Non-invasive Approaches in Dental Caries: Dietary Control, Caries Risk Assessment, Preventive Strategies, and Remineralization

Diş Çürüklerinde Non-invaziv Yaklaşımlar: Beslenme Kontrolü, Çürük Risk Değerlendirmesi, Koruyucu Önlemler ve Remineralizasyon

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ABSTRACT This chapter reviews evidence-based, non-invasive caries management for children and adolescents. Framing caries as a dynamic, reversible, biofilm-mediated disease, it emphasizes four pillars: (1) dietary control and tailored counseling; (2) structured caries risk assessment and risk-based recalls; (3) preventive measures—including twice-daily fluoridated toothpaste, professional fluoride varnish, and pit-and-fissure sealants; and (4) management of carious lesions through remineralization. Salivary function, socioeconomic determinants, medical comorbidities, and orthodontic appliances are considered in individualized care. Adjuncts such as xylitol and emerging biomimetic agents (e.g., casein phosphopeptide amorphous calcium phosphate, bioactive glass, peptides, theobromine) can complement—though not replace—fluoride. Professional guidelines support early, lifelong, risk-stratified prevention and community policies (fluoridation, sugar reduction, school programs). Future directions include nanotechnology-enabled delivery and AI-assisted diagnostics. Integrating clinical, behavioral, and public-health strategies preserves tooth structure, reduces disease burden, and improves pediatric oral-health outcomes.

Keywords: Dental caries; fluorides; pediatric dentistry; prevention and control; tooth remineralization

ÖZET Bu bölüm, çocuk ve adölesanlarda kanıta dayalı, invaziv olmayan çürük yönetimini özetlemektedir. Diş çürüğü dinamik, geri döndürülebilir ve biyofilm aracılı bir hastalık olarak ele alarak dört temel sütunu vurgulamaktadır: (1) diyet kontrolü ve kişiselleştirilmiş danışmanlık; (2) yapılandırılmış çürük risk değerlendirmesi ve riske dayalı çağrılar; (3) önleyici uygulamalar—günde iki kez florlu diş macunu, profesyonel flor verniği/jeli ve fissür örtücüler; (4) çürük lezyonların remineralizasyonla yönetimi. Tükürük fonksiyonu, sosyoekonomik etkenler, tıbbi durumlar ve ortodontik apareyler gibi ilave durumlar kişiselleştirilmiş bakımda göz önünde bulundurulmalıdır. Ksilitol ve gelişen biomimetik ajanlar (kazein fosfopeptit amorf kalsiyum fosfat, bioaktif cam, peptitler, teobromin, vb.) florun tamamlayıcısıdır. Uluslararası bilimsel kılavuzlar; erken, yaşam boyu, riske göre önlemeyi ve toplumsal politikaları (floridasyon, şeker azaltımı, okul programları) desteklemektedir. Gelecek; nano-taşıyıcılarla kontrollü salım ve yapay zekâ destekli tanı ile şekillenecektir. Çok düzeyli entegrasyon, diş dokusunu koruyarak diş çürüklerinin erken evrede yönetimini sağlar ve hastalık yükünü azaltır.

Anahtar Kelimeler: Diş çürükleri ; florürler; çocuk diş hekimliği; önleme ve kontrol; diş remineralizasyonu

Dental caries is recognized as the most common chronic disease in childhood.[1] Despite advances in restorative materials and techniques, caries remains a major public health concern that significantly affects the oral health-related quality of life of children and adolescents. Beyond its clinical manifestations, untreated caries contributes to pain, infection, impaired nutrition, difficulty in speech, and diminished self-esteem, thereby underscoring the necessity for effective preventive strategies.[2]

In recent decades, dentistry has witnessed a paradigm shift from an operative and restorative model toward prevention-focused and minimally invasive care. Traditional

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treatment approaches, which primarily relied on mechanical removal of diseased tissues followed by restorative interventions, often failed to address the underlying etiological factors. Such methods, although effective in temporarily restoring function, do not alter disease susceptibility and may initiate a "restorative cycle" that ultimately compromises tooth structure over time. This recognition has propelled the adoption of non-invasive approaches aimed at early identification, risk reduction, and biological management of dental caries.[3]

Non-invasive caries management is built upon four essential pillars: dietary control, caries risk assessment, preventive interventions, and the management of non-cavitated lesions.[4] Dietary control remains fundamental, as frequent sugar consumption and fermentable carbohydrate intake are well-documented drivers of cariogenic biofilm formation and demineralization.[5] Caries risk assessment provides a systematic method to identify individuals at elevated risk and to tailor preventive and therapeutic strategies accordingly.[6] Preventive measures, such as topical fluoride application and sealant placement, directly target the balance between demineralization and remineralization, aiming to maintain enamel integrity and halt lesion progression.[7] The management of non-cavitated lesions, through remineralization techniques, has become increasingly relevant with the availability of biomimetic agents and evidence-based clinical protocols.[8,9]

Furthermore, the concept of caries as a dynamic, multifactorial, and reversible disease has broadened the scope of management. The caries process involves a complex interplay between host factors, the oral microbiome, diet, and time. Importantly, early-stage lesions represent a window of opportunity for intervention without resorting to irreversible restorative procedures. This perspective aligns with modern dental philosophies that emphasize patient-centered care, disease prevention, and minimally invasive dentistry.[10]

The purpose of this chapter is to provide a comprehensive and evidence-based overview of non-invasive approaches to caries management in children. Specifically, it will address (1) dietary control and counseling strategies, (2) caries risk assessment models and their clinical utility, (3) preventive measures including fluoride and sealant applications, and (4) the management of carious lesions through remineralization protocols. By integrating current scientific evidence with clinical recommendations, this chapter seeks to guide clinicians in implementing effective preventive strategies that preserve tooth structure, reduce disease burden, and improve oral health outcomes in pediatric populations.

CARIES RISK ASSESSMENT

THE CONCEPT AND ITS EVOLUTION

Caries risk assessment represents a fundamental shift in the understanding and management of dental caries. For many decades, dentistry relied on a purely lesion-centered model in which treatment was initiated only when cavitation occurred. However, the modern view of caries as a dynamic, multifactorial, and reversible process emphasizes the need for early identification of risk and protective factors.[10] Caries risk assessment provides clinicians with a systematic method to evaluate the likelihood of future caries development, not only at the population level but also on an individualized, patient-specific basis. This approach aligns with the principles of preventive and minimally invasive dentistry, aiming to preserve tooth structure and maintain oral health over a lifetime.[10]

RISK FACTORS

Biological determinants form the core of caries susceptibility and progression. Tooth-related factors such as developmental defects of enamel, deep pits and fissures, and early eruption patterns create retention sites for plaque and limit natural cleaning. Saliva serves as the primary defense mechanism through its buffering capacity, antimicrobial proteins, and supply of calcium and phosphate ions. Reduced salivary flow or altered composition—whether due to dehydration, systemic diseases, or medication use—significantly increases caries risk. The balance between cariogenic and non-cariogenic bacteria determines the ecological stability of the oral biofilm. An overgrowth of *Streptococcus mutans* and *Lactobacillus* species in a carbohydrate-rich environment accelerates demineralization.[11]

Behavioral patterns strongly influence the trajectory of caries development. High frequency of sugar intake, particularly between meals and before bedtime, provides a continuous substrate for acidogenic bacteria. Liquid sugars such as fruit juices, sweetened milk, or carbonated beverages pose additional risk due to prolonged clearance times. Inadequate plaque control, irregular toothbrushing, and the absence of fluoride toothpaste directly compromise the natural balance between demineralization and remineralization. Similarly, irregular dental visits and delayed intervention in early lesions lead to progression and increase the need for operative care.[12]

Caries prevalence exhibits a strong social gradient. Children from families with lower socioeconomic status often experience higher disease burden due to limited access to preventive care and professional fluoride applications, lack of parental knowledge or awareness about dietary and oral hygiene practices, and environmental factors such as the absence of fluoridated water supply or cultural dietary preferences. Parental caries experience also serves as a predictive factor, as it reflects both genetic and environmental influences.[13]

Children with systemic diseases or special health care needs often present with additional risk factors. Medically compromised children may require long-term medication leading to xerostomia or contain sugar-based syrups. Children with physical or intellectual disabilities may have limited ability to perform oral hygiene independently. Orthodontic appliances create retention niches for plaque and complicate mechanical cleaning, increasing the risk of demineralization around brackets.[14,15]

CARIES RISK ASSESSMENT MODELS AND TOOLS

Over the years, several structured tools have been developed to guide clinicians. Caries Management by Risk Assessment (CAMBRA) incorporates disease indicators, biological risk factors, and protective factors, categorizing patients into low, moderate, high, or extreme risk and tailoring interventions accordingly.[16] The Cariogram model provides a graphical representation of the balance between risk and protective factors. Its visual "pie chart" presentation is particularly valuable in patient education, helping parents and children understand their caries susceptibility.[16] The American Academy of Pediatric Dentistry (AAPD) Caries Risk Assessment Tool emphasizes age-related determinants such as feeding patterns, parental caries experience, fluoride exposure, and socioeconomic background, designed specifically for infants, toddlers, and school-aged children. Additionally, many countries and professional bodies have adapted risk assessment forms to align with local epidemiological and cultural contexts.[17] Figures 1 and 2 illustrate the AAPD Caries Risk Assessment forms developed for dental providers. Figure 1 represents the risk assessment tool designed for children aged 0–5 years, whereas Figure 2 demonstrates the version applicable to children aged 6 years and older, including adolescents.[17]

In addition to questionnaire-based models, objective biological assessments such as salivary tests can further refine risk prediction. Evaluation of salivary flow rate, buffering capacity, and the presence of cariogenic microorganisms (e.g., *Streptococcus mutans* and *Lactobacillus* counts) provides valuable insight into an individual's caries susceptibility and complements traditional risk assessment tools.[18] Salivary diagnostics are particularly useful in children with systemic diseases, medication-induced xerostomia, or orthodontic appliances, where altered salivary function significantly modifies the caries risk profile.

CLINICAL APPLICATION OF RISK ASSESSMENT AND THE DYNAMIC NATURE OF RISK

Risk assessment is not an isolated event but rather an integral part of comprehensive patient care. Its clinical implications include individualized recall intervals, tailored preventive measures, and parental education and engagement. Children at low risk may be scheduled for standard six-month recalls, while high-risk patients may require closer monitoring every three months. Risk categorization guides the frequency and type of fluoride application, sealant placement, and dietary counseling, while explaining the child's risk profile to parents facilitates shared decision-making and improves adherence to preventive recommendations.[19]

Caries risk is not static. It evolves as children grow, their diet changes, and their oral hygiene behaviors mature. For example, a preschool child who is caries-free may transition into a higher-risk category upon entering school, when dietary exposure to snacks and sugary beverages increases. Similarly, orthodontic treatment or systemic medication may temporarily elevate risk. Therefore, risk assessment must be updated regularly—at least annually, but ideally at each clinical visit—to ensure that preventive strategies remain current and effective.[14,19]

LIMITATIONS AND FUTURE DIRECTIONS

While risk assessment tools provide valuable structure, they are not without limitations. Predictive accuracy varies among different populations, and subjective clinical judgment remains essential. Moreover, rapid advances in salivary diagnostics, microbiome profiling, and artificial intelligence may soon offer more precise and individualized risk prediction models. Integrating these technologies with traditional clinical risk assessment will likely represent the next frontier in personalized caries prevention.

DIETARY CONTROL

DIET AS A DETERMINANT IN THE CARIES PROCESS

Dietary factors play a pivotal role in the initiation and progression of dental caries. Among dietary substrates, fermentable carbohydrates—particularly sucrose, glucose, fructose, and cooked starches—are the most significant contributors. Sucrose is considered the most cariogenic due to its unique ability to serve as a substrate for extracellular

Use of this tool will help the health care provider assess the child's risk for developing caries lesions. *In addition, reviewing specific factors will help the practitioner and parent understand the variable influences that contribute to or protect from dental caries.*

Factors	High risk	Moderate risk	Low risk
Risk factors, social/behavioral/medical			
Mother/primary caregiver has active dental caries	Yes		
Parent/caregiver has life-time of poverty, low health literacy	Yes		
Child has frequent exposure (>3 times/day) between-meal sugar-containing snacks or beverages per day	Yes		
Child uses bottle or nonspill cup containing natural or added sugar frequently, between meals and/or at bedtime	Yes		
Child is a recent immigrant		Yes	
Child has special health care needs[α]		Yes	
Risk factors, clinical			
Child has visible plaque on teeth	Yes		
Child presents with dental enamel defects	Yes		
Protective factors			
Child receives optimally-fluoridated drinking water or fluoride supplements			Yes
Child has teeth brushed daily with fluoridated toothpaste			Yes
Child receives topical fluoride from health professional			Yes
Child has dental home/regular dental care			Yes
Disease indicators[β]			
Child has noncavitated (incipient/white spot) caries lesions	Yes		
Child has visible caries lesions	Yes		
Child has recent restorations or missing teeth due to caries	Yes		

α Practitioners may choose a different risk level based on specific medical diagnosis and unique circumstances, especially conditions that affect motor coordination or cooperation.

β While these do not cause caries directly or indirectly, they indicate presence of factors that do.

***Instructions:** Circle "Yes" that corresponds with those conditions applying to a specific patient. Use the circled responses to visualize the balance among risk factors, protective factors, and disease indicators. Use this balance or imbalance, together with clinical judgment, to assign a caries risk level of low, moderate, or high based on the preponderance of factors for the individual. Clinical judgment may justify the weighing of one factor (e.g., heavy plaque on the teeth) more than others.*

Overall assessment of the child's dental caries risk: High ☐ Moderate ☐ Low ☐

FIGURE 1: AAPD Caries Risk Assessment form for children aged 0-5 years [17]

polysaccharide synthesis by *Streptococcus mutans*. These polysaccharides enhance biofilm adherence, creating a retentive environment for acids and reducing plaque clearance.[20]

FREQUENCY AND PATTERN OF SUGAR CONSUMPTION AND HIDDEN SOURCES

The frequency of free sugar intake plays a more significant role in caries development than total quantity consumed. Each cariogenic challenge initiates a plaque pH drop lasting approximately 20-30 minutes, and repeated exposures throughout the day extend the total duration of acid attacks beyond the enamel's remineralization capacity.[20] Even small amounts of sugar, when consumed frequently, can be highly cariogenic, whereas larger quantities consumed at meals pose relatively lower risk. Night-time sugar intake is especially harmful due to reduced salivary flow and buffering capacity during sleep. Sticky carbohydrate forms (e.g., caramel, dried fruits) adhere to tooth surfaces and prolong acidogenic activity, while liquid sugars clear more rapidly but still contribute significantly when consumed frequently.[21]

Beyond obvious sugars, many "healthy-perceived" foods—such as fruit-flavored yogurts, cereals, snack bars, and packaged infant foods—contain hidden free sugars that increase caries risk.[22] Pediatric medications including syrups, vitamins, and analgesics often use sucrose as a vehicle, especially when administered long-term. Additionally, even sugar-free acidic beverages (e.g., sports drinks, soft drinks) contribute to erosion and potentiate demineralization in the presence of frequent carbohydrate intake.[22] The World Health Organization strongly recommends limiting free sugar intake throughout the life course to <10% of total energy intake, with a further reduction to <5% (~25

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Factors	High risk	Moderate risk	Low risk
Risk factors, social/behavioral/medical			
Patient has life-time of poverty, low health literacy	Yes		
Patient has frequent exposure (>3 times/day) between-meal sugar-containing snacks or beverages per day	Yes		
Child is a recent immigrant		Yes	
Patient uses hyposalivatory medication(s)		Yes	
Patient has special health care needs[a]		Yes	
Risk factors, clinical			
Patient has low salivary flow	Yes		
Patient has visible plaque on teeth	Yes		
Patient presents with dental enamel defects	Yes		
Patient wears an intraoral appliance		Yes	
Patient has defective restorations		Yes	
Protective factors			
Patient receives optimally-fluoridated drinking water			Yes
Patient has teeth brushed daily with fluoridated toothpaste			Yes
Patient receives topical fluoride from health professional			Yes
Patient has dental home/regular dental care			Yes
Disease indicators[b]			
Patient has interproximal caries lesion(s)	Yes		
Patient has new noncavitated (white spot) caries lesions	Yes		
Patient has new cavitated caries lesions or lesions into dentin radiographically	Yes		
Patient has restorations that were placed in the last 3 years (new patient) or in the last 12 months (patient of record)	Yes		

[a] Practitioners may choose a different risk level based on specific medical diagnosis and unique circumstances, especially conditions that affect motor coordination or cooperation.

[b] While these do not cause caries directly or indirectly, they indicate presence of factors that do.

***Instructions:** Circle "Yes" that corresponds with those conditions that apply to a specific patient. Use the circled responses to visualize the balance among risk factors, protective factors, and disease indicators. Use this balance or imbalance, together with clinical judgment, to assign a caries risk level of low, moderate, or high based on the preponderance of factors for the individual. Clinical judgment may justify the weighing of one factor (e.g., heavy plaque on the teeth) more than others.*

Overall assessment of the dental caries risk: **High** ☐ **Moderate** ☐ **Low** ☐

FIGURE 2: AAPD Caries Risk Assessment form for children aged 6 years and older, including adolescents [17]

g/day) offering additional caries-preventive benefit (*strong recommendation*).

PROTECTIVE DIETARY FACTORS

Not all dietary components are harmful. Non-cariogenic sweeteners such as xylitol inhibit Streptococcus mutans, reduce maternal transmission of cariogenic bacteria, and stimulate salivary flow. Sorbitol and erythritol provide lesser but still favorable effects. Milk, cheese, and casein-derived phosphopeptides supply calcium and phosphate and aid remineralization; cheese, in particular, rapidly raises plaque pH. Fibrous foods, including vegetables and fibrous fruits, stimulate saliva and enhance mechanical cleansing.[23,24]

DIETARY ASSESSMENT & COUNSELING STRATEGIES

Accurate assessment tools such as 24-hour recall and 3- or 7-day diet diaries help quantify frequency of cariogenic exposures. Sugar frequency indices and cariogenicity scoring systems exist but remain primarily research-oriented.[25]

Dietary counseling must be personalized and behavior-focused. Motivational interviewing is more effective than traditional didactic advice. In early childhood, parental practices strongly influence caries risk, highlighting the need to eliminate nighttime bottle feeding with milk, juice, or formula and promote water as the primary drink. Structured meals, limited between-meal snacks, and substitution with non-cariogenic alternatives benefit school-aged children, while counseling adolescents should address energy drink and carbonated beverage intake and social influences.[26]

PUBLIC HEALTH AND POLICY PERSPECTIVES AND FUTURE DIRECTIONS

Public health measures amplify individual counseling. Sugar taxation and front-of-package labeling reduce sugar-sweetened beverage consumption. School-based policies limiting soft-drink access and supervised brushing programs demonstrate positive outcomes. Community water fluoridation remains a cornerstone preventive strategy.[10,26]

Digital tools—including mobile dietary trackers and AI-driven risk prediction systems—are emerging to support real-time monitoring and tailored dietary advice. Future strategies may integrate oral microbiome profiling, salivary biomarkers, and personalized nutrition to optimize caries prevention.

CARIES PREVENTION STRATEGIES

The prevention of dental caries has become a central pillar of pediatric dentistry, reflecting the profession's shift from a restorative paradigm toward a disease-centered and health-promoting model.[10] The cornerstone of prevention is the capacity to influence the balance of risk and protective factors across different levels of care. At the individual level, the clinician has the responsibility to reduce cariogenic challenges, support the natural defense mechanisms of saliva and enamel, and introduce protective agents such as fluoride or sealants. At the behavioral level, guiding families toward healthier oral hygiene practices and dietary habits is indispensable. Finally, at the population level, effective public health policies—including community water fluoridation, sugar taxation, and school-based preventive programs—serve as critical measures for reducing the burden of disease and ensuring equity in oral health outcomes.[27]

Professional guidelines from leading organizations, including the AAPD, the European Academy of Paediatric Dentistry (EAPD), and the International Association of Paediatric Dentistry (IAPD), consistently highlight the importance of early initiation of preventive measures, their lifelong continuation, and the need for interventions to be tailored to each child's caries risk profile. This risk-based and individualized approach ensures that prevention is not applied uniformly but proportionally to need, maximizing both efficiency and effectiveness.

ORAL HYGIENE EDUCATION AND BEHAVIORAL INTERVENTIONS

Effective oral hygiene education aims not only to teach brushing techniques but also to build sustainable habits across childhood and adolescence.[15] Toothbrushing with fluoridated toothpaste remains the most important self-care practice in preventing dental caries. Children lack adequate manual dexterity to brush independently until approximately six years of age; therefore, all major pediatric dental guidelines emphasize that brushing should be performed or closely supervised by parents during early childhood, with continued oversight in high-risk children.[28,29]

Parental health literacy is central to success. Parents who understand the role of biofilm control, fluoride, and dietary habits are more likely to establish consistent oral hygiene routines, whereas misconceptions—such as the perceived safety of fruit juices, frequent snacking, or prolonged bottle use—can undermine prevention.[19] Accordingly, educational efforts should prioritize addressing common misunderstandings and empowering families with practical guidance.[19]

Traditional information-based education alone has limited long-term effect. Behavioral approaches, particularly motivational interviewing, have demonstrated greater effectiveness in improving home-care practices such as supervised brushing and reducing nighttime bottle feeding.[19] This patient-centered strategy enhances self-efficacy and fosters intrinsic motivation, making it a valuable tool in pediatric dental counseling.

School-based toothbrushing initiatives further reinforce positive behaviors and have been shown to reduce caries prevalence, especially in underserved communities.[30] These programs normalize oral hygiene as part of daily routines and provide additional fluoride exposure in structured environments.

Emerging digital interventions—including mobile reminders, interactive brushing apps, and tele-dentistry coaching—offer promising adjuncts, particularly for technology-oriented children and adolescents.[31] While long-term evidence is still developing, such tools may enhance engagement and consistency when integrated with family- and school-based strategies.

Overall, effective oral hygiene education in pediatric dentistry requires a comprehensive, behavior-focused approach that combines parental support, evidence-based counseling methods, school reinforcement, and innovative digital solutions to establish lasting oral health habits.

FLUORIDE

Fluoride is universally recognized as the cornerstone of modern caries prevention, and its effectiveness has been demonstrated across numerous clinical trials, systematic reviews, and population studies. Its caries-preventive effect is predominantly topical: fluoride promotes the formation of fluorapatite-like mineral phases that are less soluble in acidic conditions, enhances remineralization of early demineralized enamel, and inhibits demineralization during acid challenges. In addition, fluoride interferes with the metabolic pathways of cariogenic bacteria, reducing their capacity to produce acid and thereby modulating the biofilm environment in favor of oral health.[32,33]

The daily use of fluoridated toothpaste is the most widespread and evidence-based strategy for delivering fluoride. According to the EAPD guidelines. Fluoride toothpaste recommendations based on age and caries risk level are summarized in Table 1.[29] According to the AAPD guidelines, recommendations are provided for toothbrushing frequency and the amount of toothpaste to be applied on the brush; however, the specific fluoride concentration in toothpaste formulations is not explicitly stated in the guidelines.[28] Professional fluoride applications provide an additional layer of protection, especially in children with elevated caries risk. Fluoride varnish, most commonly a 5% sodium fluoride preparation (22,600 ppm), is considered the gold standard because of its strong evidence base, ease of application, and safety profile. Both the AAPD and EAPD recommend biannual application for children at moderate risk and up to quarterly applications for those with high risk or with active, non-cavitated lesions. The IAPD also endorses varnish as a cost-effective and practical method applicable in diverse populations, particularly in community and school-based preventive programs. Other modalities, such as acidulated phosphate fluoride gels or foams, can be used in older children and adolescents, but they are not recommended in children under six years of age due to the risk of ingestion.[28,29]

Fluoride rinses represent another preventive option, generally reserved for children over the age of six who can reliably expectorate. Daily use of 0.05% sodium fluoride (225 ppm) or weekly use of 0.2% sodium fluoride (900 ppm) rinses has been shown to significantly reduce caries incidence, particularly in school-based programs. However, compliance is often a limiting factor in home use.[29]

At the community level, systemic exposure through water fluoridation remains one of the most successful and equitable public health measures in dentistry. Community water fluoridation has consistently been associated with substantial reductions in caries prevalence across different socioeconomic groups, supporting its role in reducing oral health inequalities. Where water fluoridation is not feasible, alternatives such as fluoridated salt or milk have been implemented with varying success. Importantly, all major guidelines stress that systemic fluoride should not replace but complement topical exposures, which remain the primary source of caries-preventive benefit.[29]

While fluoride is safe and effective when used appropriately, the potential risk of fluorosis during enamel development necessitates careful supervision. The AAPD, EAPD, and IAPD consistently emphasize the importance of correct dosing, age-appropriate use, and professional oversight. Ensuring that children use the recommended amount of toothpaste, avoiding unnecessary supplementation in areas with fluoridated water, and carefully monitoring professional applications are essential steps to maximize benefit while minimizing risk.

PIT AND FISSURE SEALANTS

Occlusal surfaces of permanent molars represent the most vulnerable sites for caries development in children and

TABLE 1: Recommended use of fuoride toothpastes in children*

Age Group	Fluoride Concentration (ppm)	Amount of Toothpaste (g)	Frequency	Size
First tooth-up to 2 years	1,000 ppm	0.125 g	Twice daily	Grain of rice
2–6 years	1,000 ppm**	0.25 g	Twice daily	Pea
> 6 years	1,450 ppm	0.5-1 g	Twice daily	Up to full length of brush

ppm: parts per million, g: gram. *According to the European Academy of Paediatric Dentistry guidelines. **For children 2-6 years, 1000+ ppm fuoride concentrations may be considered based on the individual caries risk.

adolescents. Epidemiological studies consistently show that the majority of new carious lesions occur in pits and fissures rather than on smooth surfaces, primarily because their complex anatomy provides sheltered niches for plaque retention, limits self-cleaning by saliva, and reduces the effectiveness of toothbrushing. Preventing occlusal caries is therefore a critical priority in pediatric dentistry, and pit and fissure sealants have been established as one of the most effective evidence-based measures.[34]

Sealants act by creating a micromechanical barrier that isolates pits and fissures from the oral environment, preventing microbial colonization and fermentation of dietary carbohydrates. By transforming a retentive, plaque-prone surface into one that is smooth and easily cleansable, sealants disrupt the ecological niche necessary for lesion initiation. In addition, many sealant materials—particularly glass ionomer-based formulations—release fluoride, further enhancing their protective effect.[34]

Resin-based sealants remain the gold standard, with strong clinical evidence supporting their superior retention rates and long-term caries-preventive benefits. These materials require adequate isolation to achieve proper adhesion, making rubber dam or careful cotton-roll isolation crucial during application. When optimal moisture control cannot be achieved, as in newly erupted molars with partially covered occlusal surfaces, glass ionomer sealants provide a practical alternative. Although less durable, they release fluoride and can serve as an interim protective measure until resin placement becomes feasible.[35]

Professional guidelines provide clear recommendations regarding sealant use. The AAPD strongly advocates the placement of resin-based sealants on permanent molars in children and adolescents at risk for caries, ideally as soon as the tooth is fully erupted and moisture control can be achieved.[34] The EAPD similarly recommends sealants for high-risk children, noting that their use is justified even on sound occlusal surfaces when risk is elevated.[36] The IAPD further emphasizes the role of sealants as a cost-effective preventive strategy that should be incorporated into both individual clinical care and community-based programs, particularly in populations with high caries prevalence.[37]

The effectiveness of sealants is directly linked to their retention, making follow-up and maintenance an integral part of their preventive function. Partial or total loss of material significantly reduces protection, underscoring the need for periodic assessment and repair or reapplication when necessary. Advances in adhesive technology, including the use of self-etch systems and nanofilled resin formulations, continue to improve the longevity and ease of sealant application.[34,35]

Overall, pit and fissure sealants provide an essential adjunct to fluoride therapy, particularly in high-risk children, by targeting the most caries-prone surfaces with a safe, minimally invasive, and highly effective intervention. Their integration into routine pediatric practice represents one of the most successful examples of translating preventive evidence into clinical care.

ANTIMICROBIAL STRATEGIES

Because dental caries is a biofilm-mediated disease, antimicrobial approaches have been explored as adjunctive measures to modify the oral microbiota and reduce acidogenic potential. However, compared with fluoride-based interventions, the clinical benefit of antimicrobials remains limited and context-dependent.[38]

Chlorhexidine is the most extensively studied agent, particularly in rinses, gels, and varnishes. Although it effectively suppresses *Streptococcus mutans* in vitro, systematic reviews show inconsistent caries-preventive effects in children, mainly due to limited tooth-surface substantivity and challenges with long-term adherence.[39] Side effects such as staining and taste alteration further limit routine use. Chlorhexidine varnishes may provide greater retention, yet evidence remains inconclusive.[39] Other antimicrobial formulations, including essential oils and cetylpyridinium chloride, may reduce plaque and gingival inflammation but show minimal direct caries-preventive benefit.[40] Thus, they may only serve as supportive agents rather than substitutes for fluoride or sealants.

Antimicrobial agents should always be combined with fluoride exposure, dietary control, and behavioral strategies for meaningful clinical benefit.

PROBIOTICS AND MICROBIOME SUPPORT

Emerging strategies focus on microbiome modulation rather than broad suppression. Probiotics (e.g., *Lactobacillus rhamnosus*, *Bifidobacterium* spp.) and newer approaches such as prebiotics, synbiotics, and targeted antimicrobial peptides aim to promote ecological balance. While early data indicate reductions in *Streptococcus. mutans* counts, long-term evidence demonstrating meaningful caries prevention is still limited.[41-43] Current professional consensus supports antimicrobial and probiotics use only as adjunctive therapy in high-risk patients or where access to standard preventive measures is limited.

XYLITOL AND OTHER NON-CARIOGENIC SWEETENERS

Non-cariogenic sweeteners offer a means to provide sweetness without fueling cariogenic activity. Xylitol is the most extensively studied agent in this group. As a five-carbon sugar alcohol that cannot be metabolized by *Streptococcus mutans*, xylitol reduces acid production, limits bacterial adhesion, and stimulates salivary flow when delivered in chewing gum, contributing to pH buffering and remineralization.[44]

Clinical evidence shows that xylitol can reduce salivary *Streptococcus mutans* levels and caries incidence in children when used regularly, typically 3–5 times per day at a total daily dose of 5-7 g.[45,46] Maternal xylitol use during late pregnancy and early postpartum periods has also been shown to reduce vertical transmission of cariogenic bacteria.[47]

Other polyols, including sorbitol and erythritol, are considered low-cariogenic alternatives to sugar. Sorbitol is slowly fermented and may permit limited acid production with frequent exposure, while erythritol appears non-fermentable with potential antimicrobial activity, though evidence remains less robust than for xylitol.[48]

Despite positive findings, adherence challenges, gastrointestinal tolerance, and variability in study designs limit widespread recommendation as standalone agents. Accordingly, xylitol and related sweeteners are best viewed as adjunctive strategies, particularly in high-risk children and within broader sugar-reduction programs, rather than replacements for fluoride-based preventive measures.[45-48]

SALIVA ENHANCEMENT AND PROTECTIVE FACTORS

Saliva plays a fundamental role in maintaining oral health and is one of the most important natural defense mechanisms against dental caries. Its protective capacity stems from multiple functions: mechanical clearance of food debris and bacteria, buffering of plaque acids, provision of calcium and phosphate ions necessary for remineralization, and the presence of antimicrobial proteins such as lysozyme, lactoferrin, and immunoglobulins.[49] In healthy children, the constant interplay between salivary defenses and cariogenic challenges determines whether a lesion will progress, arrest, or regress.[49]

Beyond these well-known components, the salivary proteome—comprising hundreds of peptides and proteins including histatins, defensins, mucins, proline-rich proteins, and statherin—plays a critical role in maintaining oral homeostasis. These molecules collectively contribute to enamel pellicle formation, inhibition of bacterial adhesion, modulation of microbial growth, and enhancement of remineralization. Emerging proteomic studies demonstrate that variations in these salivary proteins can influence caries susceptibility, underscoring their diagnostic and preventive potential in pediatric populations.[50]

Reduced salivary flow significantly increases caries risk, particularly in children affected by systemic disease, long-term medications, dehydration, or chronic mouth breathing, making support for salivary function a key preventive priority.[51,52] Salivary stimulation and support are not stand-alone interventions but integral components of a comprehensive preventive plan. By optimizing the natural defenses provided by saliva, clinicians can significantly reinforce the effectiveness of other preventive measures, particularly in high-risk groups such as medically compromised children or those undergoing long-term pharmacotherapy.

REMINERALIZATION

Non-cavitated carious lesions, often visible as white spot lesions, represent the earliest clinically detectable stage of enamel demineralization. At this point, mineral loss has occurred beneath the enamel surface, but the superficial layer remains intact. This structural integrity provides a unique therapeutic window: unlike cavitated lesions, which require operative intervention, non-cavitated lesions can be effectively managed through remineralization strategies. The biological and clinical significance of this approach lies in its ability to preserve tooth structure, avoid restorative cycles, and promote long-term oral health in children.[53,54]

The modern concept of caries as a dynamic and reversible process has shifted treatment goals from surgical repair to biological control. Demineralization and remineralization occur continuously within the oral cavity, influenced by diet, biofilm activity, salivary function, and exposure to protective agents. When protective factors predominate, non-cavitated lesions can arrest or regress; when pathogenic factors prevail, they progress to cavitation. Thus, management of early lesions centers on tipping the balance toward remineralization through the use of fluoride, non-fluoride agents, and supportive behavioral measures.

BIOLOGICAL BASIS OF REMINERALIZATION

The process of remineralization is central to the non-invasive management of dental caries. Enamel is composed primarily of hydroxyapatite crystals arranged in a highly organized lattice. During cariogenic challenges, acids produced by bacterial metabolism of fermentable carbohydrates diffuse into enamel and dissolve mineral ions, particularly calcium and phosphate. This results in subsurface demineralization, while a thin surface layer often remains intact. Importantly, this surface integrity allows for the diffusion of ions back into the lesion, creating an opportunity for repair if protective factors are sufficiently strong.[8,50] The dynamic balance between demineralization and remineralization is illustrated in Figure 3.[50]

Saliva plays a pivotal role in this balance. It provides the essential ions required for remineralization—calcium, phosphate, and fluoride—while also buffering plaque acids and physically clearing fermentable substrates. Salivary proteins and peptides act as nucleation sites for crystal growth, and adequate salivary flow is indispensable for maintaining the dynamic equilibrium between demineralization and remineralization. In conditions of hyposalivation, whether due to systemic disease, medication, or mouth breathing, the remineralization potential is significantly compromised.[51,52]

Fluoride enhances this natural repair process by being incorporated into the enamel crystal lattice, forming fluorapatite-like mineral with a lower critical pH for dissolution. Even at low concentrations, fluoride promotes the redeposition of calcium and phosphate into the enamel subsurface, accelerating lesion arrest. This is why continuous, low-level fluoride exposure—whether through toothpaste, varnish, or community water fluoridation—remains the cornerstone of lesion control.[27,32]

The capacity for remineralization, however, is not unlimited. Once the surface enamel has collapsed or cavitation has occurred, the diffusion pathways for mineral ions are disrupted, and restorative treatment becomes unavoidable. This underscores the clinical importance of early detection and timely intervention. By acting within the window of reversibility, clinicians can arrest or even reverse disease progression while preserving natural tooth structure.

FLUORIDE-BASED APPROACHES

Fluoride remains the most established agent for enhancing remineralization in early, non-cavitated lesions. Beyond its well-described preventive mechanisms addressed in the main fluoride section, fluoride also facilitates repair by promoting redeposition of calcium and phosphate into demineralized enamel and forming a more acid-resistant fluorapatite-like phase.[8,27,32] Fluoride varnish is the primary professional intervention for lesion arrest in children. A 5% sodium fluoride varnish applied biannually — or quarterly in high-risk patients and active white-spot lesions — significantly increases lesion arrest rates and supports subsurface remineralization.[27-29]

Additional modalities such as high-fluoride toothpaste (1,450-5,000 ppm) and fluoride mouthrinses (0.05% daily or 0.2% weekly) may support remineralization in older children and adolescents who can reliably expectorate, particularly when used alongside daily fluoridated toothpaste.[27-29] Silver diamine fluoride (SDF), discussed elsewhere in this issue, combines antimicrobial and remineralizing actions and is particularly useful for arresting active lesions in primary teeth when conventional care is limited, though esthetic concerns limit anterior use. Overall, fluoride-based remineralization strategies are most effective when tailored to caries risk, used consistently over time, and combined with daily low-dose exposure through toothpaste.

NON-FLUORIDE REMINERALIZING AGENTS

Although fluoride remains the cornerstone of non-cavitated lesion management, non-fluoride remineralizing agents offer complementary biological pathways, particularly in

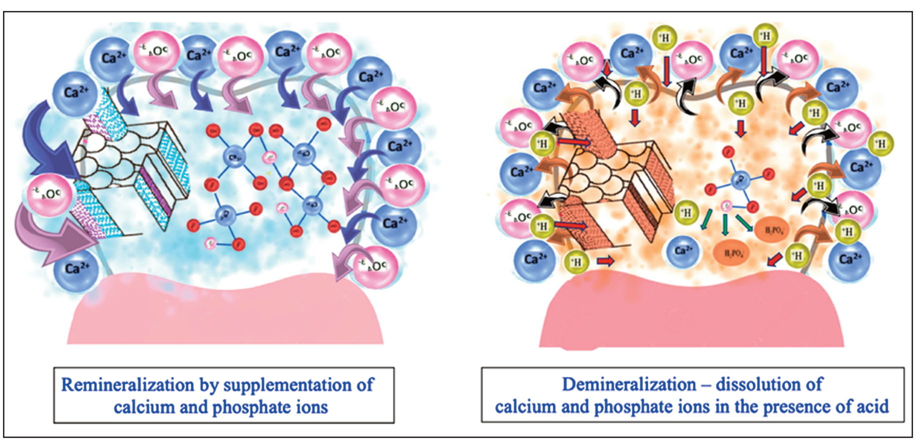

FIGURE 3: Dynamic balance between demineralization and remineralization in enamel [50]

patients requiring additional support or in cases where fluoride exposure is insufficient, contraindicated, or limited by parental preference. These materials generally function by supplying bioavailable calcium and phosphate, stabilizing the lesion microenvironment, enhancing ion diffusion, and improving surface hardness and lesion aesthetics.

Casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) and casein phosphopeptide–amorphous calcium fluoride phosphate (CPP–ACFP): CPP-ACP is the most extensively studied non-fluoride remineralizing system. By stabilizing calcium and phosphate as soluble nanoclusters, it maintains sustained supersaturation at the enamel surface, supporting subsurface mineral deposition and improving surface integrity. Clinical trials, especially in orthodontic patients, demonstrate reductions in white-spot lesion severity and improved visual outcomes. When combined with fluoride (CPP-ACFP), synergistic effects have been reported, increasing fluoride uptake and enhancing crystallite formation.[8,22,26] This dual mechanism offers improved lesion arrest compared with either agent alone.

Functionalized Tricalcium Phosphate (fTCP): fTCP has been engineered to prevent premature interaction with fluoride during storage, enabling co-delivery in the oral cavity. This promotes the formation of fluorapatite and accelerates surface remineralization. Early clinical data show incremental benefit beyond fluoride alone, though long-term, high-powered studies are still needed.[8,55]

Bioactive Glass (Calcium Sodium Phosphosilicate): Bioactive glass systems release calcium, phosphate, and sodium ions in alkaline conditions, forming a hydroxycarbonate apatite layer on enamel. This biofilm-protective mineral layer improves surface smoothness, masks opacity in white-spot lesions, and enhances resistance to future demineralization.[8] Their biocompatibility and anti-inflammatory potential support use in hypersensitivity and pediatric settings.

Nanohydroxyapatite: Nanohydroxyapatite, structurally analogous to natural enamel crystals, acts as a scaffold for mineral deposition and promotes nucleation at the lesion surface. Evidence supports improvements in surface microhardness, shine, and patient-reported outcomes, though long-term caries-preventive superiority over fluoride has not been established.[8] Its biomimetic profile has led to increased use in pediatric pastes and gels.

Self-Assembling Peptides (P11-4): P11-4 peptide represents a novel regenerative strategy. Upon diffusion into early lesions, it forms a 3-D matrix that guides site-specific enamel regeneration by attracting calcium and phosphate. Clinical studies show meaningful lesion regression and enhanced translucency, making it a valuable option in visible anterior white-spot lesions and post-orthodontic demineralization.[8,56]

Calcium Glycerophosphate (CaGP): CaGP provides bioavailable calcium and phosphate ions, enhances salivary buffering capacity, and promotes amorphous calcium phosphate precursor formation. When incorporated into toothpastes, lozenges, or rinses, it supports enamel resistance and acid neutralization, particularly in children with dry mouth, high dietary acid exposure, or reduced buffering capacity.[8,9,24,32,53,54]

Ozone Therapy: Ozone therapy has been investigated as a non-invasive adjunct for the management of early carious lesions due to its antimicrobial and oxidation effects. By disrupting bacterial membranes and neutralizing organic acids within the lesion, ozone may support a more favorable environment for mineral uptake and lesion arrest. Short-term reductions in bacterial load and improvements in surface hardness have been reported; however, long-term data remain limited and current guidelines do not support its use as a stand-alone therapy. Instead, ozone may be considered only as an adjunct in cases where conventional remineralization approaches are insufficient or traditional delivery methods are not feasible.[57]

Theobromine: Theobromine, a naturally occurring compound derived from cocoa, has also gained attention as a biocompatible remineralization enhancer. It promotes hydroxyapatite crystal growth and increases enamel microhardness, with in-vitro studies suggesting performance comparable to low-concentration fluoride in certain contexts. Although toothpastes and varnishes containing theobromine have been introduced to pediatric practice, human clinical data are still emerging. As such, theobromine is currently viewed as a supportive option—particularly appealing to families seeking "natural" alternatives—rather than a primary remineralization agent.[33,58,59]

Laser: Laser-assisted remineralization represents another adjunctive approach. Specific wavelengths such as Er:YAG, CO_2, and diode lasers induce structural modifications in enamel that reduce acid solubility and enhance the penetration of remineralizing agents. When combined with fluoride or CPP-ACP, synergistic benefits have been observed in early lesions, especially in post-orthodontic white-spot lesions. However, laser therapy requires specialized equipment and operator expertise, and its use is generally reserved for selected cases where enhanced surface conditioning may improve treatment outcomes.[60]

Overall, these adjunctive modalities expand the minimally invasive toolbox for managing early carious lesions, but none surpasses fluoride or established calcium-phosphate systems in efficacy. Their primary value lies in specific indications—such as children with high caries risk, orthodontic patients, medically compromised individuals, or families requesting fluoride-reduced protocols—where they may serve as useful complements to conventional remineralization strategies rather than replacements.

CLINICAL PROTOCOLS AND DECISION-MAKING

The clinical management of non-cavitated lesions is guided by the principle of preserving tooth structure and prioritizing non-invasive strategies whenever possible. The decision-making process begins with an accurate assessment of the lesion's activity and the patient's overall caries risk profile. Active non-cavitated lesions typically present as chalky, matte, and rough white spot areas, whereas arrested lesions appear glossy, hard, and smooth. The presence of active lesions in combination with high-risk behaviors or biological factors signals the need for intensive remineralization protocols.

For active non-cavitated lesions on smooth surfaces—such as buccal or lingual/palatal enamel—the standard protocol involves the use of fluoride varnish applications at regular intervals, supported by daily exposure to fluoridated toothpaste. In high-risk patients or in cases with multiple lesions, additional measures such as high-fluoride toothpastes or adjunctive agents like CPP–ACP may be indicated. On occlusal surfaces, where plaque retention is more pronounced, fissure sealants can be combined with fluoride to both physically protect and biologically strengthen the enamel.[61]

Clinical decision-making must also consider the depth and location of the lesion. Shallow enamel lesions with an intact surface are excellent candidates for remineralization. However, if the surface integrity is compromised, cavitation prevents diffusion of remineralizing ions into the lesion body, and restorative treatment becomes necessary. Similarly, lesions in esthetically critical areas, such as anterior teeth, may require both biological management and cosmetic considerations—for example, combining remineralization with microabrasion or resin infiltration to improve appearance.[8,61]

Risk stratification is fundamental in protocol selection. Children with low or moderate risk and isolated white spot lesions may be successfully managed with standard fluoride exposure and monitoring. In contrast, high-risk children—such as those with multiple active lesions, poor salivary function, or medical conditions—require intensified regimens, including quarterly varnish applications, prescription-strength fluoride toothpaste, and adjunctive non-fluoride remineralizing agents.[6,17]

Monitoring and recall are integral to clinical protocols. Non-cavitated lesions should be reassessed at 3-6 month intervals depending on risk level. Indicators of successful management include lesion hardness, increased translucency, and absence of progression. If progression is detected despite adherence to non-invasive measures, the treatment plan must be escalated to minimally invasive restorative interventions.[17]

Ultimately, clinical decision-making in remineralization management is not a rigid algorithm but a dynamic process that integrates lesion characteristics, patient risk profile, and evidence-based treatment options. This approach ensures that every child receives the most conservative, effective, and individualized care possible, preserving tooth structure and reducing the burden of restorative interventions.

FUTURE PERSPECTIVES

The management of non-cavitated carious lesions continues to evolve in parallel with advances in biomaterials, diagnostic technologies, and preventive dentistry. Future strategies are expected to become increasingly personalized, biomimetic, and digitally supported, moving beyond traditional fluoride-centered approaches toward a more holistic model of early lesion control.

One major area of development is the design of next-generation biomimetic remineralizing agents. By diffusing into the subsurface lesion and forming a scaffold for mineral deposition, these agents aim to regenerate enamel in a manner that closely mimics natural biomineralization. Similarly, research into nanohydroxyapatite, bioactive glass, and calcium-phosphate delivery systems continues to refine their ability to integrate with enamel structure, offering improved mechanical and esthetic outcomes.

Another promising direction is the integration of nanotechnology and controlled-release systems. Encapsulation of calcium, phosphate, and fluoride ions within nanocarriers allows for sustained delivery directly at the lesion site, enhancing efficacy while minimizing the need for frequent professional applications. Such systems could make long-term lesion management more feasible, particularly in high-risk populations with limited access to regular dental care.[62,63]

Digital technologies are also transforming the monitoring of non-cavitated lesions. Quantitative light-induced fluorescence, near-infrared imaging, and artificial intelligence–assisted diagnostic tools are being developed to detect early lesions with greater accuracy and to monitor subtle changes over time. These innovations enable clinicians to make more informed decisions about when to continue non-invasive management and when to escalate to restorative interventions.[8,64-69]

From a public health perspective, there is increasing emphasis on integrating remineralization strategies into broader caries management frameworks. School-based programs, chairside preventive protocols, and community-level initiatives are expected to increasingly incorporate evidence-based remineralizing agents beyond fluoride. The alignment of clinical innovations with public health delivery systems will be essential to ensure equitable access and to reduce disparities in caries outcomes globally.

In summary, the future of non-cavitated lesion management is likely to be shaped by the convergence of biomimetic materials, nanotechnology, and digital monitoring tools. These advances hold the promise of enhancing the effectiveness, esthetics, and accessibility of remineralization strategies, thereby consolidating the role of non-invasive management as the standard of care in pediatric dentistry.

CONCLUSIONS

The contemporary management of dental caries in children has shifted from an operative, lesion-centered paradigm to a preventive, risk-based, and biologically oriented model. Non-invasive strategies—including dietary control, caries risk assessment, preventive interventions such as fluoride therapy and pit and fissure sealants, and the remineralization of non-cavitated lesions—form the backbone of this approach. Together, these strategies underscore the principle that caries is not an inevitable disease but a dynamic and reversible process that can be controlled through timely intervention.

International guidelines consistently emphasize early initiation, risk stratification, and continuity of preventive care throughout childhood and adolescence. Fluoride remains the cornerstone of prevention and remineralization, complemented by sealants, adjunctive biomimetic agents, and behavioral guidance. At the same time, public health policies addressing diet, sugar exposure, and access to preventive services remain essential to reduce inequalities and achieve population-wide improvements.

Future perspectives highlight the potential of biomimetic materials, nanotechnology, and digital diagnostic tools to refine remineralization and monitoring strategies, further consolidating non-invasive care as the standard in pediatric dentistry. By integrating clinical interventions with behavioral and community-based measures, pediatric dentistry can move closer to achieving long-term preservation of natural tooth structure, reduction of disease burden, and promotion of lifelong oral health.

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