

Modern Caries Prevention: From Risk Assessment to Minimally Invasive Management—An Evidence-Based Review

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Abstract: Dental caries remains one of the most prevalent chronic diseases worldwide, affecting individuals across all age groups despite substantial advances in preventive dentistry. Contemporary understanding recognizes dental caries as a dynamic, biofilm-mediated, diet-modulated disease that can be prevented, arrested, or reversed through timely risk assessment and evidence-based preventive interventions. This review synthesizes current evidence on modern strategies for caries prevention, emphasizing individualized caries risk assessment, fluoride-based therapies, pit and fissure sealants, dietary modification, biofilm control, remineralization technologies, and minimally invasive management approaches. Established risk assessment models, including Caries Management by Risk Assessment (CAMBRA), the International Caries Classification and Management System (ICCMS™), and other validated tools, are discussed in relation to personalized preventive care. Emerging technologies such as silver diamine fluoride, resin infiltration, bioactive restorative materials, artificial intelligence-assisted diagnostics, and digital caries detection are also evaluated for their clinical applications and future potential. Furthermore, preventive strategies across different stages of life are explored, highlighting age-specific approaches for children, adolescents, adults, older adults, and medically compromised individuals. Current international clinical guidelines consistently support a shift from the traditional restorative model toward prevention-focused, patient-centred, and minimally invasive dentistry. Integrating evidence-based preventive measures with individualized risk assessment enables clinicians to preserve tooth structure, improve long-term oral health outcomes, and reduce the global burden of dental caries. Continued research into precision dentistry, salivary diagnostics, and digital technologies is expected to further transform preventive dental care in the coming years.

Key Words: Dental caries, Caries risk assessment, Preventive dentistry, Minimally invasive dentistry, Evidence-based dentistry.

1. Introduction

Dental caries remains one of the most prevalent chronic diseases worldwide and continues to pose a substantial challenge to oral health despite considerable advances in preventive dentistry. Affecting individuals throughout the lifespan, the disease imposes significant clinical, economic, and social burdens, particularly among children, older adults, and socioeconomically disadvantaged populations. Untreated carious lesions may result in pain, infection, impaired mastication, reduced quality of life,

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school and work absenteeism, and increased healthcare expenditure. Although dental caries is largely preventable, it continues to affect billions of people globally, emphasizing the need for effective preventive strategies that can be implemented across diverse healthcare settings. ^[1,2]

Contemporary evidence recognizes dental caries as a dynamic, biofilm-mediated, and diet-modulated disease rather than an inevitable consequence of aging or poor oral hygiene alone. The disease process is characterized by repeated cycles of demineralization and remineralization at the tooth surface, where the balance between pathological factors, such as acidogenic biofilm and frequent consumption of fermentable carbohydrates, and protective factors, including saliva, fluoride exposure, and appropriate oral hygiene, determines lesion initiation and progression. This modern understanding has shifted clinical management from treating cavitated lesions alone to controlling the underlying disease process and preserving healthy tooth structure whenever possible. ^[3,4]

Historically, caries management relied predominantly on the surgical removal of diseased tooth tissue followed by restorative procedures. While restorative treatment remains indispensable for advanced lesions, it does not address the biological causes responsible for disease initiation and recurrence. Consequently, repeated restorative interventions often contribute to the restorative cycle, progressively weakening tooth structure over time. Increasing recognition of these limitations has prompted a paradigm shift toward prevention-oriented and minimally invasive dentistry, where early diagnosis, individualized risk assessment, non-operative interventions, and selective tissue preservation are prioritized before restorative care is considered. ^[1,3]

The concept of caries risk assessment has become a cornerstone of contemporary preventive dentistry. Rather than applying identical preventive measures to every patient, risk-based approaches enable clinicians to identify individual biological, behavioural, environmental, and socioeconomic factors influencing disease susceptibility. Validated frameworks such as Caries Management by Risk Assessment (CAMBRA), the International Caries Classification and Management System (ICCMSTM), and other structured assessment models facilitate personalized preventive planning, optimize resource allocation, and improve long-term clinical outcomes by tailoring interventions according to patient-specific risk profiles. ^[5,6]

Evidence supporting preventive interventions has expanded substantially over the past decade. High-quality systematic reviews and international clinical guidelines consistently demonstrate the effectiveness of fluoride therapies, pit and fissure sealants, dietary counselling, biofilm control, and minimally invasive techniques in preventing lesion development and arresting early carious lesions. In parallel, advances in biomimetic remineralization materials, silver diamine fluoride, resin infiltration, digital diagnostics, and artificial intelligence have broadened the scope of conservative caries management and reinforced the transition toward patient-centred, evidence-based care. These innovations support the preservation of natural tooth tissues while reducing the need for invasive restorative procedures. ^[1]

Recent international policy initiatives further emphasize prevention as the foundation of oral healthcare. The World Health Organization advocates a preventive, minimally invasive, and environmentally sustainable approach to dental caries management that prioritizes early intervention, mercury-free restorative materials, and preservation of tooth structure. This global perspective aligns with contemporary concepts of minimal intervention dentistry, which integrate disease prevention, risk assessment, remineralization, and conservative operative care into a comprehensive model of lifelong oral healthcare. ^[1,2]

Given the continuous evolution of preventive technologies, clinical guidelines, and minimally invasive treatment modalities, an updated synthesis of current evidence is essential for clinicians, educators, researchers, and oral healthcare professionals. Therefore, this review aims to critically evaluate contemporary evidence regarding modern caries prevention, with particular emphasis on individualized caries risk assessment, evidence-based preventive strategies, remineralization therapies, and minimally invasive management approaches that support preservation of tooth structure and improvement of long-term oral health outcomes across the lifespan.

2. Biology of Dental Caries

Dental caries is a multifactorial, non-communicable oral disease characterized by the localized destruction of dental hard tissues resulting from prolonged interactions between cariogenic biofilm, dietary fermentable carbohydrates, susceptible tooth surfaces, and host-related factors. Rather than representing a simple infectious process, contemporary evidence recognizes dental caries as a dynamic biological condition driven by ecological changes within the dental biofilm. These alterations favour acidogenic and aciduric microorganisms, leading to sustained acid production and progressive mineral loss from enamel and dentin. Consequently, caries should be regarded as a disease of biofilm dysbiosis rather than the consequence of a single pathogenic microorganism alone. ^[3,7]

The development of dental caries is governed by the balance between pathological and protective factors. Pathological factors include frequent consumption of fermentable carbohydrates, accumulation of mature dental biofilm, reduced salivary flow, and inadequate fluoride exposure, all of which contribute to prolonged acidic conditions at the tooth surface. In contrast, protective factors such as saliva, fluoride, calcium and phosphate ions, effective plaque control, and appropriate dietary habits promote remineralization and help maintain the structural integrity of enamel. The dynamic equilibrium between demineralization and remineralization determines whether a lesion progresses, arrests, or reverses, making early intervention critical for successful disease management. ^[4,8]

Historically, the Keyes triad described dental caries as the interaction among a susceptible host, cariogenic microorganisms, and dietary substrate over time. Although this model remains fundamental for understanding disease etiology, contemporary research has expanded this concept by incorporating behavioural, environmental, socioeconomic, and biological determinants that influence disease susceptibility. Factors such as oral hygiene practices, fluoride availability, access to dental

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care, educational status, systemic health conditions, medication-induced xerostomia, and lifestyle behaviours significantly modify an individual's caries risk and should be considered during comprehensive patient assessment.

The ecological plaque hypothesis, proposed by Marsh, provides the most widely accepted explanation for the biological basis of dental caries. According to this hypothesis, dental biofilm exists as a balanced microbial community under healthy conditions. Frequent exposure to dietary sugars lowers plaque pH, creating an acidic environment that selectively favour acid-producing and acid-tolerant bacteria, including *Streptococcus mutans*, *Lactobacillus* species, and other cariogenic microorganisms. This ecological shift disrupts microbial homeostasis, resulting in biofilm dysbiosis and sustained demineralization of dental hard tissues. Importantly, restoring a neutral oral environment through dietary modification, improved oral hygiene, fluoride exposure, and salivary support can reverse this imbalance and facilitate lesion arrest or remineralization without operative intervention.^[4,10]

Demineralization occurs when organic acids produced by bacterial fermentation diffuse into enamel and dissolve hydroxyapatite crystals, resulting in the loss of calcium and phosphate ions. If acidic challenges persist, mineral loss exceeds natural repair mechanisms, leading to subsurface enamel lesions that may eventually progress to cavitation. Conversely, remineralization is a physiological repair process whereby calcium, phosphate, and fluoride ions are redeposited into partially demineralized enamel, restoring mineral density and increasing resistance to future acid attacks. The success of contemporary preventive dentistry largely depends on enhancing this natural remineralization process through evidence-based preventive strategies and early disease detection.^[8,11]

Advances in cariology have transformed the understanding of dental caries from a restorative problem to a chronic, preventable disease requiring continuous management. Current concepts emphasize that successful caries control extends beyond restoring cavitated lesions and instead focuses on identifying disease activity, modifying risk factors, controlling biofilm dysbiosis, promoting remineralization, and implementing individualized preventive care. This biological approach forms the scientific foundation of minimal intervention dentistry and supports the transition toward personalized, prevention-oriented oral healthcare.

3. Caries Risk Assessment: The Foundation Of Personalized Caries Prevention

The paradigm of contemporary cariology has shifted from a restorative approach to a preventive, patient-centred model in which treatment decisions are guided by an individual's probability of developing future disease rather than by the presence of existing cavitated lesions alone. Within this framework, caries risk assessment (CRA) has become the cornerstone of evidence-based clinical decision-making, enabling clinicians to identify patients at risk, implement targeted preventive strategies, and monitor disease progression over time. Unlike conventional restorative care that addresses the consequences of disease, CRA focuses on modifying the biological and behavioural determinants responsible for lesion initiation and progression, thereby supporting long-term disease control rather than episodic treatment.^[3,8,12]

Caries risk assessment is defined as the systematic evaluation of disease indicators, biological risk factors, protective factors, and patient-related characteristics to estimate an individual's likelihood of developing new carious lesions or experiencing progression of existing lesions within a specified period. Rather than relying on a single clinical variable, contemporary CRA incorporates multiple dimensions of oral health, including previous caries experience, dietary habits, oral hygiene practices, fluoride exposure, salivary function, socioeconomic status, medical conditions, medication use, and behavioural factors. This multifactorial assessment reflects the complex biological nature of dental caries and provides the basis for personalized preventive care.^[12,13]

One of the strongest predictors of future caries development is previous caries experience. Numerous longitudinal studies have consistently demonstrated that individuals with a history of active caries are significantly more likely to develop new lesions than caries-free individuals. However, previous disease experience alone cannot explain future risk. Salivary hypofunction, frequent sugar consumption, inadequate fluoride exposure, orthodontic appliances, poor plaque control, xerostomia-inducing medications, and limited access to oral healthcare also contribute substantially to disease susceptibility. Conversely, regular exposure to fluoride, effective plaque removal, healthy dietary practices, adequate salivary flow, and routine professional dental care function as protective factors capable of reducing disease progression. Consequently, contemporary CRA emphasizes balancing pathological and protective factors rather than considering isolated variables independently.^[7,8,13]

An equally important component of modern risk assessment is the evaluation of caries lesion activity. Current clinical management distinguishes between active and inactive lesions because not every detected lesion requires operative intervention. Active lesions are characterized by ongoing mineral loss and require preventive or therapeutic management, whereas inactive lesions may simply require periodic monitoring. This concept supports minimally invasive dentistry by preventing unnecessary restorative procedures and preserving sound tooth structure whenever possible. Integration of lesion activity assessment with individual risk status enables clinicians to make biologically appropriate treatment decisions that are consistent with contemporary evidence-based practice.^[14]

Several standardized CRA systems have been developed to improve consistency and objectivity in clinical practice. Although each model differs in methodology and complexity, all share the common objective of identifying patient-specific risk profiles and facilitating individualized management plans.

The **Caries Management by Risk Assessment (CAMBRA)** model is one of the most widely adopted evidence-based frameworks in clinical dentistry. CAMBRA categorizes patients according to disease indicators, biological risk factors, protective factors, and clinical findings before recommending individualized preventive and therapeutic interventions. Rather than functioning solely as a prediction model, CAMBRA directly links the assessed risk category with evidence-based

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management protocols, making it particularly valuable in routine clinical practice. Its emphasis on individualized prevention, recall scheduling, fluoride therapy, antibacterial agents where indicated, and behavioural modification has contributed to its widespread acceptance in both academic and private practice settings.^[12,15]

The **International Caries Classification and Management System (ICCMS™)** expand beyond traditional risk assessment by integrating lesion detection, lesion activity assessment, staging of disease severity, and comprehensive patient management into a single clinical framework. Based upon the International Caries Detection and Assessment System (ICDAS), ICCMS™ employs a structured four-step approach involving risk determination, lesion assessment, individualized treatment planning, and continuous review. This system encourages preservation of tooth structure through preventive and minimally invasive interventions while reserving restorative treatment for advanced disease. Owing to its comprehensive nature, ICCMS™ has become increasingly influential in undergraduate education, clinical practice, and international guideline development.^[16]

The **American Dental Association (ADA) Caries Risk Assessment** forms provide a practical method for categorizing patients into low-, moderate-, or high-risk groups based on clinical findings, medical history, dietary habits, fluoride exposure, and behavioural characteristics. Separate assessment forms are available for children younger than six years and individuals older than six years, reflecting age-specific differences in disease determinants. Their simplicity, ease of implementation, and compatibility with routine clinical examinations make the ADA assessment particularly useful in general dental practice and community oral health programs.^[13]

The **Cariogram** represents an algorithm-based computer model that estimates future caries risk by integrating multiple biological variables into a graphical representation of an individual's "chance to avoid new caries." Unlike checklist-based systems, Cariogram quantitatively evaluates factors including previous caries experience, dietary habits, bacterial counts, salivary parameters, fluoride exposure, and general health status. The visual output facilitates patient communication and can improve understanding of individual risk profiles. Nevertheless, the requirement for microbiological and salivary testing may limit its routine use in busy clinical settings.^[17]

Although these systems differ in design, available evidence suggests that no single CRA model demonstrates clear superiority across all patient populations. Systematic reviews indicate that standardized CRA models generally possess moderate predictive ability, with their clinical value being greatest when combined with professional judgement, comprehensive clinical examination, and regular reassessment over time. Consequently, contemporary recommendations advocate selecting the assessment tool that best suits the clinical environment while maintaining individualized, prevention-oriented patient management rather than relying exclusively on numerical risk categorization.^[18,19]

Successful implementation of CRA extends beyond assigning patients to a risk category. Risk status should directly influence preventive strategies, recall intervals, radiographic examination frequency, fluoride recommendations, dietary counselling, and minimally invasive treatment decisions. As patient risk profiles evolve over time, periodic reassessment remains essential to evaluate treatment outcomes, reinforce behavioural modifications, and adapt preventive measures according to changing biological and environmental conditions. Thus, caries risk assessment should be regarded as a continuous clinical process rather than a one-time diagnostic procedure, forming the scientific basis of personalized preventive dentistry.

Assessment System	Primary Principle	Major Variables Evaluated	Strengths	Limitations	Clinical Application
CAMBRA	Risk-based disease management	Disease indicators, biological risk factors, protective factors	Directly links risk level to treatment; evidence-based preventive protocols	Requires clinician calibration; subjective weighting of some factors	General practice, academic institutions, preventive dentistry
ICCMS™	Comprehensive caries management framework	Risk assessment, lesion severity, lesion activity, patient factors	Integrates diagnosis, prevention, monitoring and minimally invasive care	More comprehensive and time-consuming	Academic institutions, specialist clinics, comprehensive patient care
ADA CRA	Clinical risk categorization	Medical history, diet, fluoride exposure, clinical findings	Simple, rapid, easy to implement	Less comprehensive than CAMBRA and ICCMS™	Routine dental practice and community dentistry
Cariogram	Computer-based prediction model	Caries experience, saliva, bacteria, diet, fluoride, general health	Quantitative graphical output; excellent patient education tool	Requires salivary and microbiological testing; software dependent	Research, preventive clinics, high-risk patient assessment

Table 1. Comparison of Commonly Used Caries Risk Assessment Systems

Abbreviations: CAMBRA, Caries Management by Risk Assessment; ICCMS™, International Caries Classification and Management System; ADA CRA, American Dental Association Caries Risk Assessment.

4. Evidence-Based Preventive Strategies

Contemporary caries prevention is based on the principle that dental caries can be prevented or arrested by modifying biological, behavioural, and environmental risk factors before irreversible tissue destruction occurs. Current evidence supports a patient-centred, risk-based preventive approach that combines mechanical biofilm control, fluoride exposure, dietary modification, professional preventive interventions, and behavioural counselling. The selection of preventive measures should be guided by individual caries risk, age, medical status, and lesion activity rather than adopting a uniform approach for all patients.^[8,12]

A. Biofilm Control and Oral Hygiene

Effective disruption of dental biofilm remains the cornerstone of caries prevention. Twice-daily toothbrushing with fluoridated toothpaste significantly reduces caries incidence by removing cariogenic biofilm while enhancing topical fluoride delivery. Electric toothbrushes may provide additional plaque reduction, particularly in children, older adults, and individuals with limited manual dexterity; however, consistent brushing technique and patient compliance remain more important than the type of toothbrush used. Adjunctive interdental cleaning should be recommended where proximal plaque accumulation is evident.^[20,21]

B. Fluoride-Based Prevention

Fluoride remains the most extensively studied and effective preventive agent in cariology. It enhances remineralization, inhibits demineralization, and reduces bacterial acid production, thereby increasing enamel resistance to acid challenge. Fluoridated toothpaste forms the foundation of daily preventive care, while professionally applied fluoride varnishes provide additional benefit for individuals at moderate or high caries risk.

Community water fluoridation continues to demonstrate significant reductions in caries prevalence and remains one of the most cost-effective public health interventions. Current evidence supports tailoring fluoride concentration and application frequency according to individual risk assessment.^[22,23,24,1]

C. Dietary Modification

Frequent consumption of free sugars is a major determinant of caries development due to repeated acid production within dental biofilm. Contemporary dietary counselling focuses not only on reducing the total amount of sugar consumed but also on limiting the frequency of sugar exposure between meals. Encouraging healthier dietary patterns, reducing sugar-sweetened beverages, and promoting water as the primary drink contribute substantially to long-term caries prevention. Individualized nutritional counselling should therefore be incorporated into routine preventive dental care.^[25,26]

D. Pit and Fissure Sealants

Pit and fissure sealants are highly effective in preventing occlusal caries, particularly in newly erupted permanent molars of children and adolescents at increased caries risk. Resin-based sealants demonstrate excellent long-term retention, whereas glass ionomer sealants may be advantageous when moisture control is compromised due to their fluoride-releasing properties. Regular clinical review is essential to assess sealant integrity and ensure continued protection.^[27]

E. Non-Fluoride Preventive Agents

Adjunctive preventive agents may provide additional benefits in selected patients. Casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) promotes remineralization by enhancing calcium and phosphate availability at the tooth surface, although current evidence suggests it should complement rather than replace fluoride therapy. Nano-hydroxyapatite-containing products have demonstrated promising remineralizing potential, while xylitol may reduce cariogenic bacterial activity when used regularly. Despite encouraging findings, the clinical effectiveness of these agents remains less consistent than fluoride-based interventions, and further long-term studies are required.^[28-30]

F. Behavioural and Patient-Centred Prevention

Long-term success of preventive dentistry depends on sustained behavioural change and patient engagement. Oral health education should extend beyond information delivery and incorporate motivational interviewing, goal setting, and individualized self-care recommendations. Preventive advice tailored to the patient's age, lifestyle, socioeconomic background, and caries risk has been shown to improve adherence and support favourable oral health behaviours. Regular recall visits provide opportunities to reinforce preventive measures, reassess disease risk, and modify management strategies according to changing clinical needs.^[31,32]

Collectively, current evidence demonstrates that successful caries prevention relies on integrating multiple preventive strategies within a personalized care model rather than depending on a single intervention. Combining risk assessment with evidence-based preventive measures enables clinicians to reduce disease incidence, arrest early lesions, preserve natural tooth structure, and improve long-term oral health outcomes.

Preventive strategy	Primary mechanism	Level of evidence	Recommended use
Toothbrushing with fluoridated toothpaste	Biofilm removal and fluoride delivery	Strong	All age groups
Fluoride varnish	Promotes remineralization and inhibits demineralization	Strong	Moderate- and high-risk patients
Community water fluoridation	Continuous low-dose fluoride exposure	Strong	Population-level prevention
Pit and fissure sealants	Physical barrier against biofilm retention	Strong	Children and adolescents with erupting molars
Dietary counselling	Reduces frequency of acid attacks	Moderate to strong	All patients, especially high-risk individuals
CPP-ACP	Enhances calcium and phosphate availability	Moderate	Adjunctive therapy
Nano-hydroxyapatite	Biomimetic remineralization	Emerging	Early non-cavitated lesions
Xylitol	Reduces cariogenic bacterial activity	Moderate	Adjunctive preventive measure
Oral health education and motivational interviewing	Improves patient adherence and self-care	Moderate	Long-term preventive care

Table 2. Evidence-Based Preventive Interventions for Dental Caries

5. Minimally Invasive Caries Management

The contemporary management of dental caries has evolved from the traditional concept of complete caries removal to a biologically driven approach that emphasizes preservation of sound tooth structure and maintenance of pulpal health. Minimal intervention dentistry (MID) is based on early diagnosis, caries risk assessment, lesion activity evaluation, remineralization, and conservative operative procedures. Rather than treating every lesion surgically, minimally invasive management aims to arrest disease progression while preserving maximum natural tooth structure, thereby extending tooth longevity and reducing the restorative cycle. ^[1,8,16]

A. Resin Infiltration

Resin infiltration is indicated primarily for non-cavitated enamel lesions, particularly proximal lesions extending into the outer dentin. A low-viscosity resin penetrates the porous lesion body after acid etching, occluding diffusion pathways and preventing further acid penetration. Clinical studies have demonstrated that resin infiltration effectively arrests lesion progression while maintaining tooth structure and improving the aesthetic appearance of white spot lesions. As the procedure requires no drilling or local anesthesia, it represents an effective micro-invasive alternative for early carious lesions. ^[33,34]

B. Silver Diamine Fluoride (SDF)

Silver diamine fluoride has emerged as one of the most effective non-operative agents for arresting active dentinal caries. The synergistic action of silver provides potent antimicrobial effects, while fluoride promotes remineralization and increases resistance to future acid attacks. Owing to its simplicity, affordability, and minimal technique sensitivity, SDF is particularly beneficial for young children, older adults, medically compromised individuals, and patients with limited access to dental care. Its principal limitation remains the permanent black staining of arrested carious lesions, which should be discussed with patients during treatment planning. ^[23,35]

C. Atraumatic Restorative Treatment (ART)

Atraumatic Restorative Treatment involves the selective removal of soft, infected dentin using hand instruments followed by restoration with high-viscosity glass ionomer cement. ART minimizes patient discomfort, reduces aerosol generation, and preserves healthy tooth structure while providing sustained fluoride release. The technique is particularly valuable in community-based programmes, outreach services, paediatric dentistry, and resource-limited settings where conventional restorative care may not be readily available. ^[36,37]

D. Selective Caries Removal and Stepwise Excavation

Current evidence no longer supports routine complete excavation of deep carious lesions. Selective caries removal preserves affected dentin adjacent to the pulp while removing infected peripheral dentin to facilitate restoration. Similarly, stepwise excavation involves staged removal of deep carious tissue over multiple visits, allowing tertiary dentin formation and reducing the risk of pulp exposure. Both techniques demonstrate favourable long-term outcomes, improved pulpal vitality, and fewer endodontic complications compared with complete caries removal. ^[38,39]

E. Hall Technique

The Hall Technique is a minimally invasive approach for managing carious primary molars by sealing the lesion beneath a preformed stainless-steel crown without caries removal, local anesthesia, or tooth preparation. By isolating the cariogenic biofilm from its nutritional substrate, disease progression is arrested while maintaining pulp vitality. High-quality evidence has demonstrated excellent clinical success and restoration longevity, particularly in young or anxious children.

F. Silver-Modified Atraumatic Restorative Treatment (SMART)

The SMART technique combines the antimicrobial effects of silver diamine fluoride with the restorative benefits of glass ionomer cement. Following SDF application, the lesion is restored using glass ionomer, improving structural integrity while reducing bacterial activity beneath the restoration. This technique is especially advantageous in paediatric patients, individuals with high caries risk, and community settings where minimally invasive, cost-effective treatment is desirable. ^[21,42]

Overall, minimally invasive caries management represents a fundamental shift from surgical intervention toward biological disease control. Selection of the appropriate technique should be guided by lesion activity, lesion depth, patient age, caries risk, aesthetic demands, and patient cooperation. Integrating these conservative approaches into routine practice enables clinicians to preserve natural tooth structure, maintain pulpal vitality, and improve long-term treatment outcomes while reducing unnecessary operative intervention (1,18,25).

Technique	Primary indication	Advantages	Limitations
Resin infiltration	Non-cavitated enamel and proximal lesions	Arrests lesion progression, preserves enamel, excellent aesthetics	Limited to early lesions
Silver diamine fluoride (SDF)	Active dentinal caries, root caries	High caries arrest rate, inexpensive, painless, rapid application	Black staining of treated lesions
Atraumatic Restorative Treatment (ART)	Small-to-moderate cavitated lesions	Minimal equipment, fluoride release, reduced aerosol generation	Less suitable for extensive multi-surface lesions
Selective caries removal	Deep dentinal lesions	Preserves pulp vitality, reduces pulp exposure	Requires careful clinical judgment
Stepwise excavation	Very deep lesions approaching the pulp	Encourages tertiary dentin formation, lowers endodontic risk	Requires multiple appointments
Hall Technique	Carious primary molars	No local anesthesia or drilling, high long-term success	Limited to primary dentition
SMART technique	High-risk cavitated lesions	Combines SDF and glass ionomer benefits	Potential discoloration beneath restoration

Table 3. Comparison Of Minimally Invasive Caries Management Techniques

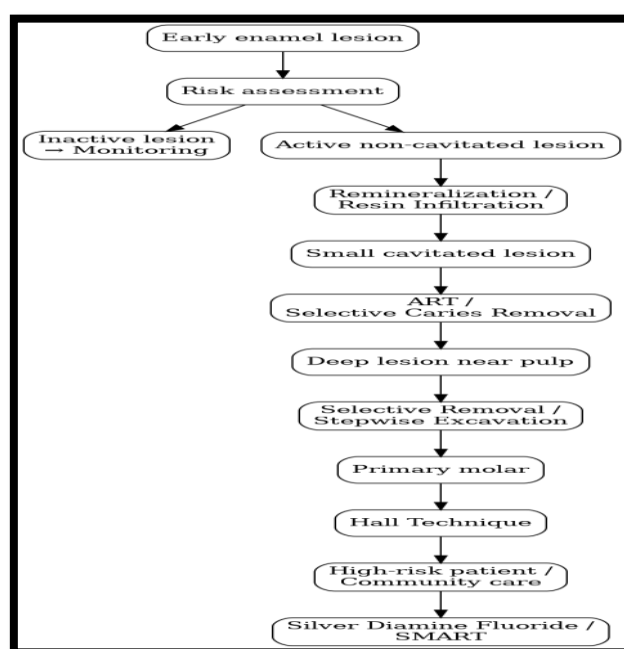


Figure 1. shows the early enamel lesion to prevention

6. Digital Innovations and Artificial Intelligence in Caries Prevention

The rapid advancement of digital technologies has transformed contemporary caries prevention by enabling earlier disease detection, improved risk assessment, and more personalized preventive care. Digital diagnostic systems and artificial intelligence (AI) complement, rather than replace, conventional clinical examination by assisting clinicians in identifying early lesions, monitoring disease progression, and supporting evidence-based treatment planning. These innovations align with the principles of minimal intervention dentistry by facilitating timely preventive interventions before irreversible tooth destruction occurs. [1,8,16,43]

A. Artificial Intelligence in Caries Detection

Artificial intelligence has emerged as a valuable adjunct in dental diagnostics, particularly in the interpretation of bitewing and periapical radiographs. Deep learning algorithms have demonstrated high diagnostic accuracy in detecting proximal caries, occlusal lesions, and secondary caries, while also reducing inter-examiner variability. AI-assisted systems can identify subtle radiographic changes that may be overlooked during routine assessment, thereby supporting earlier intervention and improving diagnostic consistency. Nevertheless, AI should be regarded as a decision-support tool that complements clinical expertise rather than replacing professional judgement. [43-45]

B. Digital Caries Detection Technologies

Several non-invasive imaging technologies have enhanced the early detection of dental caries. Quantitative Light-Induced Fluorescence (QLF), laser fluorescence devices, Near-Infrared Light Transillumination (NILT), and Optical Coherence Tomography (OCT) enable visualization of early mineral changes before cavitation develops. These technologies improve lesion monitoring, facilitate minimally invasive treatment planning, and reduce dependence on repeated radiographic examinations. Their greatest value lies in monitoring non-cavitated lesions and assessing the effectiveness of preventive interventions over time. [46-49]

C. Digital Risk Assessment and Patient Monitoring

Digital health records and computerized caries risk assessment systems allow clinicians to integrate patient history, dietary habits, fluoride exposure, salivary factors, and previous caries experience into individualized preventive care plans. In addition, mobile health applications and tele dentistry platforms enhance patient engagement by providing oral hygiene education, dietary counselling, appointment reminders, and remote follow-up. Such digital tools promote long-term adherence to preventive strategies and facilitate continuous monitoring, particularly for patients with limited access to conventional dental care. [50,51]

D. Future Perspectives

Emerging technologies are expected to further strengthen preventive dentistry through precision oral healthcare. Integration of artificial intelligence with salivary biomarkers, three-dimensional imaging, and predictive analytics may enable earlier identification of high-risk individuals and more accurate prediction of disease progression. Although current evidence is promising, further prospective clinical studies are required to establish long-term effectiveness, cost-efficiency, and ethical frameworks for widespread implementation. Future digital innovations should therefore be viewed as adjuncts that enhance evidence-based clinical decision-making while maintaining patient-centred care as the primary objective. [43,45,52]

Digital technologies represent a significant advancement in modern cariology by supporting earlier diagnosis, individualized prevention, and minimally invasive treatment planning. When integrated with comprehensive clinical examination and validated caries risk assessment models, these innovations have the potential to improve preventive outcomes while preserving natural tooth structure and promoting lifelong oral health.

Technology	Primary application	Clinical advantage	Current limitation
Artificial Intelligence	Radiographic caries detection and risk prediction	Improved diagnostic accuracy and consistency	Requires high-quality datasets and clinical validation
Quantitative Light-Induced Fluorescence (QLF)	Detection and monitoring of early enamel lesions	Non-invasive monitoring of lesion progression	High equipment cost
Laser Fluorescence (DIAGNOdent)	Detection of occlusal caries	Early lesion identification	False-positive results may occur in stained fissures
Near-Infrared Light Transillumination (NILT)	Detection of proximal and occlusal lesions	Radiation-free imaging	Limited availability
Optical Coherence Tomography (OCT)	High-resolution assessment of enamel and dentin	Excellent structural visualization	Primarily research and specialist settings
Teledentistry	Remote preventive consultation and follow-up	Improves access to preventive care	Limited intraoral examination capability

Table 4. Digital Technologies Used in Contemporary Caries Prevention

7. Caries Prevention Across the Lifespan

Dental caries is a lifelong disease that requires preventive strategies tailored to an individual's age, biological risk factors, lifestyle, and oral health needs. Although the fundamental principles of caries prevention remain consistent throughout life, the selection of preventive interventions should be modified according to the patient's stage of life and caries risk. A personalized, risk-based approach enables early disease prevention, preserves tooth structure, and promotes long-term oral health outcomes. [1,8,12]

A. Infants and Preschool Children

Early childhood represents a critical period for establishing lifelong oral health behaviours. Preventive care should begin with parental education on appropriate feeding practices, twice-daily toothbrushing using age-appropriate fluoridated toothpaste, dietary counselling to limit free sugar intake, and the establishment of a dental home by the child's first birthday. Professional fluoride varnish application should be considered for children at increased caries risk, while anticipatory guidance remains essential in preventing early childhood caries. [22,26,53]

B. School-Aged Children and Adolescents

During childhood and adolescence, preventive strategies should focus on maintaining effective oral hygiene, reinforcing dietary counselling, and protecting newly erupted permanent teeth. Pit and fissure sealants are recommended for susceptible molars, particularly in high-risk individuals, while regular fluoride exposure remains the cornerstone of caries prevention. Orthodontic treatment, increased consumption of sugar-containing snacks, and inconsistent oral hygiene practices may further increase caries susceptibility, highlighting the importance of individualized preventive care and periodic risk reassessment. [22,27,54]

C. Adults

In adults, preventive care should be directed towards controlling dietary risk factors, maintaining plaque control, and identifying early non-cavitated lesions through regular clinical examination. Caries risk assessment should guide recall intervals, fluoride recommendations, and preventive interventions. Patients with reduced salivary flow, extensive restorations, or chronic systemic diseases require additional preventive measures, including professionally applied fluoride products and individualized oral hygiene instruction to minimize disease progression. [12,21,55]

D. Older Adults

Older adults frequently present with complex risk factors, including gingival recession, exposed root surfaces, polypharmacy-induced xerostomia, reduced manual dexterity, and multiple chronic medical conditions. Consequently, prevention should emphasize meticulous plaque control, high-fluoride toothpaste, fluoride varnish application, dietary modification, and regular professional maintenance. Silver diamine fluoride has demonstrated particular value in arresting root caries among frail and medically compromised elderly individuals while avoiding invasive treatment. [21,35,56]

E. Special Care and Medically Compromised Patients

Individuals with physical disabilities, cognitive impairment, systemic illnesses, or limited access to dental services often experience a disproportionately high burden of dental caries. Preventive care should therefore be individualized, focusing on caregiver education, simplified oral hygiene measures, fluoride-based prevention, dietary support, and minimally invasive treatment approaches where appropriate. Collaboration among dental professionals, physicians, caregivers, and community healthcare providers is essential to improve access to preventive oral healthcare for these vulnerable populations. [1,56]

Overall, contemporary evidence supports a lifespan approach in which preventive strategies are continuously adapted according to changing biological, behavioural, and environmental risk factors. Integrating individualized caries risk assessment with age-specific preventive interventions enables clinicians to preserve natural tooth structure, reduce disease burden, and promote lifelong oral health through evidence-based, patient-centred care.

Age group	Major caries risk factors	Recommended preventive strategies
Infants and Preschool Children	Bottle feeding at night, frequent sugar exposure, poor parental awareness	Parent education, fluoridated toothpaste, dietary counselling, first dental visit by 12 months, fluoride varnish for high-risk children
School-Aged Children	Newly erupted permanent molars, inadequate oral hygiene, sugary snacks	Toothbrushing with fluoride toothpaste, pit and fissure sealants, fluoride varnish, dietary modification, regular dental review
Adolescents	Orthodontic appliances, poor dietary habits, inconsistent oral hygiene	Reinforced oral hygiene, fluoride products, dietary counselling, periodic caries risk assessment
Adults	High sugar intake, reduced fluoride exposure, restorations, xerostomia	Individualized risk assessment, fluoride therapy, plaque control, early lesion management

Age group	Major caries risk factors	Recommended preventive strategies
Older Adults	Root exposure, xerostomia, polypharmacy, reduced dexterity	High-fluoride toothpaste, fluoride varnish, Silver Diamine Fluoride (SDF), caregiver support, regular maintenance
Special Care Patients	Physical or cognitive limitations, systemic disease, dependence on caregivers	Simplified oral hygiene, caregiver education, fluoride therapy, minimally invasive dentistry, multidisciplinary care

Table 5. Age-Specific Evidence-Based Caries Prevention Strategies

8. Challenges And Future Perspectives

Despite substantial advances in preventive dentistry, dental caries remains one of the most prevalent chronic diseases worldwide. Effective implementation of evidence-based preventive strategies continues to be challenged by socioeconomic disparities, limited access to oral healthcare, inadequate oral health literacy, and poor patient adherence to preventive recommendations. In many low- and middle-income countries, restorative treatment remains the primary focus of dental care, while preventive services are underutilized. Furthermore, variations in clinical practice and inconsistent application of caries risk assessment models may reduce the effectiveness of personalized preventive care. [1,2,12]

Although fluoride-based interventions remain the cornerstone of caries prevention, increasing interest in biomimetic materials, salivary diagnostics, and minimally invasive treatment approaches has expanded the scope of preventive dentistry. However, many emerging technologies require additional high-quality clinical trials to establish long-term effectiveness, cost-effectiveness, and standardized clinical protocols before routine implementation. Similarly, while artificial intelligence has shown promising diagnostic accuracy, its integration into everyday clinical practice should be guided by appropriate validation, ethical considerations, and clinician oversight. [43-52]

Future caries management is expected to move toward precision dentistry, where prevention is individualized according to each patient's biological, behavioural, and environmental risk profile. Integration of artificial intelligence, digital diagnostics, salivary biomarkers, and predictive analytics may facilitate earlier disease detection and more targeted preventive interventions. At the same time, strengthening public health policies, improving access to preventive care, and promoting interdisciplinary collaboration will remain essential for reducing the global burden of dental caries.

Continued emphasis on prevention, early intervention, and preservation of natural tooth structure will ensure that minimally invasive dentistry remains central to contemporary clinical practice. Ongoing research should therefore focus not only on developing innovative technologies but also on improving their accessibility, affordability, and clinical applicability across diverse healthcare settings.

9. Conclusion

Modern caries prevention has evolved from a predominantly restorative approach to a comprehensive, evidence-based model focused on early diagnosis, individualized risk assessment, and preservation of natural tooth structure. Contemporary understanding recognizes dental caries as a dynamic, biofilm-mediated disease that can be prevented, controlled, and, in its early stages, reversed through timely preventive interventions. Consequently, effective management extends beyond treating cavitated lesions and emphasizes controlling the underlying disease process.

Evidence consistently supports the use of risk-based preventive strategies, including fluoride therapy, effective biofilm control, dietary modification, pit and fissure sealants, and patient-centred behavioural interventions as the foundation of lifelong caries prevention. In addition, minimally invasive approaches such as resin infiltration, silver diamine fluoride, atraumatic restorative treatment, and selective caries removal have transformed clinical practice by promoting lesion arrest while preserving healthy tooth structure and maintaining pulpal vitality.

Recent advances in digital dentistry and artificial intelligence further strengthen preventive care by improving early lesion detection, enhancing diagnostic accuracy, and supporting individualized clinical decision-making. However, these technologies should complement, rather than replace, comprehensive clinical examination and professional judgement. Continued research is required to establish their long-term clinical effectiveness and facilitate their integration into routine dental practice.

Ultimately, successful caries prevention requires a personalized, evidence-based approach that integrates comprehensive risk assessment with preventive and minimally invasive strategies throughout the patient's lifespan. By prioritizing disease prevention over surgical intervention, clinicians can reduce the global burden of dental caries, improve long-term oral health outcomes, and preserve the natural dentition. Future efforts should focus on expanding access to preventive care, strengthening oral health education, and translating emerging scientific evidence into practical, patient-centred clinical practice.

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