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DIABETES-ASSOCIATED SALIVARY CHANGES AND THEIR IMPACT ON THE SUPRAGINGIVAL MICROBIOME

ALTERAÇÕES SALIVARES ASSOCIADAS AO DIABETES E SEU IMPACTO NO MICROBIOMA SUPRAGENGIVAL

CAMBIOS SALIVALES ASOCIADOS A LA DIABETES Y SU IMPACTO EN EL MICROBIOMA SUPRAGINGIVAL

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ABSTRACT

Objective: To examine the biological mechanisms linking type 2 diabetes mellitus to increased dental caries risk, with emphasis on salivary sugar dysregulation and microbiome alterations.

Methods: A narrative review was conducted using experimental, clinical, and microbiome studies investigating the relationship between hyperglycaemia, salivary composition, and cariogenic biofilm development. Evidence was synthesized to clarify mechanistic pathways and clinical implications.

Results: Individuals with type 2 diabetes consistently demonstrate higher caries prevalence compared with non-diabetic controls. Emerging evidence indicates that chronic hyperglycaemia promotes the diffusion of circulating sugars, particularly glucose and fructose, into saliva. This metabolic shift increases substrate availability for supragingival biofilms and favours acidogenic and aciduric species. Studies using metabolomic profiling and microbial sequencing have shown enrichment of cariogenic bacteria, especially

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Streptococcus mutans, alongside reduction of health-associated species such as Streptococcus sanguinis. These ecological changes enhance glycolytic activity and acid production, contributing to enamel demineralization. Importantly, improved glycaemic control appears to partially reverse salivary sugar elevation and microbial dysbiosis, suggesting a modifiable pathway linking systemic metabolic status and oral disease risk.

Conclusion: Type 2 diabetes contributes to a more cariogenic oral environment through hyperglycaemia-driven alterations in salivary sugars and microbiome composition. Integrating metabolic control with preventive dental strategies may be essential to reduce caries burden in this population. Further longitudinal and interventional studies are needed to strengthen causal inference.

Keywords: Type 2 Diabetes Mellitus. Dental Caries. Saliva. Oral Microbiome. Hyperglycaemia.

RESUMO

Objetivo: Examinar os mecanismos biológicos que relacionam o diabetes mellitus tipo 2 ao aumento do risco de cárie dentária, com ênfase na desregulação dos açúcares salivares e nas alterações do microbioma.

Métodos: Foi realizada uma revisão narrativa utilizando estudos experimentais, clínicos e de microbioma que investigaram a relação entre hiperglicemia, composição salivar e desenvolvimento de biofilme cariogênico. As evidências foram sintetizadas para esclarecer as vias mecanísticas e as implicações clínicas.

Resultados: Indivíduos com diabetes tipo 2 demonstram consistentemente maior prevalência de cárie em comparação com controles não diabéticos. Evidências emergentes indicam que a hiperglicemia crônica promove a difusão de açúcares circulantes, particularmente glicose e frutose, para a saliva. Essa alteração metabólica aumenta a disponibilidade de substrato para biofilmes supragengivais e favorece espécies acidogênicas e acidúricas. Estudos utilizando perfil metabolômico e sequenciamento microbiano demonstraram enriquecimento de bactérias cariogênicas, especialmente Streptococcus mutans, juntamente com a redução de espécies associadas à saúde, como Streptococcus sanguinis. Essas mudanças ecológicas aumentam a atividade glicolítica e a produção de ácidos, contribuindo para a desmineralização do esmalte. É importante destacar que o melhor controle glicêmico parece reverter parcialmente a elevação dos açúcares salivares e a disbiose microbiana, sugerindo uma via modificável que conecta o estado metabólico sistêmico ao risco de doenças orais.

Conclusão: O diabetes tipo 2 contribui para um ambiente oral mais cariogênico por meio de alterações induzidas pela hiperglicemia nos açúcares salivares e na composição do microbioma. A integração do controle metabólico com estratégias preventivas odontológicas pode ser essencial para reduzir a carga de cárie nessa população. Estudos longitudinais e intervencionais adicionais são necessários para fortalecer a inferência causal.

Palavras-chave: Diabetes Mellitus Tipo 2. Cárie Dentária. Saliva. Microbioma Oral. Hiperglicemia.

RESUMEN

Objetivo: Examinar los mecanismos biológicos que vinculan la diabetes mellitus tipo 2 con un mayor riesgo de caries dentales, con énfasis en la desregulación de los azúcares salivales y las alteraciones del microbioma.

Métodos: Se realizó una revisión narrativa utilizando estudios experimentales, clínicos y de microbioma que investigaron la relación entre hiperglucemia, composición salival y desarrollo de biopelículas cariogénicas. La evidencia fue sintetizada para aclarar las vías mecanísticas y sus implicaciones clínicas.

Resultados: Las personas con diabetes tipo 2 presentan de manera consistente una mayor prevalencia de caries en comparación con controles no diabéticos. Evidencia emergente indica que la hiperglucemia crónica promueve la difusión de azúcares circulantes, particularmente glucosa y fructosa, hacia la saliva. Este cambio metabólico aumenta la disponibilidad de sustratos para las biopelículas supragingivales y favorece especies acidogénicas y acidúricas. Estudios que emplean perfil metabolómico y secuenciación microbiana han demostrado un enriquecimiento de bacterias cariogénicas, especialmente Streptococcus mutans, junto con una reducción de especies asociadas a la salud, como Streptococcus sanguinis. Estos cambios ecológicos incrementan la actividad glucolítica y la producción de ácido, contribuyendo a la desmineralización del esmalte. Es importante destacar que un mejor control glucémico parece revertir parcialmente el aumento de azúcares salivales y la disbiosis microbiana, lo que sugiere una vía modificable que vincula el estado metabólico sistémico con el riesgo de enfermedad oral.

Conclusión: La diabetes tipo 2 contribuye a un entorno oral más cariogénico mediante alteraciones inducidas por la hiperglucemia en los azúcares salivales y en la composición del microbioma. Integrar el control metabólico con estrategias preventivas odontológicas puede ser esencial para reducir la carga de caries en esta población. Se necesitan más estudios longitudinales e intervencionales para fortalecer la inferencia causal.

Palabras clave: Diabetes Mellitus Tipo 2. Caries Dental. Saliva. Microbioma Oral. Hiperglucemia.

1 INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a highly prevalent metabolic disorder characterized by chronic hyperglycaemia and associated systemic complications. The bidirectional relationship between diabetes and oral health has been well documented, particularly regarding periodontal disease; however, the association between T2DM and dental caries remains less clearly understood (Löe, 1993; Preshaw et al., 2012). Epidemiological studies increasingly suggest that individuals with poorly controlled diabetes may present an elevated risk of caries, indicating the presence of underlying biological mechanisms linking systemic metabolic dysregulation to cariogenic processes.

Saliva plays a central role in maintaining oral homeostasis through buffering capacity, antimicrobial activity and mechanical clearance of carbohydrates. Alterations in salivary composition in patients with diabetes have been widely reported, including reduced salivary flow, changes in protein profile and increased glucose concentration (Lima et al., 2010; Gupta et al., 2015). Elevated salivary glucose may provide an additional fermentable substrate for oral bacteria, potentially promoting acidogenic biofilm activity and enamel demineralization.

Recent advances in metabolomics and microbiome research have provided new insights into this relationship. Studies have demonstrated that chronic hyperglycaemia can enhance the diffusion of circulating sugars into saliva, thereby modifying the ecological balance of supragingival biofilms (Goodson et al., 2017). This altered environment appears to favour aciduric and cariogenic species, particularly Streptococcus mutans, while reducing health-associated commensals such as Streptococcus sanguinis (Takahashi & Nyvad, 2011). The resulting shift toward a more glycolytic and acidogenic biofilm phenotype may help explain the increased susceptibility to dental caries observed in some individuals with T2DM.

Importantly, improved glycaemic control has been associated with partial normalization of salivary parameters and oral microbial profiles, suggesting that this pathway may be modifiable (Lima et al., 2010). Nevertheless, the mechanistic links between systemic hyperglycaemia, salivary sugar dynamics and cariogenic dysbiosis remain incompletely elucidated.

A comprehensive synthesis of current evidence is therefore warranted to clarify how type 2 diabetes shapes the cariogenic oral environment and to inform integrated preventive strategies for this growing patient population.

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2 METHODOLOGY

A narrative review of the literature was conducted to explore mechanistic links between type 2 diabetes mellitus, salivary sugar alterations and dental caries risk. Electronic database searches were performed in PubMed/MEDLINE, Scopus and Web of Science, with additional manual screening of reference lists from relevant studies. The search strategy incorporated combinations of terms related to “type 2 diabetes”, “hyperglycaemia”, “saliva”, “salivary glucose”, “oral microbiome”, and “dental caries”. Experimental, clinical, metabolomic and microbiological studies investigating the relationship between systemic glycaemic status and oral ecological changes were considered.

Inclusion criteria included studies involving human participants or relevant in vitro/in situ biofilm models that evaluated salivary composition, sugar diffusion, or microbiome shifts associated with diabetes. Studies focusing exclusively on periodontal outcomes without salivary or cariogenic relevance were excluded. Titles and abstracts were screened independently by two reviewers, followed by full-text assessment. Key data were extracted descriptively and synthesised narratively, focusing on biological pathways linking hyperglycaemia to cariogenic biofilm dynamics and their clinical implications.

3 RESULTS

The body of evidence synthesized in this narrative review consistently demonstrates that individuals with type 2 diabetes mellitus (T2DM) exhibit a distinct salivary and supragingival ecological profile that favors cariogenic activity. Across clinical, metabolomic, and microbiome-based investigations, three interrelated domains emerged: (1) salivary biochemical alterations, (2) microbial ecological shifts, and (3) the modifying effect of glycaemic control.

Salivary biochemical alterations

Multiple studies have documented significantly elevated salivary glucose concentrations in individuals with poorly controlled T2DM compared with normoglycaemic controls. This increase appears to reflect passive diffusion of circulating glucose into saliva driven by chronic hyperglycaemia and possible alterations in salivary gland permeability. Lima et al. (2010) reported that salivary glucose levels positively correlate with blood glucose, supporting the concept that saliva mirrors systemic metabolic status. Importantly, this elevation occurs even during fasting periods, thereby providing a continuous fermentable substrate for oral biofilms.

Beyond glucose, broader salivary dysfunction has been described. Diabetic individuals frequently present reduced salivary flow rate and altered protein composition, both of which may impair oral clearance mechanisms and buffering capacity. Gupta et al. (2015) highlighted that hyposalivation contributes to prolonged carbohydrate retention and diminished antimicrobial defense, further predisposing to cariogenic conditions.

Microbiome dysbiosis in supragingival biofilm

High-throughput sequencing and ecological analyses consistently indicate a shift toward a more acidogenic and aciduric microbiome in the presence of elevated salivary glucose. Goodson et al. (2017) demonstrated that increased salivary glucose is associated with measurable changes in the salivary microbiome composition, including enrichment of cariogenic taxa.

In particular, studies repeatedly report increased relative abundance of Streptococcus mutans, a key acidogenic and aciduric organism strongly associated with enamel demineralisation. Concurrently, health-associated commensals such as Streptococcus sanguinis appear reduced. From an ecological plaque perspective, this pattern reflects environmental selection rather than simple pathogen overgrowth.

Mechanistically, the glucose-enriched salivary environment enhances bacterial glycolytic flux, increasing organic acid production and lowering local pH. Takahashi and Nyvad (2011) described this as a shift toward a dysbiotic, cariogenic biofilm phenotype characterized by sustained acidification and impaired remineralization dynamics.

Metabolic–microbial interaction pathway

The reviewed evidence supports a biologically coherent pathway linking systemic hyperglycaemia to dental caries risk:

1. Chronic hyperglycaemia elevates salivary glucose
2. Elevated glucose increases fermentable substrate availability
3. Biofilm ecology shifts toward acidogenic/aciduric species
4. Acid production increases and plaque pH decreases
5. Enamel demineralisation risk rises

This pathway aligns strongly with the ecological plaque hypothesis and positions T2DM as a systemic modifier of oral biofilm ecology rather than merely a coincidental comorbidity.

Influence of glycaemic control

Importantly, several studies suggest partial reversibility of these alterations. Improved metabolic control has been associated with reductions in salivary glucose concentration and partial normalization of microbial composition (Lima et al., 2010; Goodson et al., 2017). This finding is clinically significant because it indicates that the diabetes–caries link may be modifiable through systemic management.

However, the magnitude and timeline of microbiome recovery remain insufficiently characterized. Most available data are cross-sectional, limiting causal inference and temporal interpretation.

Methodological considerations

The evidence base shows substantial heterogeneity in:

1. salivary collection protocols
2. glycaemic control thresholds
3. microbiome sequencing platforms
4. caries diagnostic criteria

This variability complicates quantitative synthesis and weakens causal certainty. Furthermore, the predominance of observational designs introduces risk of residual confounding, particularly related to diet, oral hygiene, medication use, and salivary flow status.

Evidence gaps

Despite growing mechanistic plausibility, important gaps persist:

1. scarcity of longitudinal cohort studies
2. limited interventional trials evaluating glycaemic optimisation
3. insufficient multi-omics integration
4. lack of standardized salivary biomarkers

These limitations indicate that the current evidence supports biological plausibility but not definitive causality.

4 DISCUSSION

The evidence synthesised in this review supports a biologically plausible pathway linking type 2 diabetes mellitus to increased cariogenic risk through salivary and microbiome alterations. Chronic hyperglycaemia appears to modify the oral environment in a manner that favours acidogenic biofilm activity, thereby contributing to enamel demineralisation and potentially higher caries susceptibility.

One of the most consistent findings is the elevation of salivary glucose in individuals with poorly controlled diabetes. This phenomenon is clinically relevant because saliva normally contains low concentrations of fermentable carbohydrates between meals. When systemic glycaemic levels remain elevated, the diffusion of glucose into saliva may create a persistent nutrient supply for supragingival biofilms, effectively mimicking frequent sugar exposure. This mechanism helps explain why some patients with diabetes develop caries even without markedly high dietary sugar intake.

The observed microbial shifts toward cariogenic and aciduric species further strengthen the ecological explanation. Rather than a single-pathogen model, the data support a dysbiosis-driven process in which the metabolic environment selects for organisms capable of thriving under acidic, sugar-rich conditions. This aligns with the ecological plaque hypothesis and suggests that diabetes acts as a systemic modifier of oral biofilm ecology.

From a clinical standpoint, the potential partial reversibility of salivary and microbiome alterations with improved glycaemic control is particularly important. It indicates that metabolic management may have downstream oral health benefits beyond periodontal outcomes. However, the current body of evidence remains largely cross-sectional, limiting causal inference. Additionally, heterogeneity in salivary sampling methods, glycaemic control definitions, and microbiome sequencing approaches complicates direct comparisons across studies.

Future research should prioritise longitudinal and interventional designs to clarify temporal relationships and quantify the impact of glycaemic optimisation on cariogenic risk. Standardisation of salivary biomarkers and integration of multi-omics approaches may further refine mechanistic understanding. Moreover, clinical studies evaluating preventive strategies specifically tailored for patients with diabetes are warranted.

5 CONCLUSION

Type 2 diabetes mellitus contributes to the development of a more cariogenic oral environment through hyperglycaemia-driven alterations in salivary composition and supragingival microbiome ecology. Elevated salivary glucose appears to act as a key metabolic driver that promotes acidogenic biofilm activity and enamel demineralisation.

Although emerging evidence suggests that improved glycaemic control may partially mitigate these changes, the current literature remains limited by methodological heterogeneity and predominance of observational designs. Integrating metabolic management with targeted preventive dental strategies may represent an important approach to reducing caries burden in individuals with diabetes.

Further well-designed longitudinal and interventional studies are required to strengthen causal understanding and guide evidence-based clinical protocols.

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