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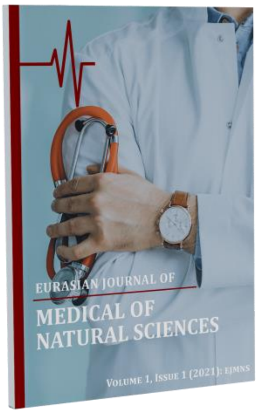

MANAGEMENT OF DENTAL CAVITIES AND THEIR TREATMENT

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ABSTRACT

The management of dental caries has undergone significant evolution in recent years. Contemporary practical strategies now emphasize early detection and prevention, along with diagnostic assessments based on risk indicators and factors. The latest management approaches prioritize the preservation of healthy tooth structure, aligning with the principles of minimally invasive dentistry. These approaches aim to fulfill multiple objectives, including fostering a preventive mindset, tailoring risk assessments to individual patients, promptly identifying carious lesions, and promoting remineralization of non-cavitated lesions. Recognizing that restorative procedures can compromise tooth structure and potentially perpetuate a cycle of restoration and re-restoration, there's a growing emphasis on employing minimally invasive techniques when intervention is necessary. This involves strategies such as repair, refurbishment, or polishing rather than outright replacement of defective restorations. Moreover, when caries exposes the pulp, there's a shift towards more conservative management options, favoring vital pulp treatments (VPT) like partial or complete pulpotomy over pulpectomy. Despite advancements, many dentists still default to invasive procedures for managing dental caries and pulp conditions. However, transitioning to non-invasive and minimally invasive approaches in routine clinical practice will undoubtedly require time and concerted effort. This article provides an overview of minimally invasive dental caries control and explores various procedures employed in minimally invasive dentistry based on the extent of carious lesions. By presenting this information, readers will be better equipped to detect, diagnose, and treat dental caries in its early stages, as well as when it progresses to dentin, utilizing minimally invasive treatment modalities.

Materials and Methods (Search Procedure)

1. Search Strategy We utilized the MEDLINE database via PubMed to identify pertinent literature covering dental caries, encompassing definitions, epidemiological insights, causative factors, and risk determinants. Employing a Boolean search approach, we combined various terms and applied filters such as abstract, free full text, full text, clinical trial, randomized controlled trial, systematic review, meta-analysis, and review. The search scope was confined to a five-year timeframe, and exclusively English-language studies were considered. Subsequently, we selected the most relevant studies meeting our predefined inclusion criteria for incorporation into the present review.

2. Inclusion and Exclusion Criteria We included studies focusing on dental caries and caries lesions published in English within the past five years (May 30, 2018–May 29, 2022). This encompassed:

(i) Prospective and retrospective in vivo studies

(ii) In vitro studies examining the histology of dental caries

(iii) Data pertaining to dental caries and caries lesions sourced from:

- Peer-reviewed articles
- Systematic reviews and meta-analyses
- Google Scholar
- Recently published textbooks

Manual searches conducted within the reference lists of selected articles. Exclusion criteria encompassed studies that did not align with the aforementioned inclusion criteria.

Results

A total of six hundred and eighty-three articles and studies were retrieved, with the references list comprising those utilized in this review.

1. Dental Caries Dental caries presents as a multifaceted condition characterized by the demineralization of dental hard tissues (enamel, dentine, and cementum) in both primary and permanent teeth. With appropriate management, dental caries is both preventable and reversible. The development of dental caries necessitates four key elements: bacterial biofilm (plaque), fermentable carbohydrates, dental hard tissues, and time. Additionally, personal and oral environmental factors significantly influence the onset and progression of the disease.

2. Examination, Detection, and Diagnosis of Dental Caries

2.1. Visual-Tactile and Radiographic Examination of Dental Caries Diagnosing dental caries typically involves a clinical examination, often conducted through a visual-tactile approach, which is commonly complemented by radiographic assessment. Additionally, techniques such as fibre-optic transillumination (FOTI), electrical conductivity, and laser fluorescence are frequently employed for dental caries diagnosis. The visual examination necessitates adequate lighting and a clean, dry tooth surface. Moreover, it is imperative to clean the tooth surface prior to conducting the examination (see Figure 1).

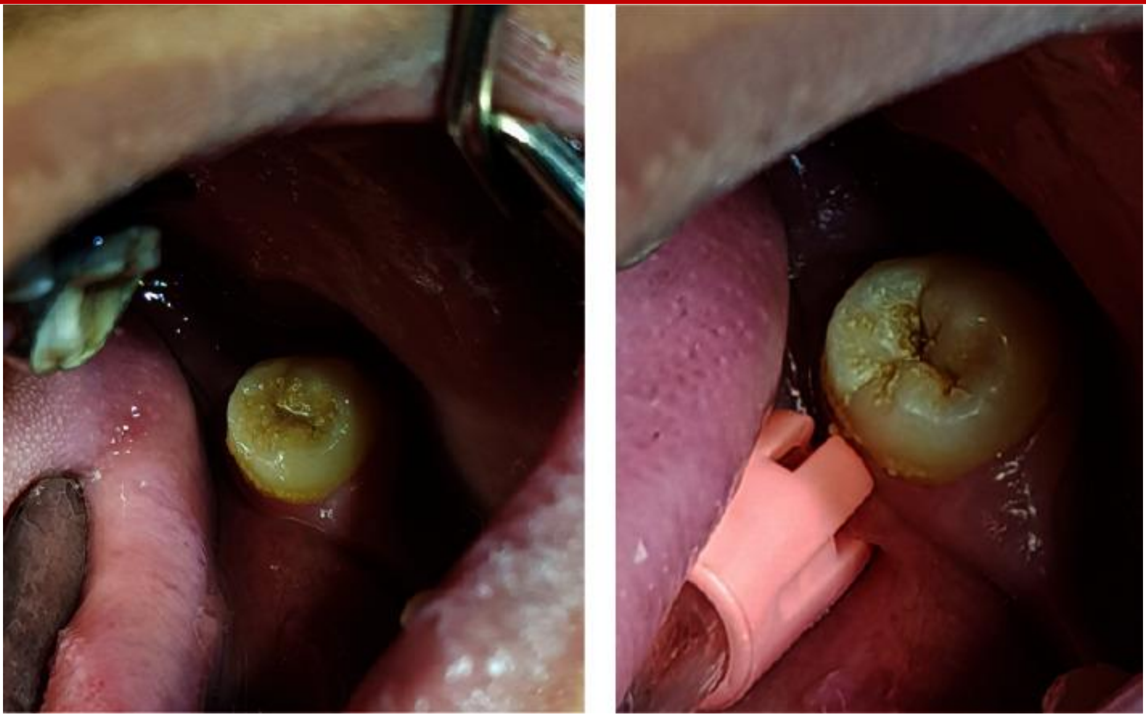

Figure 1

Teeth should be cleaned to remove food debris that may conceal dental caries. A carious lesion is covered by food debris in (a), and it is visible after cleaning (b).

Traditionally, the dental explorer has been employed in clinical settings for detecting carious lesions. However, its utility is a subject of controversy and debate due to its limited additional benefits. For example, inserting the explorer into a fissure does not necessarily confirm the presence of caries but may merely indicate a snug fit within the fissure. Additionally, the explorer runs the risk of causing irreversible physical damage to demineralized and fragile surfaces. Its use may also exacerbate the spread of cariogenic bacteria into deeper layers and areas where routine oral hygiene measures are ineffective. Moreover, a dental explorer can facilitate the transmission of cariogenic bacteria from infected to non-infected pits and fissures. Furthermore, the explorer's diagnostic sensitivity is relatively low.

2.2. Radiographic Evaluation Visual inspection coupled with radiographic examination is standard practice for assessing and diagnosing occlusal and proximal caries. However, it's important to recognize that radiography provides a 2-dimensional representation of a 3-dimensional object, and approximately 25% of the mineral content of tooth structure must be lost before dental caries become radiographically visible. For instance, cavitation is improbable when interproximal carious lesions are confined to the enamel on radiographs. Conversely, carious lesions are more likely to progress to cavitation if they extend into the middle third of the dentine. The likelihood of cavitation varies for lesions reaching the outer third of the dentine or situated around the dentin-enamel junction.

It's crucial to acknowledge that radiographs may underestimate the extent of carious lesions, as they are often deeper than depicted radiographically. Therefore, interpreting radiographs requires caution, particularly in distinguishing between artifacts such as burn-out or Mach bands and actual proximal caries. Moreover, factors like overlapping, overexposure, and underexposure can adversely affect the quality of images depicting carious lesions.

When dental radiographs are necessary, their use should be optimized to minimize patient exposure to ionizing radiation in line with the ALADAIP principle (As Low as Diagnostically Achievable while Indication-oriented and Patient-specific). Alternatives such as fibre-optic transillumination should always be considered. This technique can effectively detect proximal carious lesions, although it lacks the ability of bitewing radiographs to monitor dental caries over time.

2.3. Histological and Clinical Description of Carious Lesions

(1) Carious Lesions in Enamel (White Spot Lesion)

The initial stage of enamel caries manifests as a demineralized area clinically observed as a white spot lesion (WSL) [32, 33], also referred to as an initial or early carious lesion. This lesion presents as a chalky white zone on the tooth surface when dry (see Figure 2). The pronounced porosity in the subsurface zone resulting from demineralization contributes to the distinctive appearance of WSLs [29]. Unlike the subsurface, the surface retains relative integrity with only a few pores. Light transmission is altered within these pores due to differences in refractive indices between enamel, air, and saliva. With refractive indices of 1.00n, 1.33n, and 1.66n, respectively, enamel, air, and saliva cause differential light transmission. The contrast between enamel and air refractive indices, approximately 0.66n, enhances caries visibility when saliva within the enamel pores is displaced by air upon tooth dryness. Therefore, ensuring the tooth surface and suspected lesion are dry facilitates clear visualization of WSLs. Figure 2 depicts clinical images of WSLs.

Figure 2 A clinical photograph of a white spot lesion on the canine cervical region (the blue arrow).

WSLs are frequently encountered around fixed orthodontic appliances and pose a significant challenge during orthodontic treatment .

Comprising four distinct zones, the WSL includes the surface zone, the body lesion, the dark zone, and the transparent zone. The surface zone retains relatively intact structure, with a pore volume of less than 1%. Situated between the surface and the dark zone, the body lesion is the most demineralized, exhibiting pore volumes ranging from 5% to 25%. The dark zone contains pore volumes ranging from 2% to 4%. As for the transparent zone, positioned at the innermost part of the lesion's advancing front, it typically features a pore volume of around 1% and displays slightly more pores than sound enamel, although its presence is not consistent. Figure 3 provides a schematic representation of the demineralized enamel zones within WSLs.

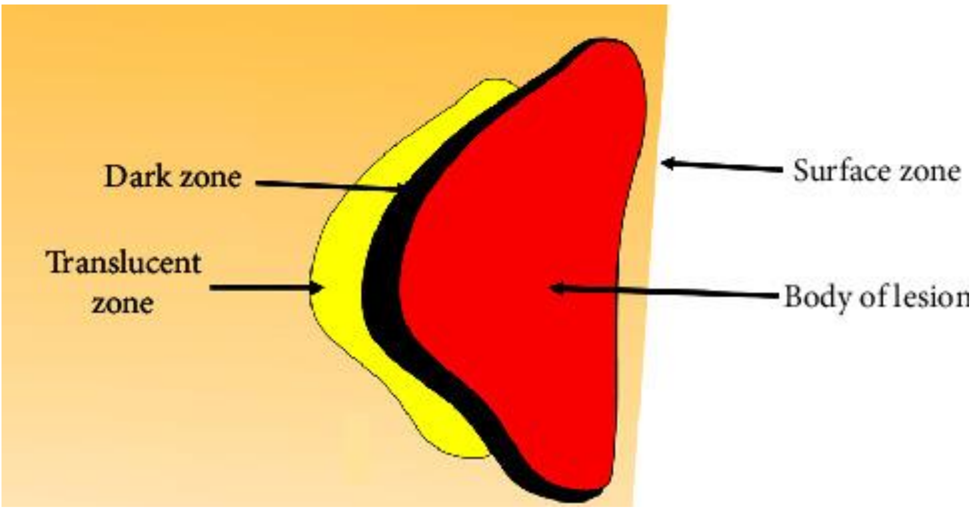

Figure 3

A schematic representation of histological zones of noncavitated demineralized enamel carious lesion

(2) Carious Lesions in Dentine

Dentine and enamel exhibit structural disparities, resulting in a distinct progression of caries within dentine compared to enamel. Dentine, characterized by lower mineral content, features microscopic tubules that facilitate bacterial ingress and mineral egress. This process leads to progressive demineralization of the body of the enamel lesion. Consequently, the surface enamel undergoes weakening and eventual collapse.

Caries dentine is histologically categorized into four zones: soft (infected) dentine, firm (affected) dentine, dark zone, and transparent zone. The first two zones, soft and firm dentine, hold greater clinical significance compared to the latter two zones. Therefore, the discussion will primarily concentrate on these two zones.

a) Soft dentine, previously termed infected dentine and also known as outer dentine caries, represents the most superficial, necrotic, and irreparable form of dentine. It can be easily excavated using a hand excavator and removed with rotary tools . Its mineral content is dissolved by acid, and its collagen matrix is denatured by proteolytic enzymes. Dentinal tubules within this zone are enlarged and distorted, harboring a substantial bacterial population (see Table 1). Clinically, soft dentine presents as dark-brown, soft, moist, and mushy. Soft dentine is often removed during the caries removal phase of cavity preparation due to its necrotic nature, irreparability, and inability to provide a reliable binding surface for adhesive materials to create a secure seal. However, there is growing consensus in recent years that soft dentine can be preserved near the pulp.

The features of soft dentine.

(i) Loaded with a high volume of bacteria
(ii) Has low mineral content (demineralized)
(iii) Has irreversibly denatured collagen
(iv) Histologically, it may be referred to as necrotic and contaminated
(v) Clinically, it can be easily excavated with hand and rotary instrumentation
(vi) It may be retained in extremely deep carious lesions when the possibility of pulp exposure is high

b) Firm dentine, previously termed "affected" dentine, is also referred to as inner carious dentine. It is firmer than soft dentine and exhibits resistance to hand excavation owing to its higher mineral and collagen content (refer to Table 2). While its mineral dissolution is less pronounced compared to soft dentine, firm dentine is considered partially demineralized. It typically appears as a paler brown, sticky, harder, and scratchy material when probed. Firm dentine is located directly beneath soft dentine and exhibits slight demineralization while retaining the potential for remineralization and recalcification. The ongoing process of mineral deposition within the tubules beneath the carious lesion contributes to tubular obliteration and sclerosis, potentially reducing bond strengths.

The characteristics of the firm carious dentine.

(i) Characterised by demineralisation of intertubular dentine
(ii) Initial formation of intratubular fine crystals at the advancing front of the caries lesion
(iii) The tubule lumen becomes filled with minerals
(iv) Histologically, firm dentine may be referred to as demineralized
(v) Due to the demineralisation process, firm dentine is softer than hard dentine
(vi) Clinically, unlike soft dentine, firm dentine is resistant to hand excavation and can only be removed by exerting some pressure

The collagen cross-linking remains intact and can serve as a template for remineralization of intertubular dentine. As a result, if the pulp remains viable, firm dentine can be remineralized.

c) Hard dentine

It includes normal (sound), tertiary, and sclerotic dentine. Clinically, it cannot be easily penetrated with a blunt explorer and can only be removed by a bur or a sharp cutting instrument.

The responses of the dentine-pulp complex to various stimuli such as thermal, chemical, bacterial, or mechanical factors, as well as caries and fractures, trigger the formation of tertiary dentine. Tertiary dentine can be categorized into reactionary and reparative dentine. Reactionary dentine arises from mild stimuli, such as normal tooth wear, while reparative dentine is formed in response to extensive injuries like caries or cavity preparation.

Reactionary dentine is generated by odontoblasts located in the pulp chamber wall adjacent to the region affected by factors such as caries. In cases of pulp exposure, newly differentiated odontoblast-like or odontoblastoid cells replace irreversibly damaged odontoblasts at the site of exposure, resulting in the formation of a reparative tubular dentine bridge. Figure 4. illustrates examples of firm and hard dentine.

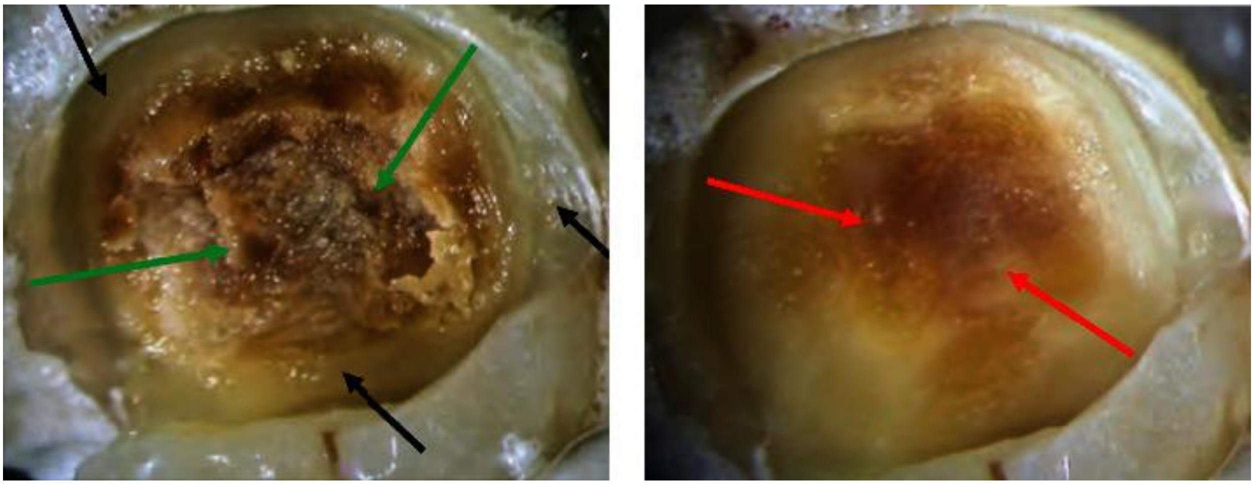

Figure 4 Nonselective caries removal to hard dentine at the periphery (black arrows) (a). Green arrows indicate soft dentine, (b) selective caries removal to firm (affected) dentine overlying the pulpal aspect (red arrows).

Strategies for Caries Removal

Generally, there are two approaches to caries removal for cavitated carious lesions in teeth with sensible and asymptomatic pulps: nonselective caries removal and selective caries removal.

1. Nonselective Caries Removal (Complete Caries Removal) Approach

This traditional method involves removing both soft and firm dentine, regardless of the proximity of the carious lesion to the pulp. Also known as complete caries removal or complete caries excavation, it eliminates caries dentine, both soft and firm, irrespective of depth or proximity to the pulp. Advocates argue that this approach prevents further spread of caries by eradicating all bacteria and carious tissue, providing a solid foundation for effective restoration . However, it is associated with a high risk of pulp exposure. The validity of this method is being questioned due to a lack of evidence-based support, although it may still be used when carious lesions are not close to the pulp.

2. Selective Caries Removal Approach

In this method, caries are selectively removed based on their proximity to the pulp, preserving soft and/or firm dentine. Also known as partial caries removal (PCR), this approach can be implemented as a one- or two-step procedure. The one-step method involves selectively removing carious dentine and restoring the cavity with a permanent restoration in a single visit, with indirect pulp capping (IPC) being an example. Conversely, the two-step technique, such as the stepwise (SW) method, involves caries removal in two separate clinical appointments.

The selective caries removal methods aim to avoid pulp exposure and maintain pulp vitality. Studies have shown that the SW method has a significantly lower pulp exposure rate compared to nonselective caries removal to hard dentine. Supporters of the one-step approach argue against re-entry, as recommended in the SW method, suggesting it may jeopardize the pulp. Conversely, proponents of the two-step technique debate that leaving soft dentine in the one-step method could result in shrinkage and compromise the permanent restoration.

Selective caries removal is further categorized into two subtypes based on the type of caries dentine removed: selective caries removal to soft dentine and selective caries removal to firm dentine. The former preserves soft dentine, while the latter removes soft dentine but preserves firm dentine. Figure 4 illustrates a carious lesion before and after caries removal to hard and firm dentine. It's important to note that the terms "soft" and "firm" dentine were previously referred to as "infected" and "affected" dentine, respectively, within this article.

I. Selective caries removal to soft dentine (soft dentine is retained)

II. The pulpal and axial soft caries dentine is left to prevent pulp exposure and “stress” to the pulp. However, the peripheral dentine and dentine-enamel junction are carried out using rose head burs or a sharp excavator until hard, dry dentin remains (nonselective) to ensure an appropriately sealed restoration. Compared to nonselective caries removal to hard dentine, this approach dramatically minimizes the likelihood of pulpal exposure. As a result, it is advised to use it in extremely deep cavitated carious lesions.

III. Selective caries removal to firm dentine (firm dentine is retained)

This method differs from the previous approach in that soft dentine is extracted from the cavity's pulpal aspect while retaining firm dentine near the pulp. It is advisable for managing shallow or moderately deep cavitated dentine carious lesions to prevent pulp exposure and preserve pulp vitality. However, as previously stated, the boundaries of the cavity must consist solely of hard dentine. This approach is also appropriate when lesions on radiographs extend to less than the pulpal third or quarter of the dentine. However, it should be avoided in cases where the carious lesion is excessively deep and close to the pulp, as pulp exposure becomes inevitable.

Noncaries Removal/Caries Sealing Approach

This method is recommended for clinically noncavitated occlusal carious lesions that appear to extend into the dentine on radiographs. In such cases, fissure sealants may be applied when plaque control alone proves insufficient to arrest decay. However, regular monitoring is essential to ensure the sealant's integrity and prevent lesion progression. Additionally, this approach may be suitable for selective cavitated carious dentine lesions. As a result, the carious lesion becomes inactive upon sealing. Sealant materials such as composite resins or glass ionomers are typically utilized. Further details regarding this method are elaborated below.

Nonrestorative Cavity Control (NRCC) Approach

This approach is determined based on factors such as the shape and depth of the carious lesion, the patient's ability to maintain oral hygiene and prevent plaque buildup, and the patient's aesthetic preferences. The cavity entrance is widened to enhance cleanliness, ease of cleaning, and the patient's ability to maintain oral hygiene. Consequently, the patient engages in repeated tooth cleaning to eliminate biofilm and halt lesion progression, with remineralization therapies such as fluoride toothpaste being employed. It is crucial to modify patient behavior to control biofilm and address habits contributing to lesion development. Therefore, patient education regarding the causes of dental caries and methods to reduce or eliminate them is essential. This approach is also advisable for cases involving early-stage active root surface caries with shallow defects, where emphasis is placed on promoting remineralization and managing caries through good oral hygiene practices and fluoride treatment.

Methods of Management of Carious Lesions

1. Caries Management through Risk Assessment

Prevention is deemed superior to treatment, and the various phases and activities of caries may necessitate diverse management approaches. The Caries Management by Risk Assessment (CAMBRA) system, established in 2002, stands as a reliable patient-centric methodology. It factors in a patient's health and lifestyle risk elements, drawing upon peer-reviewed literature on caries risk assessment, saliva impact, and nutritional influences on caries development. CAMBRA has undergone thorough evaluation and validation, proving to be valuable guidance for healthcare practitioners in caries assessment and management. Accordingly, patients are categorized into high, moderate, and low-risk groups, allowing for tailored preventive counseling and actions based on individual risk levels. The CAMBRA guidelines are succinctly outlined in

Table 3

A summary of the CAMBRA guideline.

Caries management by risk assessment (CAMBRA) is used to produce a custom risk assessment for individual patients [48]

(1) Assess risk indicators

(2) Assess risk factors

(3) Assess protective factors

(1) Risk indicators

(i) The “WREC” (an acronym for risk indicator factors). These factors consist of the followings

(a) White spot lesions

(b) Restorations (in last 3 years)

(c) Enamel lesions visible on radiographs

(d) Cavitation into dentine

(2) Risk factors

(i) BAD (an acronym for risk factors). These factors consist of the followings

(a) Bacteria (Streptococcus mutans and Lactobacilli 103–105 cfu)

(b) Absence of saliva

(c) Dietary habits (frequency of snacking with sugary foods; poor or al hygiene)

(3) Protective factors

(i) SAFE (is an acronym for protective factors). These factors include

(a) Saliva and Sealants

(b) Antibacterial (chlorohexidine)

(c) Fluoride

(d) Effective diet/lifestyle habits (including plaque control; use of xylitol)

Chemical therapy involving antibacterial agents and fluoride treatment is imperative for high- and extreme-risk patients. To mitigate bacterial challenges, alter biofilm composition, and deter ongoing caries development, fluoride therapy must be complemented with antibacterial agent usage. For high-risk and extreme-risk patients, a regimen combining daily antibacterial therapy (0.12% w/v chlorhexidine gluconate mouth rinse) and twice-daily application of high-concentration fluoride toothpaste (5,000 ppm fluoride) for home use is recommended.

In high-caries-risk adult individuals, the daily use of a combination of chemical therapy and restorative treatment has been observed to reduce caries incidence by 20–38%. Topical fluoride application has shown significant reduction in smooth surface caries occurrence.

However, according to Momoi and colleagues, cavity preparation and immediate intervention are warranted if more than one of the following indicators is present:

- Visual detection of a cavity after tooth cleaning and drying.
- Sensitivity or discomfort upon exposure to cold water or food.
- Unsatisfactory appearance.
- Radiographic evidence of carious lesions penetrating more than one-third of the dentin.
- High caries risk in a patient.

2. White Spot Lesions and Their Management (WSLs)

In recent times, there has been a growing consensus regarding the viability of sealing noncavitated carious lesions, even if they have extended to the outer dentine surface, as an effective method for controlling caries progression. This approach stands out as one of the most conservative strategies for preserving tooth structure and pulp vitality while avoiding invasive interventions, referred to as the "microinvasive concept".

WSLs can be managed noninvasively through diligent oral hygiene practices and the application of fluoride-containing products such as toothpaste, mouthwash, gels, and varnish, as well as using casein phosphopeptide amorphous calcium phosphate (CPP-ACP) and casein phosphopeptide-amorphous calcium phosphate fluoride (CPP-AFCP). Additionally, the resin infiltration technique has emerged as a viable option for managing WSLs, demonstrating the ability to delay or even reverse the progression of noncavitated carious lesions. Further elaboration on this method is provided below.

3. Sealing Noncavitated Caries Lesions

As previously discussed, sealing noncavitated carious lesions has demonstrated efficacy in halting lesion progression both in vivo and in vitro. Proximal carious lesions can be effectively sealed following the separation of the affected tooth to access the lesion. According to Chen et al., resin infiltration and sealing proved more effective than noninvasive treatments, such as fluoride varnish, in arresting noncavitated proximal lesions.

The choice of sealing material significantly influences the effectiveness of the sealing procedure. Arslan et al. emphasize the importance of resin selection, noting that certain resins may be more susceptible to water sorption over time than others, underscoring the need for careful consideration and caution in material selection, application, and follow-up. However, further long-term randomized clinical trials are warranted to contribute to the existing body of evidence.

Sealing and resin infiltration of carious lesions represent two microinvasive approaches, both involving the removal of dental hard tissue surface at the micron level, typically during an etching step, as seen in sealing or infiltration techniques. In infiltration techniques, etching is performed using an acid such as 15% HCl-gel for a specific duration, such as 120 seconds, followed by the application of an infiltrating resin (e.g., "Resin Infiltration"; Icon; DMG). Table 4 illustrates the literature-proposed management of noncavitated carious lesions, while Table 5 provides a summary of various studies on noninvasive, microinvasive, and minimally invasive approaches to carious lesion management. As a result, the following conclusions can be drawn:

- Patient education on proper oral hygiene and dietary habits is crucial for preventing or halting the progression of dental caries.
- Infiltration and sealing proved more effective in halting the progression of noncavitated proximal lesions compared to noninvasive treatments.
- In terms of slowing the progression of noncavitated caries lesions, infiltration demonstrated superiority over sealing.

Table 4

Summary of management of noncavitated proximal carious lesions with the most conservative methods.

Noninvasive strategies	**Microinvasive strategies**	**Minimally invasive (restorative) strategies**
(i) Based on the use of topical fluorides and other chemical agents to control plaque accumulation, such as interdental cleaning using interproximal brush and floss, rather than removing dental hard tissue, as well as patient education and diet control. (ii) This may be sufficient for lesion arrest in individuals with low caries risk/susceptibility and when lesions are radiographically confined to the enamel.	(i) This represents the dental hard tissue surface removal at the micron level, usually during an acid etching step, such as in sealing or infiltration techniques. The infiltration technique involves etching with 15% HCl-gel for two minutes and then infiltrating with a low-viscositylight-curing resin such as “Resin Infiltration”; Icon; (DMG). (ii) It is recommended for individuals who are at high risk/susceptible or when lesions extend radiographically into dentine. When such treatment is intended, many factors, such as clinical experience or cost, should be considered. (iii) Microinvasive treatment combined with noninvasive measures significantly improves the outcome of noncavitated enamel and initial dentine lesions (limited to the outer third of dentine based on radiograph and clinically noncavitated). It is considerably more efficient than	(i) This method entails removing a small amount of dental hard tissue with sharp excavators or rotary instruments. It is usually followed by the replacement of the removed hard tissue with appropriate restorative materials such as composite resin. (ii) Cavitated lesions frequently necessitate restorative strategies. Adhesive direct restorations allow for minimally invasive tooth preparations, making them the material of choice for restoring proximal lesions in many cases. Amalgams, on the other hand, have a lower risk of secondary lesions and failure, and because their placement is less technique-sensitive, they may be preferred in more clinically complex scenarios, depending on national policy guidelines, as amalgam is not used in several countries.

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Noninvasive strategies	Microinvasive strategies	Minimally invasive (restorative) strategies
	noninvasive management alone. (iv) There is evidence that sealing and resin infiltration can stop lesions confined to the enamel or near the enamel-dentine junction. Still, only infiltration techniques can stop lesions that involve the dentin [52]. (v) The distinction between sealing and infiltration is that while fissure sealing acts as a diffusion barrier on the lesion's surface, infiltration creates a barrier within the lesion by replacing the mineral lost with the resin.	

Table 5
A summary of several studies on noninvasive, microinvasive, and minimally invasive carious lesion management.

Reference	Study type	Materials and methods	Conclusions
Abuchaim et al.	In vivo	The study included 44 adolescents who had bitewing radiographs taken to diagnose caries. The sample included noncavitated lesions extending up to half the thickness of the dentin. After tooth separation, the proximal caries-lesion surfaces in the experimental group ($n = 33$) were sealed with an adhesive. The control group ($n = 11$) was given oral hygiene instructions, including dental floss. After one year, follow-up radiographs were taken and compared to baseline radiographs.	Approximately 22% of the sealed lesions showed reduction, 61% no change, and 16% progressed. The corresponding values for the control lesions were 27%, 36%, and 36%, respectively. Sealing proximal caries lesions was not shown to be superior to lesion monitoring over a year.
Kantovitz et al.	A systematic review	The Cochrane Library, Embase, PubMed, and Web of Science (ISI) databases were searched for papers published between January 1970 and September 2008.	While fissure sealing acts as a diffusion barrier on the lesion's surface, infiltration creates a barrier within the lesion by replacing the mineral lost with a low-viscositylight-curing resin.

Reference	Study type	Materials and methods	Conclusions
Borges et al.	In vivo	Sixty teeth from patients with a high caries risk had noncavitated dentinal occlusal caries. Patients were randomly assigned to one of two groups, each with 30 teeth. Oral hygiene instructions and a fissure sealant were given to the experiment group. Only oral hygiene instructions were given to patients in the control group. Over a 36-month period, clinical and radiographic examinations were used to track caries progression and sealant loss.	At 36 months, the pit and fissure sealant used in this study was shown to be effective in stopping carious lesions.
Ammari et al.	A systematic review and meta-analysis	A thorough search was carried out in the following systematic electronic databases until June 2013: PubMed, Cochrane Library, Scopus, IBI Web of Science, Lilacs, SIGLE, and ClinicalTrials.gov. The study included only controlled clinical trials and randomised controlled clinical trials that evaluated the effectiveness of sealing on noncavitated proximal caries with a minimum follow-up of 12 months.	The findings indicate that sealing noncavitated proximal caries effectively controls proximal caries in the short and medium term. More long-term randomised clinical trials are needed to strengthen this evidence.
de Assuncao et al.	A systematic review	Through November 2013, the MEDLINE/PubMed, LILACS, SciELO, and Scopus databases were searched for relevant publications. Only clinical trials evaluating the ability of noninvasive methods to stop the progression of occlusal noncavitated dentin carious lesions were considered.	Occlusal fissure sealing with a resin-based sealant may be used to arrest the progression of noncavitated occlusal dentine caries. Additional clinical trials with longer follow-up times are needed to enhance scientific evidence.
Dorri et al.	A systematic review	The Cochrane Oral Health Group Trials Register, the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE via OVID,	According to the available evidence, microinvasive treatment of proximal caries lesions stops noncavitated

Reference	Study type	Materials and methods	Conclusions
		EMBASE via OVID, LILACs via BIREME Virtual Health Library, Web of Science conference proceedings, ZETOC conference proceedings, proquest dissertations and theses, ClinicalTrials.gov, OpenGrey, and the World Health Organization (WHO) International Clinical Trials Registry Platform were all searched until December 31, 2014. The metaRegister of controlled trials was searched up to and including October 1, 2014. There were no language or date restrictions in the electronic database searches. The investigation sought to assess the efficacy of microinvasive treatments for managing proximal caries lesions in children and adults with primary and permanent dentition.	enamel and initial dentinal lesions (limited to the outer third of dentine, based on radiograph) and is significantly more effective than noninvasive professional treatment (e.g., fluoride varnish) or advice (e.g., to floss).
Anauate-Netto et al.	In vivo	A controlled clinical trial included 23 volunteers with clinically and radiographically noncavitated occlusal caries and caries risk ranging from "low" to "very high." A total of 86 teeth were randomly assigned to one of two experimental groups: Group one received a commercial pit-and-fissure sealant; while group two received Icon infiltrant (DMG). Over a three-year period, caries progression was monitored using clinical (laser fluorescence caries detection) and radiographic examinations at 12-month intervals. The marginal integrity of the sealing materials was also evaluated.	After three years of clinical evaluation, the infiltrant was effective in preventing caries progression in noncavitated pit-and-fissures, comparable to the conventional sealant. The infiltrant also showed better radiographic results in caries progression at the 3-year evaluation time.
Krois et al.	Systematic review and meta-analysis	Hand searches and cross-referencing were used in addition to searching three electronic databases (MEDLINE, Embase, and Cochrane Central). Randomized controlled trials	Microinvasive (sealing or infiltration) approaches are likely to be more effective than noninvasive approaches for

Reference	Study type	Materials and methods	Conclusions
		comparing microinvasive strategies, noninvasive treatment, or placebo for treating proximal carious lesions were included in the study. The primary outcome was the radiographic progression of the lesion. For synthesis, pairwise and Bayesian network meta-analysis, as well as TSA, were used.	arresting early (noncavitated) proximal lesions.
Abdelaziz et al.	In vivo study	Extracted human posterior teeth with noncavitated proximal carious lesions (ICDAS code 1-2) were cut vertically to obtain two symmetrical lesions. Group: Noninvasive proximal adhesive restoration (NIPAR)—half of the paired lesions' surfaces ($n = 13$) were abraded with metallic strips and etched with 37% H_3PO_4 for 120 seconds. Group 2: The infiltration concept technique (ICON)—the other half of the paired lesions' surfaces ($n = 13$) were etched with 15% HCl gel for 120 seconds. Group 1 samples were infiltrated with Scotchbond universal for 180 seconds. Group 2 samples were infiltrated with ICON infiltrant	Noninvasive proximal adhesive restoration allowed for better infiltration of noncavitated proximal carious lesions than ICON. Clinical significance: The combination of infiltration and sealing using noninvasive proximal adhesive restoration (NIPAR) offers a suitable noninvasive treatment option for noncavitated proximal lesions combining the advantages of sealing and infiltration.
Chen et al.	Systematic review	Six electronic databases were searched for published literature, and references were manually searched. Split-mouth randomised controlled trials comparing the efficacy of infiltration/sealing versus noninvasive treatments in proximal lesions were included. The primary outcome was determined by radiographic readings.	Infiltration and sealing were more efficacious than noninvasive treatments for halting noncavitated proximal lesions.

4. The Step-Wise (SW) Caries Removal (Excavation)

Technique involves two separate sessions spaced six months apart to allow for dentine and pulp changes to occur [1, 19, 43, 66]. It is recommended when the carious lesion is near the pulp based on radiographic assessment (approximately 75% into the dentine). The rationale behind the SW caries removal technique is that partial caries removal (PCR) followed by tooth sealing can lead to lesion arrest. Additionally, there is a significant decrease in anaerobic and aerobic bacteria counts, including Lactobacilli and Streptococci mutans, by the end of treatment [44]. Thus, complete dentinal caries removal is not always necessary for caries control [44]. The SW technique is a viable treatment option regardless of patient age, though it may yield better results in younger patients [66].

During the initial visit, a selective caries removal to soft dentine approach is employed, followed by restoration with glass ionomer. At the second appointment, scheduled 6 to 12 months later, a new periapical radiograph is taken to assess periapical pathosis. Any signs or symptoms of potential pulp pathosis are evaluated, and a sensibility/vitality test is conducted. Selective removal to firm/hard, dry dentine is performed centrally, or glass ionomer is used as a base without further tissue removal, followed by composite resin restoration [10].

The SW technique can also be effectively implemented using a calcium hydroxide-containing base material and a temporary filling [22, 67].

In contrast, some clinical studies have shown promising outcomes where carious dentine was retained in deep cavities, and the cavities were restored with final restoration without re-entry.

5. Indirect Pulp Capping

(IPC) involves selectively removing soft dentine and is considered a conservative approach to caries removal. Typically employed in deep cavity preparations where there is proximity to the pulp but no apparent exposure, IPC encourages the formation of reparative dentine. This technique aims to maintain pulp vitality by carefully eliminating soft carious dentine and applying a therapeutic material such as calcium hydroxide. Traditionally, calcium hydroxide serves as a liner before permanent filling material placement, though its use has been questioned due to drawbacks, leading to exploration of alternative biomaterials like calcium silicate-based materials [71, 73].

IPC can be conducted in either one or two steps. With the one-step method, the final restoration is placed during the same visit, while in some cases, a second appointment may be necessary after 6–8 weeks.

6. Atraumatic Restorative Treatment

(ART) was developed in the mid-1980s to address caries management in children residing in economically disadvantaged regions with limited access to resources and professional dental care [30, 54, 74]. ART is a minimally invasive procedure that involves decay removal using hand instruments, often without the need for anesthesia or electrical equipment, followed by cavity restoration using glass ionomer cement or resin-modified glass-ionomer cement and compomers [75]. This technique comprises two clinical steps conducted during the same appointment. Initially, soft carious dentine is removed with hand instruments and replaced with high-viscosity glass ionomer restorative material. Subsequently, adjacent pits and fissures are sealed with the same material, typically applied using the "press-finger" technique. Variations of the original procedure have incorporated alternative restorative materials [30].

ART serves as a valuable therapeutic option, particularly for children, anxious patients, individuals with special needs, those residing in elderly care facilities, remote areas, or underprivileged communities, and in outreach settings where conventional dental instruments and equipment may be lacking [30]. Its benefits include tooth structure preservation and reduced discomfort, as local anesthesia is often unnecessary. However, the effectiveness of ART is influenced by various factors such as caries prevalence, the chosen restorative material, and the operator's skill level.

Discussion

Prevention is always preferable to treatment. Having strategies or procedures in place to combat caries before its onset is crucial. Implementing community education programs can be highly beneficial [47, 79].

The current approach to controlling dental caries emphasizes evidence-based methods focusing on risk assessment and disease prevention [22]. Consequently, there has been a shift towards selective caries removal and minimally invasive, or even non-restorative, models in recent years [80].

The minimal intervention approach relies on preventive strategies and individualized risk assessments, tailoring the management of each patient's condition according to their risk level. Thus, accurate early lesion diagnosis and remineralization of non-cavitated lesions are vital. When operative intervention is necessary, it should be as minimally invasive as possible. Additionally, efforts should be made to avoid reintroducing patients into the restorative cycle and replacing poor restorations. Instead, defective restorations should be polished, refurbished, or repaired whenever possible.

Regular check-ups coupled with less invasive and conservative methods can achieve successful prevention and management of demineralized and early caries lesions. Mechanical plaque control, effective oral hygiene practices, fluoride and antimicrobial applications, and minimizing sugar intake between meals are key elements in controlling the caries process [6, 7]. Resin infiltration of white spot lesions (WSLs) and sealing non-cavitated lesions have garnered support from various studies, representing minimal invasive treatment options [51, 56, 59].

The concept of non-restorative cavity control (NRCC) is widely adopted and boasts a high success rate [6, 7]. This approach aims to make carious lesions cleanable by enlarging their openings.

Selective caries removal implementation has resulted in reduced pulp exposure compared to non-selective removal approaches. This method is based on the proximity of decay to the pulp [3, 5, 7, 39], allowing for the removal or retention of soft dentine to prevent pulp exposure.

Conclusions

Having a strategy and system that prioritize community education programs and patient-centered care is paramount in fulfilling our dental responsibilities. Caries management should be founded upon evidence-backed caries risk assessment methods. The availability of new information, knowledge, and materials should encourage professionals to adopt these methods.

Noninvasive, microinvasive, and minimally-invasive approaches should be carefully considered, especially for non-cavitated carious lesions. The selective caries removal approach presents a viable option for halting caries progression, albeit requiring meticulous case selection for optimal outcomes.

Restorative procedures should prioritize minimal invasiveness to preserve healthy tooth structure and ensure long-term restoration success. Additionally, repair or refurbishment should be preferred over outright replacement of defective restorations whenever feasible.

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