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Type 2 Diabetes Mellitus and Oral Health: Understanding the Bidirectional Relationship: A Narrative Review

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ABSTRACT

Diabetes mellitus, a common endocrine disorder, has critical systemic impacts and well-documented consequences for oral health. This review analyzes studies from 2020 to 2025 that demonstrated the complex bidirectional relationship between Type 2 Diabetes Mellitus (T2DM) and oral disease.

Evidence confirms that poor glycemic control leads to higher incidence and severity of periodontitis, tooth decay, candidiasis, dry mouth, burning mouth syndrome, impaired wound healing, among other oral complications. These conditions can also contribute to worsening diabetic management, creating a self-perpetuating cycle.

Integrated patient care is therefore essential to break this cycle and reduce its effects on patients, which must include targeted education among diabetic patients about their increased oral health risks, alongside management strategies that emphasize both metabolic control and regular professional dental care.

This review also highlights the urgent need for context-specific strategies in the Arab world, a region with a high prevalence of T2DM, exemplified by an estimated number of 85 million affected adults in the Middle East and North Africa (MENA) region Translating the firm evidence on the oral-systemic relationship into routine practice requires closing the gap between existing research and clinical application. Addressing this gap is fundamental to developing clinical guidelines that are effective healthcare protocols specific to the region.

Keywords: Diabetes mellitus, Type 2, Periodontitis, Bidirectional relationship, Glycemic control, Oral health, Xerostomia.

1. Introduction

Type 2 diabetes mellitus represents a major and growing public health problem, estimated to affect approximately 589 million people by the end of 2025, accounting for over 90% of diabetes cases worldwide (1). While its systemic complications are widely recognized, the profound bidirectional relationship between T2DM and oral health often receives limited attention from diabetes care providers.

Oral complications are common outcomes of diabetes (2) and function as active components in a vicious cycle: poor glycemic control exacerbates oral disease, which in turn fuels systemic inflammation and worsens metabolic control (3). This bidirectional relationship produces negative effects on the quality of life for diabetic patients and increases the difficulties that these individuals experience (4). Despite robust evidence, a stark care gap persists, as recent evidence indicates that nearly a half of people with diabetes do not receive any oral health guidance from their healthcare providers (5).

To inform more integrated care approaches, this narrative literature review aims to answer the following two central questions: First, what did recent studies

(2020–2025) reveal about the mechanisms of the bidirectional cycle between type 2 diabetes mellitus and oral health complications? Second, what evidence-based interventions can break this cycle to improve patient outcomes? To address these questions, the review will synthesize studies and analyze their results, with a specific focus on the underlying pathological processes that form the basis of this relationship and present recommendations for clinical practice aimed at reducing these effects.

2. Materials and Methods

This review is designed as a narrative literature review. A structured search was applied to improve transparency, with the primary emphasis placed on critical appraisal and thematic synthesis over exhaustive study enumeration, consistent with the principles of the narrative review model.

2.1 Search Strategy

A comprehensive literature search was performed in three electronic databases; PubMed (MEDLINE), Scopus, and Web of Science, for English studies published between January 2020 and September 2025 on Type 2 Diabetes Mellitus (T2DM), oral health conditions. Keywords and controlled vocabulary terms were combined *via* Boolean operators. The exact search string was adapted to the syntax of each database, as provided below:

- PubMed: ("Diabetes Mellitus, Type 2"(Mesh) OR "Type 2 Diabetes" OR T2DM) AND ("Oral Health" (Mesh) OR "Periodontal Diseases" (Mesh) OR "Xerostomia" (Mesh) OR "Candidiasis, Oral" (Mesh)) AND ("Glycation End Products, Advanced"(Mesh) OR "Microbiota" OR "Oxidative Stress" (Mesh) OR "Wound Healing" (Mesh)).
- Scopus: TITLE-ABS-KEY (("type 2 diabetes" OR t2dm) AND ("oral health" OR periodont* OR xerostomia OR candidiasis) AND ("glycation end products" OR microbiome OR "oxidative stress" OR "wound healing").
- Web of Science: TS = (("type 2 diabetes" OR T2DM) AND ("oral health" OR periodont* OR xerostomia) AND ("advanced glycation end products" OR microbiota).

2.2 Study Selection

Analytical priority was given to systematic reviews, meta-analyses, randomized controlled trials, cohort studies, and large cross-sectional studies conducted in adults with T2DM. Studies on Type 1 diabetes, pediatric populations, case reports, editorials, and non-peer-reviewed studies were excluded.

From an initial yield of 400 records, following duplicate removal, 320 unique records underwent title/abstract screening. Of these, 85 full-text articles were screened against the eligibility criteria, resulting in the identification of 53 key studies.

2.3 Data Extraction and Critical Appraisal

Data on study design, population, and key findings was extracted. Analysis followed established thematic synthesis steps: repeated reading and line-by-line coding of findings, development of descriptive categories, and iterative revision into the four analytical themes that structure the results and discussion of this review.

The methodological quality of the included studies supporting each theme was critically examined. The outcomes of these appraisals are integrated narratively within the results section, where the consistency and limitations of the evidence that supports each key theme are discussed. It should be acknowledged that the methodology of this review, the selection of studies, and their interpretation may have been influenced by the analytical perspectives of the researchers to build a coherent argument. Additional constraints include language restriction, exclusion of grey literature, and possible selection bias.

3. Results

3.1 Oral Manifestations in T2DM

The oral cavity is a frequent site for complications in patients with type 2 diabetes mellitus (2). This sub-section reviews the most prominent of these manifestations, with a focus on those of greatest clinical relevance.

3.1.1 Periodontal Disease: A Prevalent and Severe Complication

Clinical and epidemiological evidence consistently shows that patients with type 2 diabetes mellitus (T2DM) have a higher prevalence and severity of gingival and periodontal disease compared to individuals without diabetes mellitus (6-8). This is clinically manifested by the rapid progression of gingivitis, bleeding on probing, the formation of

pathological pockets, and alveolar bone loss. This frequently results in increased tooth mobility and elevates the risk of tooth loss (8).

Importantly, the severity of periodontitis in these patients is closely correlated with the degree of glycemic control; individuals with higher HbA1c levels typically present with more advanced disease (9).

3.1.2 Xerostomia (Salivary Hypofunction)

Xerostomia affects approximately 42.5% of T2DM patients, with a higher prevalence among those with poor glycemic control (HbA1c >7%) (10,11). Characteristic symptoms include persistent dry mouth, difficulty speaking (dysphonia), swallowing (dysphagia), and tasting food (dysgeusia). Patients may also experience a burning sensation in the mouth (burning mouth syndrome) and increased thirst (12).

This condition leads to increased susceptibility to dental caries and erosive tooth wear and mucosal irritation (7,8,13), which collectively contribute to nutritional difficulties and a reduced quality of life (4).

3.1.3 Increased Susceptibility to Oral Infections

Patients with T2DM are more susceptible to a spectrum of oral infections compared to the non-diabetic population, including:

- Fungal Infections: Oral candidiasis is a frequent complication, with reported prevalence rates ranging from 2% to 24.3% in this patient group (14). It commonly presents in clinical forms, such as pseudomembranous (thrush) and erythematous (atrophic) candidiasis, and angular cheilitis.
- Bacterial Infections: Beyond chronic periodontitis, T2DM patients experience more frequent acute and severe bacterial infections, including periodontal abscesses and severe necrotizing periodontal diseases (15).
- Viral Infections: Reactivation of latent viruses, such as herpes simplex virus (HSV), occurs more frequently and severely, manifesting as recurrent herpetic gingivostomatitis and herpes labialis (13).

These infections contribute to significant oral pain, functional limitations, and psychological discomfort, which collectively impair nutritional intake and substantially reduce oral health-related quality of life in patients with T2DM, as confirmed by a recent systematic review and meta-analysis (16).

3.1.4 Delayed Wound Healing

T2DM patients experience delayed healing of oral wounds, extraction sockets, and surgical sites (7,17). This manifests clinically as prolonged tissue repair, an increased risk of postoperative infection, extended treatment times, and a greater healthcare burden (7), significantly prolonging the overall recovery period following dental procedures (17).

3.1.5 Additional Oral Manifestations

T2DM also affects oral health through several other significant manifestations:

- **Neuropathic Oral Manifestations :**Patients may experience burning mouth syndrome, oral paresthesia, and taste alterations. These sensory disturbances significantly impact nutrition and quality of life (4,12,18).
- **Dental Caries and Enamel Demineralization:** There is an increased prevalence of dental caries, particularly root caries, leading to more rapid tooth destruction and complex treatment needs (11,13,19).
- **Oral Mucosal Lesions:** Higher incidence of conditions, such as fissured tongue, lichenoid reactions, recurrent aphthous ulcers, and mucosal pigmentation changes, is observed. These conditions cause significant discomfort and require monitoring for potential malignancy risk (7,13).
- **Other Manifestations:** Halitosis and increased tissue fragility are commonly reported, further complicating oral hygiene and social well-being (4,10,13).

3.2 Integrated Pathophysiological Basis of the Bidirectional Relationship

The oral manifestations observed in patients with T2DM arise from a multifactorial network of interconnected pathological mechanisms driven primarily by chronic hyperglycemia. Together, these processes generate a self-perpetuating cycle of inflammation and tissue damage that accelerates disease progression at both the systemic and oral levels (20). The following interconnected pathways form the core of this network:

- **The AGE-RAGE Inflammatory Axis**

Sustained hyperglycemia leads to the formation and accumulation of Advanced Glycation End Products (AGEs) in periodontal tissues. The binding of AGEs to

their receptor (RAGE) acts as a master inflammatory switch, triggering inflammatory signaling (e.g. NF-κB) and the release of potent pro-inflammatory mediators, such as TNF-α and IL-6 (15,21). This persistent, low-grade inflammation is a primary driver of periodontal tissue and bone destruction, and its level directly correlates with the clinical severity of periodontitis in diabetic patients (9,22).

- **Oral Microbiome Dysbiosis**

Chronic hyperglycemia creates a favorable environment that alters the natural composition of the oral microbiota, reducing overall diversity and promoting the proliferation of pathogenic, periodontitis-associated bacteria (11). This dysbiosis has consequences beyond the oral cavity; it serves as a persistent reservoir that fuels systemic inflammation through the release of components, like lipopolysaccharides (LPS), thereby exacerbating insulin resistance (23,24). Thus, the oral microbiome forms a critical link in the bidirectional cycle: hyperglycemia induces dysbiosis, which escalates systemic inflammation and impairs glycemic control, creating a feedback loop (3,15,25).

- **Systemic Immune Dysregulation and Increased Susceptibility to Oral Infections**

Hyperglycemia impairs the immune system comprehensively, increasing susceptibility to oral infections and disrupting wound healing. This manifests as dysfunctional innate immune responses (e.g. impaired neutrophil chemotaxis and phagocytosis (13,17)), and a disruption in lymphocyte balance favoring pro-inflammatory (e.g. Th17) over regulatory T cells (Tregs) cells (15). This immune impairment leaves oral tissues more vulnerable to microbial challenge and less capable of repair (24).

This impaired immune environment is further compounded by local metabolic changes, primarily elevated glucose levels in saliva and gingival crevicular fluid, which favor microbial growth. In the case of fungal infections, hyperglycemia facilitates the proliferation and epithelial adherence of *Candida albicans*, partly through increased expression of adhesins, such as Als3 (26). Regarding bacterial infections, neutrophil dysfunction weakens host defense against acute conditions, like periodontal abscesses (24). In addition, impairment of cell-mediated immunity, which compromises the host's ability to maintain viral latency and suppresses latent viral reservoirs, results in more frequent and severe oral manifestations (27).

- **Microvascular and Neuropathic Complications**

Long-term complications of diabetes mellitus involve damage to small blood vessels (microangiopathy) and peripheral nerves (neuropathy) (7,28). Within the oral cavity, diabetic microangiopathy reduces blood perfusion, creating a hypoxic environment that compromises tissue nutrition, delays wound healing, and increases susceptibility to bacterial invasion (13,15,17). In parallel, diabetic neuropathy, which affects 50%-66% of long-term diabetic patients (18), gives rise to a range of clinically relevant sensory disturbances. These include xerostomia resulting from salivary gland dysfunction (13,18), reported in up to 42.5% of patients with T2DM (4,10), burning mouth syndrome, affecting up to 58.1% of patients (12), as well as taste disturbances (dysgeusia) and oral paresthesia (29).

- **Oxidative Stress and the Convergence on Impaired Healing**

Oxidative stress, resulting from an excess production of reactive oxygen species (ROS) (13,15), represents a common final pathway that amplifies cellular damage, collagen degradation, and endothelial dysfunction (30). Within the oral cavity, these processes contribute to periodontal tissue breakdown and impaired gingival repair (24,28). Ultimately, the convergence of oxidative stress with chronic inflammation, tissue hypoxia, and immune dysfunction represents the clinical endpoint: delayed and impaired healing of oral wounds and surgical sites (6,17,21).

3.2.1 The Systemic Metabolic Impact: Completing the Bidirectional Cycle

The systemic consequences of the oral pathological network are what establish the true bidirectionality of the relationship. The chronic inflammatory state and microbial dysbiosis originating from the periodontium have direct detrimental effects on systemic metabolic control. Pro-inflammatory cytokines (e.g. TNF-α, IL-6) (15,24), and bacterial components, like lipopolysaccharides (LPS) translocated from the oral biofilm (23), interfere with insulin signaling pathways, promoting peripheral insulin resistance (31). Concurrently, this inflammatory milieu can increase

hepatic glucose production and reduce peripheral glucose utilization (13,15). Collectively, this evidence positions oral diseases, particularly periodontitis, not merely as local complications, but also as active modifiers of endocrine function, contributing to hyperglycemia and making glycemic control more difficult to achieve. This completes the self-perpetuating cycle where hyperglycemia prompts oral tissue damage, which in turn worsens hyperglycemia (Figure 1).

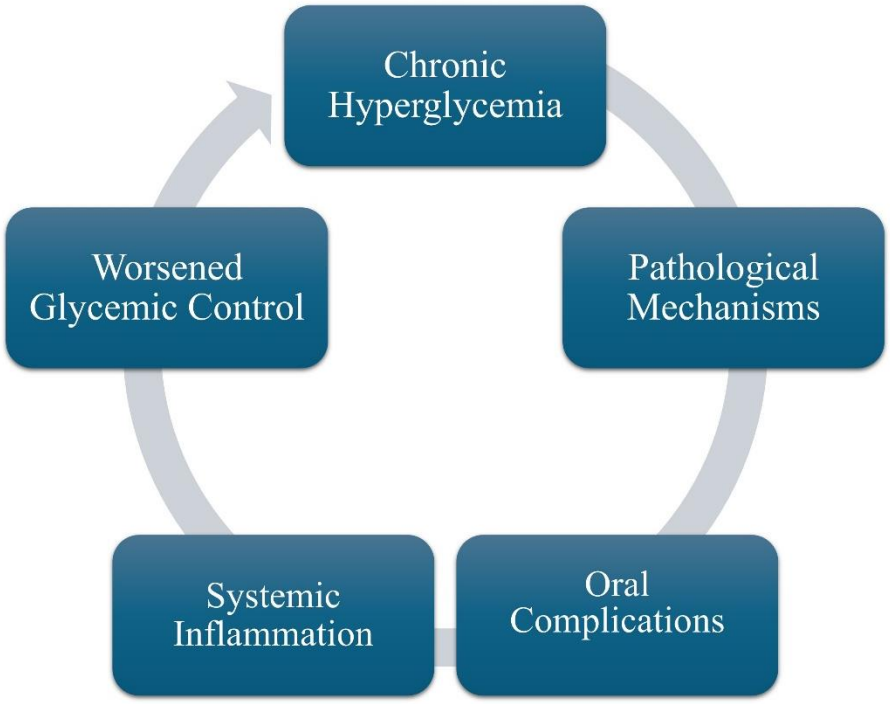

Figure 1: The core bidirectional cycle linking type 2 diabetes mellitus and oral complications. Arrows represent the directionality of these interactions

Chronic hyperglycemia drives pathological mechanisms (e.g. AGE-RAGE axis, dysbiosis), leading to oral complications, such as periodontitis and xerostomia. These oral conditions promote systemic inflammation, which in turn exacerbates insulin resistance and further impairs glycemic control, thus completing a self-perpetuating vicious cycle.

While these mechanistic pathways are well-defined, a critical question remains regarding their relative contribution and the magnitudes of their effects on glycemic control across different patient phenotypes. This highlights the need for personalized medicine approaches to optimally disrupt this cycle in clinical practice.

3.3 From Evidence to Practice: Strategies for Integrated Care

The well-established bidirectional relationship between T2DM and oral health represents a paradigm shift in understanding diabetic complications. While the associative evidence is robust (3,32), the critical clinical imperative lies in leveraging this relationship to improve patient outcomes through integrated care models.

3.3.1 Clinical Evidence Supporting Integrated Intervention

- **Periodontal Therapy Impact**

Interventional studies demonstrated compelling evidence for metabolic improvement following oral care. Sato et al. (2024) (33) documented statistically significant HbA1c reductions sustained for ≥12 months after non-surgical periodontal therapy, while Oliveira et al. (2023) (34) confirmed these findings through meta-analysis, identifying key moderating factors through meta-regression. Critical analysis reveals that treatment efficacy depends on baseline HbA1c, periodontitis severity, and comprehensive diabetes care, highlighting the need for patient-specific approaches rather than for one-size-fits-all interventions.

- **Oral Hygiene and Self-care Benefits**

Beyond professional treatment, daily oral care significantly influences glycemic control. Zhang et al. (35) associated regular flossing with 0.30% lower HbA1c levels, while Kumar et al. (11) demonstrated direct correlation between oral health status and glycemic control. Additionally, Yu et al. (36) demonstrated that patients with poor glycemic control (HbA1c ≥ 8%) were more likely to experience severe tooth loss (having <19 teeth) compared to those with good control to HbA1c < 6.5%.

However, the observational nature of these studies necessitates caution in interpreting causality, as flossing adherence may reflect overall health consciousness rather than direct physiological benefits.

- **Comprehensive Complication Management**

The relationship extends beyond periodontitis to encompass other oral manifestations. Kumar et al. (2024) (11) showed that poor glycemic control (HbA1c >7%) correlates with higher xerostomia prevalence (52.2% *vs*. 24.5%) and hyposalivation (47.8% *vs*. 6.4%), requiring integrated management approaches for fungal infections and impaired wound healing (10, 4). This broader perspective underscores that successful glycemic management requires addressing the entire spectrum of oral complications.

3.3.2 Implementation Challenges and Educational Imperatives

Beyond biological mechanisms and clinical evidence, successful implementation faces significant practical challenges. The translation of this robust scientific knowledge into routine clinical practice encounters substantial barriers that must be systematically addressed.

- **Patient Awareness Deficit**

Maia et al. (2022) identified significant knowledge gaps regarding the oral-systemic link among diabetes mellitus patients, creating a fundamental barrier to effective care (32). This deficiency is evident in region-specific studies. For example, research from Saudi Arabia found that most diabetic patients (40.5%) only visit the dentist when experiencing pain, and only a small percentage (7.8%) visit the dentist regularly for routine check-ups (37). A clear awareness gap exists in these studies, hindering effective implementation, as patient participation depends on understanding this connection. Educational interventions, such as telemedicine (38), create practical opportunities to expand communication and patient education.

- **Healthcare System Integration**

The greatest challenge lies in translating evidence into practical care models. Addressing this gap requires a dedicated focus on developing scalable, integrated patient care systems, with clear referral pathways, shared decision-making tools, and appropriate payment mechanisms. This system-level change is crucial for transforming the two-way relationship into a therapeutic application. Successful implementation depends on many factors, including staff experience, capacity, and the clarity of new clinical roles (39).

3.3.3 Building the Foundation: Policy and Healthcare System Integration

Moving from evidence to practice requires a strategic shift from isolated interventions to a coordinated, multi-level framework. This approach must simultaneously engage policymakers, healthcare professionals, and patients to redesign care pathways.

Effective integration begins with systemic and policy-level reforms, a direction powerfully mandated by global health agendas. The 2021 World Health Organization (WHO) Resolution (40) and its subsequent Global Oral Health Strategy (41) explicitly advocate for integrating oral health into primary care and universal health coverage (UHC). For individuals with T2DM, a critical step toward this goal is overcoming the financial exclusion of essential oral care from many national health plans. Therefore, national policies must formally mandate oral health assessment in diabetes care protocols (42), and reimbursement models should be restructured, for example, by including preventive dental screenings in diabetes care packages to overcome key financial barriers to access and address the broader health-economic burden (16,43).

These policies are enacted at the clinical and professional levels, through practical tools. Establishing formal referral pathways supported by shared digital records facilitates seamless collaboration, a cornerstone of successful interdisciplinary care models. Training healthcare providers in rapid oral screening and promoting joint interdisciplinary education are essential to building a common understanding and coordinated

treatment goals, as recommended by international clinical guidelines.

Finally, success hinges on patient and community empowerment. Community-based education must clearly explain the oral-systemic link, guiding patients on navigating both care systems to bridge the significant awareness gap that persists (33,44). Digital tools, from reminder apps to educational platforms, can foster active patient engagement, a strategy supported by evidence on the role of telemedicine in patient education (38).

Overall, this framework transforms the bidirectional relationship from a biological concept into a shared systemic responsibility. Its implementation depends on institutional commitment to create accountable, collaborative structures, thereby converting a pathological cycle into a sustainable therapeutic pathway.

3.4 Applying Evidence: Clinical Guidelines and Patient-level Strategies

Effective management of oral health in patients with type 2 diabetes mellitus (T2DM) requires an integrated care model that closely links glycemic control with preventive oral healthcare (23). This is critically important, as adults with diabetes are approximately 40% more likely to have untreated cavities (43). Recent evidence confirmed that targeted oral health interventions not only prevent these local complications, but also positively influence systemic metabolic regulation by reducing the overall inflammatory burden (3,15).

3.4.1 Glycemic Control: The Cornerstone of Prevention

Maintaining blood glucose levels within the target range (HbA1c < 7%) is fundamental for reducing the risk and severity of oral complications and for improving the outcomes of dental treatments (6). Poor glycemic control exacerbates inflammation, impairs immune response, and accelerates periodontal tissue damage (17,24). Conversely, good glycemic control contributes to better periodontal treatment outcomes and faster wound healing (33).

Despite its importance, studies indicated a high prevalence of inadequate glycemic control (ranging from 45.2% to 93%) due to various personal, clinical, behavioral, and medication-related factors (45). This poor control significantly impacts oral health; a recent meta-analysis showed an overall xerostomia prevalence of 42.49% in T2DM patients (10), with poorly controlled patients (HbA1c >7%) demonstrating a significantly higher prevalence of both xerostomia (52.2% *vs*. 24.5%) and hyposalivation (47.8% *vs*. 6.4%) compared to well-controlled patients (11). For patients requiring dental implants, achieving glycemic control (HbA1c < 7%) before implantation is essential, as emphasized by Nibali et al. (2022) (6), to reduce the risk of peri-implantitis and ensure long-term therapeutic success.

Patients should be educated on the importance of self-monitoring and regular medical follow-up. Critical communication between the dental and medical teams is essential; dental providers should inquire about the patient's most recent HbA1c level and inform the physician of any active oral infections that may be impacting glycemic control (14).

3.4.2 Professional Dental Care and Periodic Prevention

Routine dental visits, including examinations and professional cleaning (such as scaling and root planing), are crucial for the early detection and management of periodontal disease. A recent prospective study provided compelling evidence, showing that tailored interventions-including scaling, root planing, oral hygiene education, and pharmacotherapy for conditions, like candidiasis and xerostomia—resulted in a remarkable 61% improvement in oral health outcomes among T2DM patients (46). Meta-analyses, such as that conducted by Oliveira et al. (2023), confirmed that non-surgical periodontal therapy is associated with a statistically significant reduction in HbA1c levels, with studies showing a mean decrease of approximately 0.4% (34). These findings support the bidirectional nature of the relationship, where active periodontal treatment contributes to improved metabolic control (3). To maintain stability, patients with T2DM should be placed on a more frequent re-care schedule, typically every 3-4 months, especially if active periodontitis or poor glycemic control is present (14). Furthermore, due to their increased caries risk, the application of fluoride varnish every 3-6 months is a key preventive intervention (14).

3.4.3 Personal Oral Hygiene and Health Education

Effective daily oral hygiene practices—including

twice-daily brushing with fluoride toothpaste and interdental cleaning—constitute self-care cornerstones. Studies consistently linked proper oral hygiene with improved glycemic control (35). However, patient awareness regarding the oral health-diabetes bidirectional relationship remains insufficient, representing a major integrated care barrier (32,47). Consequently, management strategies should therefore encompass educational initiatives empowering patients and improving oral hygiene adherence alongside clinical interventions.

3.4.4 Behavioral and Lifestyle Interventions

Effective management supports both systemic and oral health by addressing relevant lifestyle factors:

- Smoking cessation: Smoking significantly increases the risk and severity of periodontal disease and impairs wound healing.
- Balanced nutrition: Patients who may experience taste dysfunction (dysgeusia) should be guided toward healthy, low-sugar food choices to protect their teeth and support glycemic control (29). A referral to a registered dietitian or nutritionist can be invaluable for comprehensive diabetes management (14).
- Adequate hydration: Regular water intake helps alleviate symptoms of dry mouth (xerostomia), a common complaint that affects quality of life (4).
- Management of neuropathic symptoms: Patients should be screened for symptoms, such as burning mouth syndrome, which is associated with peripheral neuropathy, and referred for appropriate care (12,18).

Addressing these behavioral factors enhances the effectiveness of glycemic management and oral disease prevention, forming a comprehensive care strategy for diabetic patients (13,39).

3.4.5 Clinical Implementation: Towards an Integrated Care Model

Closing awareness gaps is the first step towards effective clinical implementation. According to recent UAE findings, only 48.7% of diabetic patients understand oral complications, stressing the importance of systematic education programs (44). To close this gap, integrated education programs linking diabetes and periodontitis should be implemented. Evidence shows that they improve patient awareness and behavior when used by healthcare professionals (48). To align with current recommendations, clinical protocols should make oral health assessment a standard part of diabetes evaluation, including detailed oral tissue checks and HbA1c review before treatment (49). According to evidence-based recommendations, morning visits after food and medication intake help minimize the risk of hypoglycemia, while high-fluoride treatments are advised to prevent patients at risk of xerostomia (14). Achieving success requires two strategies: giving patients strong, evidence-based education and providing clinicians with practical tools at the chairside to disrupt the diabetes-oral disease cycle.

4. Discussion

The current review synthesizes evidence that the oral cavity is a critical indicator and modifier of systemic health in T2DM. The findings not only reaffirm the bidirectional pathogenesis involving AGEs, dysbiosis, and chronic inflammation, but also demonstrate that clinical interventions, particularly periodontal therapy, can achieve modest, yet clinically relevant, improvements in glycemic control.

Despite these advances, translating this growing body of evidence into routine clinical practice remains challenging. Although significant strides have been made in understanding the relationship between T2DM and oral health, many gaps in knowledge remain. This review highlighted several areas where evidence is still evolving, particularly concerning immune dysregulation, oxidative stress pathways, and patient awareness (15,24,34).

These gaps are especially pronounced in Arab countries, where the diabetes prevalence is alarmingly high; yet region-specific research on oral complications is limited. According to the International Diabetes Federation (IDF) Diabetes Atlas (2025) (1), the Middle East and North Africa (MENA) region has approximately 85 million adults living with diabetes, projected to rise to 135.7 million adults by 2045. In the Gulf Cooperation Council (GCC) countries, prevalence exceeds 15%-20% of adults.

5. Recommended Directions for Future Research

To address these gaps, the following key directions for future research are proposed:

- **Patient-centered and Educational Interventions**

Recent mixed-methods research revealed critical gaps between T2DM patients' perceptions and actual

oral health practices, with a study from the UAE showing that only 48.7% of patients were aware of oral complications (44). This finding is consistent with other research from the region, which has shown that health professionals and the media do not play the requisite role in disseminating this information, resulting in a significant educational vacuum (37). Prospective studies demonstrated that structured interventions combining education with clinical care can significantly reduce oral complications (46). Future research should focus on developing and evaluating culturally adapted modules, similar to the integrated diabetes-periodontitis education module proven effective by Jamil et al. (2021) (48), addressing specific barriers to oral care adherence.

- **Mechanistic Insights and Oral Microbiome Research**

A critical frontier is elucidating the oral microbiome's role in T2DM pathophysiology. Recent microbiomic studies revealed distinct compositional shifts in T2DM patients, but methodological inconsistencies limit comparability (50). Future research must standardize methodological approaches (e.g. 16S rRNA sequencing protocols) to establish reliable microbiome-derived biomarkers and to clarify their mechanistic links to metabolic dysregulation (51).

- **Longitudinal and Interventional Studies**

Large-scale multicenter studies are needed to assess the sustained impact (>12 months) of oral health interventions on glycemic control and microvascular complications. While meta-analyses confirmed short-term benefits (3,34), longitudinal data is scarce, particularly for integrated care models that combine medical and dental management following evidence-based clinical protocols (14).

- **Personalized and Precision Medicine**

Research should transition to individualized approaches by examining genetic polymorphisms, microbiome signatures, and lifestyle factors that influence treatment response. Variations in complications, like xerostomia and neuropathy (11,12), suggest the need for predictive models that can guide personalized prevention strategies.

- **Digital Health and Implementation of Science Frameworks**

Emerging technologies offer promising avenues for improving care delivery. Research should evaluate mobile health applications, tele-dentistry models, and AI algorithms for early detection of oral complications, particularly in underserved populations where traditional care access is limited (38). These approaches should align with implementation of science frameworks to ensure successful adoption in diverse healthcare settings.

- **Policy and Collaborative Care Models**

Future studies should assess the real-world effectiveness of multidisciplinary care models that facilitate collaboration between medical and dental professionals, as highlighted by recent reviews calling for research into cross-sectorial collaboration to reduce care fragmentation (52). Research is needed to develop clear referral pathways and reimbursement mechanisms that support the integration of oral health assessment into routine diabetes management (14).

- **Region-specific Research in High-prevalence Populations**

The Arab region represents a critical priority given its substantial diabetes burden. Studies must account for local dietary patterns, healthcare access barriers, and sociocultural factors to develop effective, culturally competent interventions (5).

In summary, future research must address these interconnected gaps through multidisciplinary collaborations that bridge basic science, clinical investigation, and implementation of science frameworks. Prioritizing standardized methodologies, patient-centered approaches, and regionally relevant strategies will accelerate progress toward personalized, effective management of the oral-systemic connection in T2DM, ultimately improving quality of life for patients worldwide.

6. Conclusions

This review is based on an evaluation of recent studies addressing that the oral cavity serves as both a critical indicator and an active contributor to the systemic health of individuals with type 2 diabetes mellitus (T2DM). The synthesized data confirms a bidirectional cycle: chronic hyperglycemia leads to a spectrum of oral complications, most notably periodontitis and xerostomia, while these oral inflammatory conditions, in turn, exacerbate insulin

resistance and impair glycemic control.

Evidence indicated that more coordinated, multi-level approaches are needed to address this interconnected process. As demonstrated, clinical interventions, particularly professional periodontal therapy coupled with sustained personal oral hygiene, can yield measurable improvements in metabolic regulation and clinical outcomes. The application of this evidence in routine care involves factors that extend beyond the clinical visit. Effective implementation therefore rests on policy alignment (such as inclusive financing aligned with WHO directives), improved coordination across healthcare disciplines, and sustained educational support for patients.

Achieving this goal will depend on sustained institutional commitment to shared accountability between medical and dental disciplines. Future research should focus on developing and evaluating integrated care models, particularly in regions with a high prevalence of disease, like the Arab world. By embedding oral health firmly within diabetes management, the persistent pathological cycle can be reshaped into a constructive clinical pathway, leading to improved health outcomes and quality of life for patients worldwide.

Conflict of Interests

The author declares that there is no conflict of interests, directly or indirectly, that may influence the author's objectivity towards this research.

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