INTERRELATIONSHIP BETWEEN DIET QUALITY AND DENTAL OUTCOMES: A SYSTEMATIC REVIEW OF NUTRIENT DEFICIENCIES, CARIOGENIC BEHAVIORS, AND PROTECTIVE DIETARY INTERVENTIONS

Amal Hazza Ismail Ghazwani[1], Raghad Ali Saleh Johaly[2], Mashael Fahad Mohammad Alshammari[3], Samira Saeed Abdullah Al Asmari[4], Sheikha Abdullah Albishy[5]

[1]Najran armed forces hospital, Saudi Arabia, aml.ghazwni@gmail.com
[2]Najran armed forces hospital, Saudi Arabia, Riga.sa@hotmail.com
[3]Najran armed forces hospital, Saudi Arabia, Mashaelfahad997@gmail.com
[4]Najran armed forces hospital, Saudi Arabia, ssemo2770@gmail.com
[5]Najran armed forces hospital, Saudi Arabia, shoosh201760@hotmail.com
Corresponding Author: Amal Hazza Ismail Ghazwani

Abstract

This systematic review examines the interrelationship between diet quality and dental health outcomes, focusing on nutrient deficiencies, cariogenic dietary behaviors, and protective nutritional interventions. Oral diseases such as dental caries, enamel erosion, and periodontal disease remain among the most prevalent non-communicable conditions worldwide, with diet recognized as a modifiable risk factor influencing both disease initiation and progression. Following the **PRISMA** guidelines, peer-reviewed studies published between 2016 and 2025 were systematically retrieved from major databases. Evidence was synthesized across three core domains: micronutrient deficiencies affecting tooth integrity and periodontal tissues; dietary patterns and behaviors contributing to cariogenic risk; and protective dietary interventions shown to enhance oral health resilience. Findings indicate that deficiencies in calcium, vitamin D, phosphorus, and antioxidants are strongly associated with enamel demineralization and periodontal inflammation, while frequent sugar intake and ultra-processed foods exacerbate cariogenic biofilm activity. Conversely, diets rich in dairy products, fibrous foods, and polyphenol-containing items demonstrate protective effects through enhanced remineralization and modulation of the oral microbiome. The review highlights the necessity of integrating nutritional assessment and counseling into preventive dental care and public health strategies. Strengthening interdisciplinary collaboration between dental professionals and nutrition experts may significantly improve population-level oral health outcomes.

Keywords: Dental health; Diet quality; Nutrition; Dental caries; Periodontal disease; Preventive dentistry

Introduction & Background

Oral health is an essential component of general health and well-being, influencing nutrition, communication, social interaction, and overall quality of life. Dental caries and periodontal diseases remain among the most prevalent chronic conditions worldwide, affecting individuals across all age groups and socioeconomic levels. According to the **World Health Organization**, oral diseases constitute a major public health burden, with dental caries of permanent teeth being the most common health condition globally. Despite advances in preventive dentistry and oral hygiene practices, the global prevalence of dental diseases has shown limited decline, highlighting the need to address broader upstream determinants, particularly diet quality.

Diet plays a dual and complex role in oral health. On one hand, frequent consumption of free sugars, refined carbohydrates, and acidic beverages promotes the growth of acidogenic oral bacteria, leading to enamel demineralization, dental caries, and erosion. On the other hand, adequate intake of essential nutrients supports tooth development, enamel mineralization, salivary function, and periodontal tissue integrity. This balance between cariogenic exposure and nutritional protection underscores the critical interrelationship between diet quality and dental outcomes.

Modern dietary transitions characterized by increased intake of ultra-processed foods and sugar-sweetened beverages have intensified oral health risks, especially among children and adolescents. Evidence consistently shows that the frequency of sugar consumption, rather than total quantity alone, is a key driver of cariogenic activity, as repeated acid attacks limit the natural remineralization capacity of enamel (Moynihan & Kelly, 2017). Concurrently, deficiencies in calcium, vitamin D, phosphorus, and antioxidants have been associated with compromised enamel strength, delayed tooth eruption, increased susceptibility to caries, and heightened periodontal inflammation (Hujoel, 2019; Woelber et al., 2016).

Beyond individual nutrients, overall diet quality and dietary patterns are increasingly recognized as critical determinants of oral health. Diets rich in fruits, vegetables, whole grains, dairy products, and bioactive compounds such as polyphenols have been linked to improved periodontal status and reduced caries risk. These protective effects are mediated through multiple mechanisms, including enhanced salivary flow, buffering capacity, anti-inflammatory activity, and modulation of the oral microbiome (Chapple et al., 2017; Woelber & Tennert, 2020).

Despite growing recognition of the diet–oral health connection, nutritional assessment and counseling remain underintegrated into routine dental care. Research in this field is often fragmented, with studies focusing separately on nutrient deficiencies, cariogenic behaviors, or isolated interventions. A comprehensive synthesis of contemporary evidence is therefore needed to clarify how diet quality influences dental outcomes through interacting biological and behavioral pathways. This systematic review aims to address this gap by critically examining nutrient deficiencies, cariogenic dietary behaviors, and protective dietary interventions, thereby providing an integrated evidence base to inform clinical practice, preventive strategies, and public health policy.

Methodology

This systematic review was conducted and reported in accordance with the **PRISMA** 2020 statement to ensure methodological transparency and reproducibility.

A comprehensive literature search was performed across four electronic databases: PubMed, Scopus, Web of Science, and ScienceDirect. The search covered studies published between January 2016 and March 2025 to capture contemporary evidence reflecting recent dietary transitions and preventive dentistry approaches. Search terms were developed using Medical Subject Headings (MeSH) and free-text keywords, combined with Boolean operators, and included: *diet quality*, *nutrition*, *nutrient deficiency*, *dietary patterns*, *dental caries*, *periodontal disease*, *oral health*, and *dietary intervention*. Reference lists of eligible articles were manually screened to identify additional relevant studies.

Studies were included if they met the following criteria: (1) peer-reviewed original research; (2) observational (cross-sectional, cohort, or case–control) or interventional (randomized or non-randomized trials) study designs; (3) conducted in human populations across any age group; and (4) reported quantitative associations between dietary factors or nutrient status and dental outcomes such as dental caries, enamel erosion, gingivitis, or periodontitis. Exclusion criteria comprised animal or in vitro studies,

narrative reviews, conference abstracts, case reports, and studies lacking explicit dietary assessment or oral health outcomes.

Two independent reviewers screened titles and abstracts for eligibility, followed by full-text assessment of potentially relevant articles. Discrepancies were resolved through discussion and consensus. A standardized data extraction form was used to collect information on study characteristics, population demographics, dietary exposure measures, dental outcomes assessed, and key findings.

Methodological quality and risk of bias were evaluated using validated appraisal tools appropriate to study design. Due to heterogeneity in dietary assessment methods and outcome measures, a narrative synthesis approach was employed, with findings organized across nutrient deficiencies, cariogenic behaviors, and protective dietary interventions.

Nutrient Deficiencies and Dental Outcomes

Adequate nutritional intake is fundamental for the development, maintenance, and repair of oral tissues. Teeth and periodontal structures are metabolically active systems that depend on a continuous supply of essential macro- and micronutrients to preserve enamel integrity, dentin strength, gingival health, and immune defense mechanisms. Nutrient deficiencies can disrupt these processes, increasing vulnerability to dental caries, enamel defects, and periodontal disease.

Calcium and phosphorus are primary components of hydroxyapatite crystals, which provide structural strength to enamel and dentin. Insufficient intake of these minerals is associated with reduced enamel mineral density, increased porosity, and heightened susceptibility to acid dissolution. Epidemiological studies indicate that low dietary calcium intake correlates with higher caries prevalence, particularly in children and adolescents whose teeth are still developing (Moynihan, 2016). In adults, inadequate calcium intake has also been linked to periodontal attachment loss and alveolar bone resorption, suggesting a role in long-term periodontal stability (Chapple et al., 2017).

Vitamin D plays a critical regulatory role in calcium and phosphorus absorption and bone metabolism. Deficiency in vitamin D has been consistently associated with increased caries risk, enamel hypoplasia, and periodontal inflammation. A systematic review by Hujoel (2019) demonstrated that vitamin D supplementation was associated with a significant reduction in caries incidence, particularly in populations with baseline deficiency. Beyond mineral metabolism, vitamin D also modulates immune responses, reducing inflammatory processes that contribute to periodontal tissue breakdown.

Vitamin C is essential for collagen synthesis and connective tissue integrity. Deficiency impairs wound healing and weakens the periodontal ligament and gingival tissues, leading to bleeding, increased probing depths, and tooth mobility. Observational studies have shown inverse relationships between vitamin C intake and periodontal disease severity, especially among smokers and older adults (Amarasena et al., 2018). Chronic marginal deficiency, rather than overt scurvy, is increasingly recognized as a contributor to subclinical periodontal inflammation.

Magnesium supports enamel crystal formation and influences calcium metabolism. Low magnesium intake has been associated with enamel defects and altered salivary composition, potentially increasing cariogenic risk. Trace minerals such as zinc and iron also contribute to oral health through antimicrobial activity and immune regulation. Zinc deficiency, for example, has been linked to impaired salivary gland function and increased plaque accumulation, while iron deficiency anemia has been associated with atrophic oral mucosa and increased susceptibility to infections.

Oxidative stress plays a key role in the pathogenesis of periodontal disease. Diets deficient in antioxidants such as vitamins A, E, and polyphenols may exacerbate inflammatory responses within gingival tissues. Clinical and observational studies suggest that higher antioxidant intake is associated with reduced gingival bleeding and improved periodontal parameters (Woelber & Tennert, 2020). These nutrients help neutralize reactive oxygen species generated during chronic inflammation, thereby protecting periodontal tissues from progressive damage.

Nutritional status during pregnancy and early childhood has lasting implications for dental outcomes. Deficiencies in calcium, vitamin D, and protein during tooth development stages are associated with enamel hypoplasia and increased caries susceptibility later in life. Developmental enamel defects create rough surfaces that facilitate plaque retention, amplifying the effects of cariogenic dietary behaviors.

Table 1. Key Nutrient Deficiencies and Associated Dental Outcomes

Nutrient	Primary Dental Outcome	Mechanistic Pathway
Calcium	Enamel demineralization	Reduced hydroxyapatite formation
Vitamin D	Increased caries risk	Impaired calcium absorption & immune regulation
Vitamin C	Periodontal bleeding	Defective collagen synthesis
Magnesium	Enamel defects	Altered mineral metabolism
Antioxidants	Gingival inflammation	Increased oxidative stress

Overall, evidence strongly supports the role of nutrient sufficiency as a foundational determinant of dental health. Nutrient deficiencies do not act in isolation but interact with cariogenic dietary behaviors and oral hygiene practices to shape dental outcomes. Addressing these deficiencies through dietary improvement or supplementation represents a critical preventive strategy, particularly in vulnerable populations such as children, older adults, and socioeconomically disadvantaged groups. Understanding these nutritional pathways provides essential context for interpreting cariogenic risk and evaluating protective dietary interventions, which are explored in subsequent sections.

Cariogenic Dietary Behaviors and Risk Patterns

Dietary behaviors play a decisive role in shaping the cariogenic environment of the oral cavity. Beyond nutrient composition, the frequency, timing, physical form, and processing level of foods substantially influence oral pH dynamics, microbial metabolism, and enamel integrity. Cariogenic dietary behaviors are now recognized as central behavioral risk factors for dental caries and erosion, interacting synergistically with nutrient deficiencies and oral hygiene practices.

One of the most consistently documented cariogenic behaviors is the frequent intake of free sugars, particularly sucrose, glucose, and fructose. These sugars serve as substrates for acidogenic and aciduric bacteria, such as *Streptococcus mutans*, leading to lactic acid production and repeated enamel demineralization episodes. Evidence indicates that the **frequency** of sugar exposure is more predictive of caries development than total sugar quantity, as frequent consumption limits the time available for salivary buffering and remineralization (Moynihan & Kelly, 2017). Snacking between meals, especially on sugary foods, has been strongly associated with increased caries incidence in both children and adults.

Sugar-sweetened beverages, including soft drinks, energy drinks, and sweetened juices, contribute to cariogenic and erosive risk through combined sugar and acid exposure. Their liquid form facilitates rapid diffusion into dental plaque and prolongs enamel contact time, particularly when consumed slowly or repeatedly throughout the day. Acidic beverages lower oral pH directly, weakening enamel and making it more susceptible to bacterial acid attack. Epidemiological studies consistently report higher caries prevalence and dental erosion among individuals with high consumption of sugar-sweetened beverages, especially adolescents and young adults (Bernabé et al., 2020).

The global shift toward ultra-processed foods represents a major dietary transition with implications for oral health. These products are typically rich in refined carbohydrates, added sugars, and fermentable starches, while being low in protective nutrients and fiber. Sticky textures and high glycemic load prolong oral retention and enhance plaque adherence, intensifying acid production. Moreover, ultra-processed foods often displace nutrient-dense options, indirectly contributing to micronutrient deficiencies that further compromise enamel resilience and periodontal health.

Eating behaviors related to meal timing also influence cariogenic risk. Late-night snacking and eating before sleep are particularly harmful due to reduced salivary flow during sleep, which diminishes natural buffering capacity and antimicrobial action. Studies show that nocturnal sugar intake significantly increases caries risk, even in individuals with otherwise adequate oral hygiene, underscoring the importance of behavioral timing alongside dietary composition.

Cariogenic dietary behaviors are unevenly distributed across populations. Children, adolescents, and individuals from lower socioeconomic backgrounds are disproportionately exposed to high-sugar diets due to marketing practices, food accessibility, and limited nutrition literacy. Cultural dietary norms and urbanization further shape consumption patterns, reinforcing disparities in oral health outcomes. Importantly, these behaviors often cluster with other risk factors, such as inadequate oral hygiene and limited access to preventive dental care, amplifying disease burden.

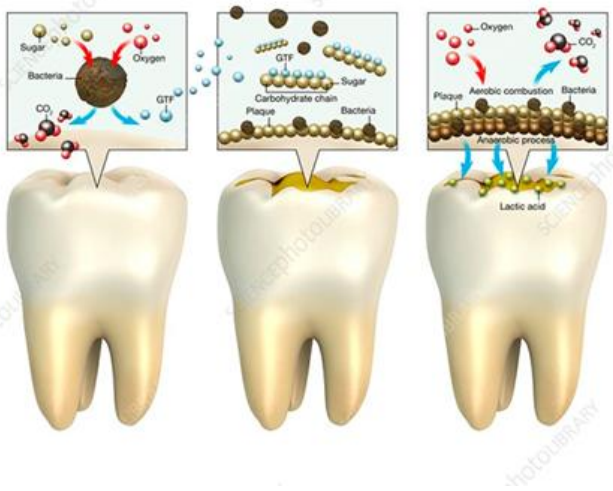


Figure 1: Interaction with Saliva and Oral Microbiome

Cariogenic behaviors exert their effects through complex interactions with salivary function and the oral microbiome. Frequent sugar exposure selects for acid-tolerant bacterial species, shifting the microbial ecology toward a dysbiotic state. Reduced salivary flow, whether due to dehydration, medication use, or nocturnal eating, exacerbates this imbalance by impairing buffering capacity and antimicrobial defense.

These mechanisms highlight how behavioral patterns influence biological processes that culminate in dental disease.

Collectively, evidence demonstrates that cariogenic dietary behaviors are potent and modifiable determinants of dental outcomes. Their impact extends beyond sugar quantity to include consumption frequency, food form, acidity, and timing. These behaviors interact closely with nutrient deficiencies and protective dietary practices, reinforcing the need for integrated dietary guidance rather than isolated sugar reduction messages. Addressing cariogenic behaviors through targeted nutrition education, behavioral interventions, and public health policies is essential for reducing the global burden of dental caries and erosion.

Protective Dietary Interventions and Oral Health Promotion

Protective dietary interventions represent a critical counterbalance to cariogenic exposures and nutrient deficiencies, offering biologically plausible and cost-effective strategies for improving oral health across the lifespan. Increasing evidence demonstrates that specific foods, nutrients, and dietary patterns actively enhance enamel resilience, modulate the oral microbiome, and reduce inflammatory processes associated with periodontal disease. Unlike purely restrictive approaches focused on sugar reduction, protective dietary strategies emphasize positive dietary inclusion and overall diet quality improvement.

Dairy products such as milk, cheese, and yogurt are among the most consistently supported protective foods for dental health. They provide bioavailable calcium, phosphorus, and casein phosphopeptides, which facilitate enamel remineralization and inhibit demineralization. Cheese consumption, in particular, has been shown to increase salivary calcium concentration and elevate plaque pH following sugar exposure, thereby counteracting acidogenic challenges. Clinical and observational studies indicate lower caries prevalence among individuals with regular dairy intake, especially in children and adolescents during critical periods of tooth development (Moynihan, 2016).

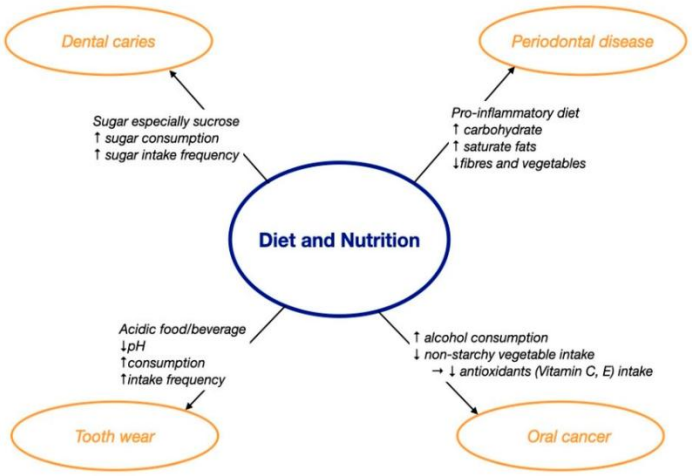
Diets rich in fibrous fruits, vegetables, and whole grains promote oral health through mechanical and physiological mechanisms. Chewing fibrous foods stimulates salivary flow, enhancing buffering capacity and accelerating clearance of fermentable carbohydrates. Increased saliva production also supports antimicrobial defense and provides minerals essential for remineralization. Population-based studies associate higher fruit and vegetable intake with improved periodontal status and reduced gingival bleeding, even after adjusting for oral hygiene behaviors (Chapple et al., 2017). Importantly, these foods contribute antioxidants and micronutrients that further support gingival health.

Polyphenols found in tea, berries, cocoa, and certain herbs exhibit antimicrobial and anti-inflammatory properties relevant to oral health. Experimental and clinical studies suggest that polyphenols inhibit the adhesion and metabolic activity of cariogenic bacteria while promoting a more balanced oral microbiome. Green tea catechins, for example, have been associated with reduced plaque accumulation and improved periodontal parameters. These effects extend beyond direct antimicrobial action to include modulation of inflammatory signaling pathways in gingival tissues (Woelber & Tennert, 2020).

Non-fermentable sugar substitutes such as xylitol and sorbitol play a well-established role in caries prevention. Xylitol, in particular, disrupts *Streptococcus mutans* metabolism and reduces bacterial adherence to tooth surfaces. Regular consumption of xylitol-containing products, including chewing gum, has been shown to decrease caries incidence and enhance salivary flow. These interventions are especially effective when integrated into broader dietary and oral hygiene strategies rather than used in isolation.

Beyond individual foods or nutrients, whole dietary patterns exert cumulative protective effects. Anti-inflammatory dietary patterns—characterized by high intake of vegetables, fruits, whole grains, lean proteins, and unsaturated fats—have been associated with reduced periodontal inflammation and improved clinical attachment levels. Interventional studies demonstrate that dietary modification alone, without changes in oral hygiene, can significantly reduce gingival inflammation, highlighting the independent contribution of diet quality to periodontal health (Woelber et al., 2016).

Incorporating protective dietary interventions into oral health promotion requires coordinated action across clinical practice and public health systems. Dental professionals are uniquely positioned to deliver brief, targeted dietary counseling during routine visits, yet nutrition remains underemphasized in dental education and practice. Population-level interventions, including school-based nutrition programs and alignment with dietary guidelines advocated by the **World Health Organization**, can amplify individual-level benefits and reduce oral health inequalities.



Synthesis

Protective dietary interventions offer multidimensional benefits for oral health by enhancing remineralization, stimulating saliva, modulating the oral microbiome, and reducing inflammatory burden. Evidence increasingly supports shifting oral health promotion from a deficit-focused model toward one that emphasizes diet quality and protective food choices. Integrating these strategies into preventive dentistry and public health policy can substantially reduce the burden of dental caries and periodontal disease while supporting broader nutritional well-being.

Evidence Synthesis & Integrated Conceptual Model

This section synthesizes evidence from the preceding domains—nutrient deficiencies, cariogenic dietary behaviors, and protective dietary interventions—into an integrated explanatory framework that clarifies how diet quality influences dental outcomes through interacting biological and behavioral pathways. Rather than acting independently, these dietary dimensions operate simultaneously within the oral ecosystem, shaping enamel integrity, microbial balance, salivary function, and periodontal inflammation across the lifespan.

The reviewed evidence demonstrates that **nutrient sufficiency forms the biological foundation of dental resilience**. Adequate intake of calcium, phosphorus, vitamin D, vitamin C, magnesium, and antioxidants supports enamel mineralization, collagen synthesis, immune competence, and oxidative balance within oral tissues. When deficiencies are present, enamel becomes structurally weaker, periodontal tissues more

vulnerable, and reparative capacity diminished. These biological vulnerabilities amplify the harmful effects of cariogenic exposures.

Conversely, **cariogenic dietary behaviors function as behavioral accelerators of dental disease**. Frequent consumption of free sugars, sugar-sweetened beverages, ultra-processed foods, and nocturnal snacking repeatedly lowers oral pH and promotes acidogenic bacterial dominance. The literature consistently shows that frequency and timing of exposure are more decisive than total sugar intake alone, as repeated acid attacks overwhelm natural remineralization processes. Importantly, cariogenic behaviors exert disproportionate harm in individuals with underlying nutrient deficiencies, illustrating a synergistic rather than additive risk model.

In contrast, **protective dietary interventions act as biological and ecological moderators**. Dairy products enhance remineralization and buffering capacity, fibrous foods stimulate salivary flow, polyphenol-rich foods modulate microbial composition, and sugar substitutes reduce bacterial virulence. At the dietary pattern level, anti-inflammatory and nutrient-dense diets demonstrate measurable reductions in gingival inflammation even without changes in oral hygiene practices. These findings highlight diet quality as an independent and modifiable determinant of oral health.

Collectively, the evidence supports a **dynamic interaction model** in which dental outcomes are determined by the balance between risk-enhancing behaviors and protective nutritional exposures, mediated through biological pathways involving saliva, enamel chemistry, immune response, and the oral microbiome.

Integrated Conceptual Model

Based on the synthesized evidence, an integrated conceptual model is proposed to illustrate how diet quality influences dental outcomes (Figure 1). The model consists of three interacting layers:

1. **Nutritional Status Layer**: Represents micronutrient sufficiency or deficiency influencing enamel strength, connective tissue integrity, and immune function.
2. **Dietary Behavior Layer**: Captures cariogenic exposures such as sugar frequency, beverage acidity, food processing level, and meal timing.
3. **Protective Modulation Layer**: Includes dietary elements that buffer acids, stimulate saliva, promote remineralization, and regulate microbial ecology.

These layers converge on **oral biological mediators**—salivary flow and buffering, microbial balance, enamel demineralization–remineralization cycles, and inflammatory pathways—which ultimately determine **clinical dental outcomes**, including caries incidence, enamel erosion, gingivitis, and periodontitis.

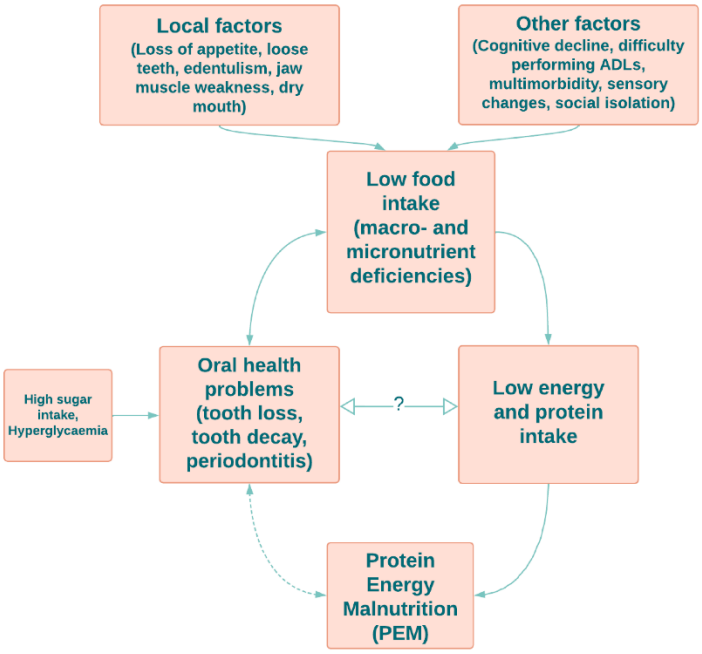


Figure 3. Integrated conceptual model illustrating the pathways linking diet quality, nutrient status, dietary behaviors, and protective interventions to dental outcomes through biological mediators.

This integrated synthesis advances three key insights. First, **diet quality should be conceptualized as a system**, not a set of isolated nutrients or behaviors. Second, **nutritional adequacy modifies susceptibility**, meaning that identical cariogenic behaviors may produce different outcomes depending on underlying nutritional status. Third, **protective dietary strategies offer dual benefits**, mitigating risk while actively promoting oral tissue health.

Table 2. Integrated Evidence Mapping of Diet Quality and Dental Outcomes

Evidence Domain	Key Dietary Factors	Primary Biological Mediators	Dental Outcomes
Nutrient Deficiencies	Low calcium, vitamin D, vitamin C, antioxidants	Reduced mineralization, impaired collagen synthesis, immune dysfunction	Enamel defects, increased caries risk, periodontal inflammation
Cariogenic Behaviors	Frequent sugar intake, acidic drinks, ultra-processed foods	Repeated pH drops, dysbiotic microbiome, reduced remineralization	Dental caries, enamel erosion
Protective Interventions	Dairy intake, fibrous foods, polyphenols, xylitol	Salivary stimulation, buffering, microbial modulation	Reduced caries incidence, improved periodontal health
Dietary Patterns	Anti-inflammatory, nutrient-dense diets	Lower oxidative stress, enhanced tissue repair	Improved gingival indices, periodontal stability

The model also helps explain inconsistencies in previous research by demonstrating how failure to account for interacting dietary dimensions may obscure true associations. For example, sugar intake studies that do not assess calcium or vitamin D status may underestimate protective buffering capacity, while intervention studies focusing solely on sugar reduction may overlook the additive benefits of nutrient-dense diets.

The proposed framework provides a structured basis for future empirical studies, dietary risk assessment tools, and integrative preventive strategies. It supports a shift from single-factor dental nutrition research toward **multidimensional dietary models**, aligning with contemporary preventive healthcare paradigms. For clinicians and policymakers, the model underscores the value of embedding nutrition-based oral health promotion within broader dietary and public health strategies.

Discussion

This systematic review provides a comprehensive synthesis of contemporary evidence demonstrating that diet quality is a central, modifiable determinant of dental health. By integrating findings across nutrient deficiencies, cariogenic dietary behaviors, and protective dietary interventions, the review advances understanding beyond isolated risk factors toward a multidimensional dietary model that more accurately reflects real-world oral health dynamics.

A key finding of this review is that **nutritional adequacy underpins dental resilience**. Adequate intake of calcium, vitamin D, vitamin C, magnesium, and antioxidants supports enamel mineralization, connective tissue integrity, immune regulation, and oxidative balance. Deficiencies in these nutrients weaken structural and biological defenses, thereby increasing susceptibility to dental caries and periodontal disease. Importantly, the evidence suggests that subclinical deficiencies—common in populations consuming energy-dense but nutrient-poor diets—may exert cumulative adverse effects even in the absence of overt malnutrition. This finding reinforces the need to consider overall diet quality rather than focusing exclusively on sugar restriction.

Consistent with previous literature, this review confirms that **cariogenic dietary behaviors remain the dominant behavioral drivers of dental disease**. Frequent intake of free sugars, sugar-sweetened beverages, and ultra-processed foods promotes repeated acid challenges, shifts the oral microbiome toward a dysbiotic state, and accelerates enamel demineralization. Notably, frequency and timing of exposure emerged as stronger predictors of caries risk than total sugar quantity alone, particularly when combined with nocturnal eating and reduced salivary flow. These findings support public health recommendations emphasizing both reduction and restructuring of sugar consumption patterns.

However, a novel contribution of this review lies in highlighting the **moderating role of protective dietary interventions**. Evidence indicates that dairy products, fibrous foods, polyphenol-rich items, and sugar substitutes do more than simply offset harm; they actively promote protective biological processes such as remineralization, salivary stimulation, microbial regulation, and inflammation reduction. Intervention studies demonstrating reductions in gingival inflammation without changes in oral hygiene practices underscore diet quality as an independent determinant of periodontal health. This challenges the traditional oral health paradigm that prioritizes mechanical plaque control while underestimating dietary influence.

The integrated conceptual model proposed in this review helps reconcile inconsistencies observed in prior research. Studies examining sugar intake without accounting for nutrient status or protective food consumption may overestimate cariogenic risk, while nutrient-focused studies that ignore behavioral exposures may underestimate real-world disease burden. By conceptualizing dental outcomes as the product of interacting dietary layers—nutritional status, behaviors, and protective modulation—the model offers a more nuanced and explanatory framework for both research and practice.

From a clinical perspective, the findings underscore a critical gap between evidence and practice. Nutritional counseling remains underutilized in routine dental care, often due to time constraints, limited

nutrition training, and lack of integrated care pathways. Yet brief, targeted dietary interventions delivered in dental settings have the potential to significantly enhance preventive outcomes. Incorporating dietary screening tools and interdisciplinary collaboration with nutrition professionals could strengthen patient-centered oral health care.

At the public health level, these findings align with broader non-communicable disease prevention strategies advocated by the **World Health Organization**, which emphasize reducing free sugar intake while promoting nutrient-dense diets. Integrating oral health objectives into national nutrition policies, school-based feeding programs, and community education initiatives could yield synergistic benefits for both oral and systemic health. Such integration is particularly important for addressing oral health disparities linked to socioeconomic status and food accessibility.

Despite its strengths, this review has limitations. Heterogeneity in dietary assessment methods, outcome measures, and study designs limited the feasibility of meta-analysis. Many studies relied on self-reported dietary data, which may be subject to recall bias. Additionally, most interventional studies were short-term, limiting conclusions about long-term sustainability of dietary effects on dental outcomes. Future research should prioritize longitudinal designs, standardized dietary metrics, and intervention studies that assess combined dietary strategies rather than isolated components.

In conclusion, this review reinforces diet quality as a foundational determinant of dental health and supports a paradigm shift from single-nutrient or sugar-centric approaches toward integrated dietary models. Addressing nutrient adequacy, modifying cariogenic behaviors, and promoting protective dietary practices collectively represent a powerful strategy for improving oral health outcomes across the lifespan.

Conclusion

This systematic review demonstrates that diet quality plays a fundamental and multifaceted role in shaping dental health outcomes across the lifespan. The synthesized evidence confirms that dental caries, enamel erosion, and periodontal diseases are not solely the result of inadequate oral hygiene practices, but are strongly influenced by nutritional status, dietary behaviors, and the presence or absence of protective dietary components. Nutrient deficiencies compromise enamel integrity, connective tissue health, and immune responses, thereby increasing vulnerability to oral disease. At the same time, frequent exposure to free sugars, acidic beverages, and ultra-processed foods accelerates cariogenic processes through repeated acid challenges and microbial dysbiosis.

Importantly, this review highlights that protective dietary interventions offer active biological benefits rather than merely reducing harm. Diets rich in calcium-containing foods, fibrous fruits and vegetables, polyphenol-rich items, and non-fermentable sugar substitutes enhance remineralization, stimulate salivary defenses, modulate the oral microbiome, and reduce inflammatory burden. These effects operate independently and synergistically, reinforcing the concept that diet quality should be addressed as an integrated system rather than through isolated nutritional recommendations.

The proposed integrated conceptual model provides a practical framework for understanding how nutritional adequacy, dietary behaviors, and protective modulation interact to determine dental outcomes. This framework supports a shift in preventive dentistry toward incorporating nutritional assessment and dietary counseling as core components of oral healthcare delivery. Aligning clinical practice with broader dietary guidance advocated by the **World Health Organization** and other public health authorities may yield substantial benefits for both oral and systemic health.

Overall, improving diet quality represents a cost-effective, sustainable, and equitable strategy for reducing the global burden of oral diseases. Integrating nutrition-focused interventions into dental practice and public health policy is essential for advancing comprehensive, preventive oral healthcare.

References

1. Amarasena, N., Ogawa, H., Yoshihara, A., & Miyazaki, H. (2018). Serum vitamin C–periodontal relationship in community-dwelling elderly. *Journal of Clinical Periodontology*, 45(3), 344–352. https://doi.org/10.1111/jcpe.12863
2. Bernabé, E., Ballantyne, H., Longbottom, C., & Pitts, N. B. (2020). Early introduction of sugars and caries development: A longitudinal evaluation. *Community Dentistry and Oral Epidemiology*, 48(6), 543–550. https://doi.org/10.1111/cdoe.12573
3. Chapple, I. L. C., Bouchard, P., Cagetti, M. G., et al. (2017). Interaction of lifestyle, behaviour or systemic diseases with dental caries and periodontal diseases. *Journal of Clinical Periodontology*, 44(S18), S39–S51. https://doi.org/10.1111/jcpe.12685
4. Hujoel, P. P. (2019). Vitamin D and dental caries in controlled clinical trials: Systematic review and meta-analysis. *Nutrition Reviews*, 77(10), 699–720. https://doi.org/10.1093/nutrit/nuz037
5. Kassebaum, N. J., Smith, A. G. C., Bernabé, E., et al. (2017). Global, regional, and national prevalence, incidence, and disability-adjusted life years for oral conditions. *Journal of Dental Research*, 96(4), 380–387. https://doi.org/10.1177/0022034517693566
6. Moynihan, P. (2016). Sugars and dental caries: Evidence for setting a recommended threshold for intake. *Advances in Nutrition*, 7(1), 149–156. https://doi.org/10.3945/an.115.009365
7. Moynihan, P., & Kelly, S. (2017). Effect on caries of restricting sugars intake: Systematic review to inform WHO guidelines. *Journal of Dental Research*, 96(1), 15–22. https://doi.org/10.1177/0022034516678954
8. Peres, M. A., Macpherson, L. M. D., Weyant, R. J., et al. (2019). Oral diseases: A global public health challenge. *The Lancet*, 394(10194), 249–260. https://doi.org/10.1016/S0140-6736(19)31146-8
9. Sheiham, A., & James, W. P. T. (2015). A reappraisal of the quantitative relationship between sugar intake and dental caries. *Journal of Dental Research*, 94(10), 1345–1352. https://doi.org/10.1177/0022034515590371
10. Touger-Decker, R., & van Loveren, C. (2016). Sugars and dental caries. *The American Journal of Clinical Nutrition*, 78(4), 881S–892S. https://doi.org/10.1093/ajcn/78.4.881S
11. Woelber, J. P., & Tennert, C. (2020). Diet and periodontal diseases: Impact of nutrition on periodontal health. *Oral Health & Preventive Dentistry*, 18(1), 1–8. https://doi.org/10.3290/j.ohpd.a43920
12. Woelber, J. P., Bremer, K., Vach, K., et al. (2016). An oral health optimized diet can reduce gingival and periodontal inflammation in humans. *BMC Oral Health*, 17(1), 28. https://doi.org/10.1186/s12903-016-0257-1
13. World Health Organization. (2015). *Guideline: Sugars intake for adults and children*. Geneva: WHO.
14. World Health Organization. (2022). *Global oral health status report: Towards universal health coverage for oral health by 2030*. Geneva: WHO.