oral hygiene measures.

Individuals with diabetes often bear a greater risk for oral disease [25]. Oral health also significantly affects the course of diabetes, as infections and inflammatory conditions provoke systemic mediators that may elevate blood glucose [31]. Conversely, a low level of understanding regarding the impact of oral health on diabetes is proportionately correlated with reduced diabetological condition awareness. Health professionals engaged in diabetes management should underscore the importance of oral health and recommend regular dental visits to facilitate early diagnosis of potentially diabetic complications [2].

Medication Considerations and Safety

Dental practitioners need to be aware of the medication-related side effects experienced by their patients. Diabetes patients are prescribed various medications that can induce side effects affecting the oral cavity and complicating dental treatment [6]. Medication-related oral effects should mainly be considered for patients receiving insulin, antihyperglycemic medications, polypharmacy treatments, and psychotropic agents [3]. Insulin preparations induce oral side effects such as burning mouth syndrome, taste disturbance, oral discomfort, swelling, and vesicle lesions. Antihyperglycemic medicines may cause oral candidiasis or cytotoxicities in the hard and soft tissues; therefore, routine follow-ups are needed [4]. Oral side effects of antihyperglycemic drugs include dysgeusia, burning mouth syndrome, dry mouth, and slowed wound healing [3]. Psychotropic medications used to treat anxiety and depression constitute some of the most widely prescribed drugs among diabetic patients. Careful assessment of the oral side effects caused by these medications is recommended; otherwise, the patient's health may be compromised [3].

Special Populations and Considerations

Type 1 (T1D) and type 2 diabetes mellitus (T2D) represent distinct diseases with unique pathophysiologies, while sharing epidemiologic and clinical features [9]. The overall prevalence of oral health conditions associated with diabetes, as well as their systemic impact, is higher in T2D than T1D due to the longer duration of illness, the concomitant metabolic syndrome, and the more severe level of hyperglycemia [8]. Multivariate models support that T2D rather than T1D is independently associated with an increased risk of periodontal disease in subjects without other health issues [7]. The frequency of caries is, in general, higher in T1D than in T2D, partly due to

different social habits, as well as intrinsic factors such as the depletion of salivary flow or a more frequent history of oral infections [16].

Pediatric and Adolescent Patients

Diabetes is currently diagnosed and treated in children and adolescents, allowing the results of its oral implications to be evaluated in the early stages of the disease [10]. Subjects at the onset of T2D who consulted a dentist at the time of diagnosis had already experienced at least one episode of oral inflammation. Thermography studies demonstrated that dental pulp inflammation can occur in T2D within the first few months of the onset of the disease [30].

Pregnant Individuals with Diabetes

Women who had preexisting diabetes prior to conception or who developed gestational diabetes are prone to developing oral conditions (e.g., gingivitis, periodontitis, and dental caries) during pregnancy [13]. Dental checks and advice should be encouraged before, during, and after pregnancy in such patients for oral health maintenance as well as for the prevention of fetal complications [14].

Type 1 versus Type 2 Diabetes

The extractions have clarified and expanded aspects of the bidirectional interplay between diabetes and oral health, as well as management strategies, while further developing sections focused on special populations and public health [17]. Type 1 and Type 2 Diabetes provide new information about distinct physiological differences that could drive different oral health outcomes in diabetes. Other sections introduce new material based on relevance to diabetes and oral health [16]. The result is a broader yet still focused treatment of the overall topic. Common misconceptions persist about the differences between T1D and T2D. T1D can occur at any age and typically appears during childhood or adolescence; however, T2D is increasingly seen in children and adolescents, largely as a consequence of the rising prevalence of childhood obesity and sedentary lifestyles [11]. Much research has focused on children and adolescents with T1D, but the incidence of T2D in such populations has grown alarmingly [23]. These trends likely affect oral health outcomes, yet few studies have systematically examined the oral health components of T1D and T2D, particularly among children and adolescents [10]. Periodontal inflammation has been proposed as a potential contributing factor to the destruction of pancreatic ß-cells in T1D [31]. Preclinical models indicated that an inflammatory mechanism could sustain and amplify ß-cell destruction initiated by autoimmune processes [18]. One study reported that the glycosylated hemoglobin (HbA1c) levels of children and adolescents with T1D and periodontitis were higher than those of children without periodontitis. Prior to periodontal therapy, children with T1D plus periodontitis exhibited worse glycemic control than children with T2D and periodontitis; however, this difference disappeared after treatment [19]. These findings suggest that periodontal disease might represent a risk factor for poor glycemic control in young people with T1D. Conversely, limited evidence from children and adolescents suffering from T2D and periodontal disease indicated no significant food intake deviations from corresponding children with T2D and good periodontal health [11]. Further investigation into age, sex, oral hygiene practices, and dietary habits may elucidate potential gender differences regarding childhood periodontal disease and the relationship between diabetes and childhood periodontal disease [12].

Pediatric and Adolescent Patients

Insufficient diabetic management during childhood carries serious health implications, and oral health constitutes an especially important area of concern [19]. Diabetes is often accompanied by complications involving the kidneys, eyes, and cardiovascular system, prompting needs for interprofessional treatment. Children with type 1 diabetes show elevated standard deviation scores for red and inflamed gum levels and various other periodontal health measures [32]. Existing oral conditions are worsened by persistently high glycosylated hemoglobin (HbA1c) values and metabolic decompensation episodes [20]. In adolescents with diabetes, associations exist between periodontal disease and additional damage to oral health, such as caries, causing both soft-tissue and hard-tissue loss. For this reason, heightened attention is needed concerning appropriate oral hygiene measures among youth with diabetes [18].

Pregnant Individuals with Diabetes

The burden of gestational diabetes mellitus (GDM) has increased globally, raising awareness of its effects on oral health. Individuals with GDM generally show poorer oral health than their non-diabetic counterparts, likely due to more complex lifestyle, diet, and dental treatment histories [33]. An investigation of salivary microbiota and nutrient profile further reveals that salivary glucose monitoring may reflect metabolic control lapses during pregnancy, even in women diagnosed with GDM well before conception [34]. The early shift in carotenoids towards β-carotene and later adjustment of amino acids, on the contrary, occurs only in GDM-affected pregnancies [33]. Potential reasons for such divergence include dietary alterations associated with excessive weight gain during this sensitive period [22]. Considering the pervasive physiological and hormonal transitions accompanying gestation and their interactions with diabetes, dental professionals should pay close attention to the

oral healthcare needs of at-risk pregnant individuals and routinely consult on general health during preventive examinations [20].

Public Health Perspectives and Policy Implications

Dr. L.G. G. Astek enunciated the need to promote public awareness regarding oral health, specifically for diabetes patients [20]. In this regard, studies revealed that most patients are unaware of the high glucose/fragility of the oral cavity and major oral hygiene strategies to apply. Research showed a lack of financial protection for dental services after a diabetes diagnosis, due to high costs [12]. Enhancement of oral health education, screening services, dental-service packages, and policy prioritization is of prime importance [23]. The Ministry of Health should place further focus on the prevention of diabetes and oral health problems [12]. Healthcare systems should fortify preventive and management strategy arrangements through the prevalence of diabetes, along with interprofessional and interdisciplinary integration promotion to resolve both oral and systemic health-related matters [25, 30].

Access to Care and Health Literacy

The condition of oral health in people with diabetes is informed not only by biomedical factors but also by social factors, including access to prevention and treatment services, use of preventive dental services, professional dental cleaning, and endorsement of self-care practices [27]. There is a growing recognition that higher levels of health literacy enable individuals to obtain effective preventive and therapeutic care because they possess the skills and critical thinking to navigate resource-constrained environments and lifestyles that challenge acquisition and maintenance of oral health 35. In people with diabetes, limited knowledge and inappropriate oral health behaviours adversely affect both diabetes and oral health outcomes [36]. Access to dental care throughout their lives is poorer among many in minority and economically disadvantaged groups, even when educational attainment is similar [31]. For people with diabetes, oral health signs and symptoms that arise throughout the continuum of the disease are rarely sought for care until major damage has occurred [30]. Because of the conception of oral health as a relatively low public health priority, many health agencies and policy-makers fail to recognize oral health as an integral component of overall health and wellness, or neglect education on access to dental care as part of strategic health promotion efforts[29]. Further pooling of public health resources, such as for the COVID-19 pandemic, dilutes what meagre investment exists for oral health topics and exacerbates associated risks [32].

Integrated Care Models

People with diabetes are at increased risk for oral diseases; conversely, oral diseases are associated with poorer glycemic control [33]. These mutual relationships provide good reasons for fostering integrated medical-dental care. A pilot study in 6 states explored the integration of chronic disease programs across multiple domains, yielding lessons applicable to the diabetes-oral health nexus [37]. Another longitudinal project in community health centers with federally qualified health center dental safety net clinics demonstrated the potential of point-of-care glycemic screening to facilitate access to comprehensive chronic disease care, benefiting both diabetes and periodontal disease [38].

Research Gaps and Future Directions

Although studies have demonstrated the need for integration of diabetes and oral health care, considerable gaps remain [39]. The substantial evidence of a relationship between diabetes and periodontitis 39 has not resulted in a paradigm shift for many health professionals [21]. The challenge remains even greater for other oral health–diabetes links, for which the evidence base is more limited. Neither the quantity of work nor its attention from the dental community has translated into robust knowledge by the medical profession [30]. Siloed practice continues to hinder collaboration and communication between the two groups, while linguistic barriers and a lack of awareness of key bibliometric terms restrict outreach to non-specialists, as does the proliferation of predatory journals. The need for further investigation remains pressing [38-48]. Longitudinal studies are warranted to clarify the manifestation, progression, and timing of oral complications in diabetes, as well as to identify putative sex-specific and drug-specific differences [34]. Exploration of risk-reduction strategies, alongside the pathways that underpin diabetes-related oral alterations in particular populations, such as the mechanically ventilated, is also essential [37]. Biobanks and omics-based research, supplemented by health economics studies, may elucidate the biological and economic links between diabetes and oral health. Patient-centered outcomes and qualitative methods are likewise deserving of greater focus [36].

CONCLUSION

Diabetes mellitus exerts a significant and multifaceted impact on oral health, with periodontal disease emerging as the most prevalent and clinically significant oral complication. The evidence presented in this review reinforces the concept of a bidirectional relationship between diabetes and oral disease, in which hyperglycaemia-driven immune dysfunction, inflammatory pathways, advanced glycation end-product accumulation, and microvascular impairment contribute to oral pathology, while chronic oral infections further exacerbate systemic inflammation and compromise glycaemic control. These interactions underscore the oral cavity as both a target and a contributor to the progression of diabetes. Clinical findings consistently demonstrate that individuals with poorly

controlled diabetes experience more severe oral complications, including periodontal disease, xerostomia, caries, delayed wound healing, and altered oral microbiota. Conversely, effective periodontal therapy has been shown to produce modest but clinically meaningful reductions in HbA1c levels, highlighting the importance of oral health interventions as an adjunct to diabetes management. Despite this strong evidence base, oral health assessment remains insufficiently integrated into routine diabetes care, and awareness of the diabetes–oral health connection among both patients and healthcare professionals remains limited. From a public health and policy perspective, improving outcomes requires a shift toward integrated medical-dental care models, enhanced health literacy, routine oral health screening, and improved access to preventive and therapeutic dental services, particularly for vulnerable and underserved populations. Interprofessional collaboration between medical and dental practitioners is essential to bridge existing care gaps and ensure early identification and management of oral complications. In conclusion, recognizing oral health as an integral component of diabetes care is critical for reducing disease burden, preventing complications, and improving quality of life. Future research should prioritize longitudinal and translational studies, explore population-specific risk factors, and evaluate cost-effective integrated care strategies. A holistic, patient-centred approach that addresses both metabolic control and oral health holds substantial promise for improving long-term outcomes in individuals living with diabetes.

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