Minimally Invasive Approaches in Caries Management - I

Çürük Yönetiminde Minimal İnvaziv Yaklaşımlar - I

Nur KODAMAN DOKUMACIGİL[a],
Başak DURMUŞ[a]

[a]Marmara University Faculty of Dentistry,
Department of Pediatric Dentistry,
İstanbul, Türkiye

Correspondence/*Yazışma Adresi:*
Nur KODAMAN DOKUMACIGİL
Marmara University Faculty of Dentistry,
Department of Pediatric Dentistry,
İstanbul, Türkiye
nurkodaman92@gmail.com

ABSTRACT Recent advances in caries microbiology, caries risk assessment, lesion activity classification, and the understanding of demineralization-remineralization dynamics have substantially transformed contemporary approaches to caries management, shifting the focus from operative interventions toward biologically driven, evidence-based decision-making.[1] Within this framework, dental caries is increasingly recognized as a dynamic, biofilm-mediated disease, and treatment strategies are guided not solely by lesion depth but by clinical parameters such as lesion activity, cavitation status, and cleansability. Minimally invasive techniques -including microabrasion, resin infiltration, pit and fissure sealants, sonic and ultrasonic approaches, laser-assisted methods, ozone therapy, silver diamine fluoride (SDF), and Silver Modified Atraumatic Restorative Treatment (SMART)- provide mechanical or biological barriers that limit biofilm activity and reduce lesion progression while preserving sound tooth structure. These approaches aim to delay entry into the restorative cycle and constitute the cornerstone of modern minimal intervention dentistry.

Keywords: Dental caries; caries management; minimally invasive dentistry;
preventive dentistry

ÖZET Çürük mikrobiyolojisi, çürük risk değerlendirmesi, lezyon aktivitesinin sınıflandırılması ve demineralizasyon-remineralizasyon süreçlerine ilişkin anlayışta kaydedilen son gelişmeler, çürük yönetimine yönelik çağdaş yaklaşımları belirgin biçimde yeniden şekillendirmiş; tedavi paradigmasını geleneksel operatif girişimlerden biyolojik temelli ve kanıta dayalı karar verme süreçlerine doğru yönlendirmiştir. Bu bağlamda dental çürük, dinamik ve biyofilm aracılı bir hastalık olarak ele alınmakta; tedavi stratejileri yalnızca lezyon derinliği temelinde değil, lezyon aktivitesi, kavitasyon durumu ve lezyonun temizlenebilirliği gibi klinik parametreler doğrultusunda belirlenmektedir. Mikroabrazyon, rezin infiltrasyon, pit ve fissür örtücüler, sonik ve ultrasonik yöntemler, lazer destekli uygulamalar, ozon tedavisi, gümüş diamin florür (SDF) ve Gümüş Modifiye Atravmatik Restoratif Tedavi (SMART) gibi minimal invaziv yaklaşımlar; biyofilm aktivitesini sınırlayan ve lezyon progresyonunu azaltan mekanik ve/veya biyolojik bariyerler oluşturarak sağlam diş dokusunun korunmasını hedeflemektedir. Bu yaklaşımlar, restoratif döngüye girişin ertelenmesini hedeflemekte olup, modern minimal invaziv diş hekimliğinin temel taşını oluşturmaktadır.

Anahtar Kelimeler: Dental çürük; çürük yönetimi; minimal invaziv diş hekimliği;
koruyucu diş hekimliği

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AIR ABRASION

Although air abrasion was first described by Black in 1945, it failed to gain widespread clinical acceptance for many years due to the extensive use of amalgam restorations, inadequate control over cavity margins, and concerns regarding the potential ocular hazards associated with airborne abrasive particles.[1]

Air abrasion is based on the principle of removing mineralized tooth structure through micromechanical erosion by directing abrasive particles-most commonly aluminum oxide or, more recently, bioactive glass-onto the tooth surface using compressed air. In clinical practice, aluminum oxide particles with sizes ranging from 27-50 µm are most frequently employed. In recent years, bioactive glass particles, which exhibit a more "self-limiting" effect on demineralized enamel, have also been introduced as an alternative abrasive medium.[2]

Several advantages of air abrasion have been reported, including a reduced need for local anesthesia, minimal vibration and heat generation, preservation of sound tooth structure, and the creation of a surface roughness that may enhance adhesive bonding.[1] However, important limitations have also been identified. These include limited predictability of cutting depth, the inability to reliably distinguish carious dentin from sound tissue, and evidence from some studies indicating a more aggressive removal of healthy tooth structure.[2]

Within this context, comparative studies and evidence syntheses have focused on clarifying the clinical indications and optimal protocols for air abrasion use. More recent systematic reviews indicate that air abrasion alone does not clearly outperform conventional acid etching; however, when used according to appropriate protocols, it may improve sealant retention and facilitate fissure cleaning, particularly in anatomically deep pits and fissures.[3]

Although clinical trials and review studies do not support air abrasion as a standalone "standard technique," the available evidence suggests that it can be safely used as an adjunctive tool, particularly for minimally invasive cavity preparation, conservative management of pit and fissure lesions, and surface conditioning prior to restorative procedures.[1]

RESIN INFILTRATION

Resin infiltration is a minimally invasive approach developed to bridge the gap between lesion-monitoring and restorative intervention in the management of non-cavitated proximal and smooth surface lesions in both primary and permanent teeth. This technique is based on the penetration of low-viscosity, triethylene glycol dimethacrylate (TEGDMA)-based resin infiltrants into demineralized enamel, where polymerization leads to the occlusion of intercrystalline spaces. As a result, a barrier against hydrogen ion diffusion is formed, diffusion pathways are blocked, and lesion progression is arrested. The principle can be compared with the saturation of a sugar cube or sponge with a liquid.[4]

Meta-analyses evaluating the effectiveness of resin infiltration in non-cavitated proximal lesions have demonstrated that the technique is effective in permanent teeth when lesions involve enamel and the outer third of dentin.[5] In permanent teeth, the risk of caries progression in infiltrated lesions was reported to be 4-14% over a three-year follow-up, compared with 42-48% in control groups; at seven years, these rates increased to 9% and 45%, respectively.[6] Although early meta-analyses regarding primary teeth failed to reach definitive conclusions due to study heterogeneity, RI exhibits low mechanical strength, high polymerization shrinkage, and low wear resistance, and its low viscosity limits its ability to fill cavities.[5,6] To overcome these limitations, micro-filled infiltrant resins (MFIRs) have been developed by incorporating glass and organic fillers into RI formulations. The addition of fillers has been shown to improve mechanical properties such as flexural strength and elastic modulus, while also reducing polymerization shrinkage and water sorption.[7,8]

In occlusal carious lesions, the use of resin infiltrants alone is not recommended due to their poor mechanical properties.[7,8] In contrast, combining RIs with pit and fissure sealants has been shown to partially overcome limitations associated with conventional sealants in carious occlusal fissures, such as reduced retention, insufficient penetration, and microleakage, thereby representing an effective minimally invasive treatment option. In addition, the incorporation of antimicrobial agents into RIs has been reported to enhance their caries-arresting efficacy by facilitating the elimination of bacteria trapped within deeper portions of the lesions.[9]

Opaque white lesions emerge as a result of porosities linked to enamel demineralization or developmental enamel defects and are associated with negative psychosocial effects, including loss of self-esteem in children, particularly in the anterior region.[9] The primary goal in the management of white spot lesions (WSLs) is the reversal of demineralization and the improvement of aesthetics; for this purpose, methods such as fluoride-containing agents, followed by microabrasion and bleaching, may be applied. However, the masking efficacy of these techniques is limited and inconsistent.[10] Resin infiltrants penetrate the intercrystalline spaces of porous enamel, bringing the refractive index closer to that of sound enamel, thereby providing rapid and marked aesthetic improvement.[10] Meta-analyses confirm that RI provides faster and higher levels of optical improvement compared to fluoride varnish, and offers more durable aesthetic results when compared to microabrasion.[8,9]

The European Academy of Paediatric Dentistry (EAPD) recommends RI as a viable treatment option for

MIH-affected incisors, potentially combined with microabrasion, bleaching, or composite resin restorations depending on lesion severity.[10,11]

The primary limitations of resin infiltration (RI) can be summarized as the difficulty in radiographically monitoring lesion margins post-infiltration due to the lack of radiopacity in the infiltrant, limited penetration depth particularly in sclerotic lesions or those extending into dentin, and the associated risk of partial infiltration. The requirement for high-level moisture control and careful isolation, as well as the potential for saliva contamination to negatively affect resin penetration and polymerization, represent other significant limitations. Furthermore, as RI does not eliminate the underlying caries risk, it should be planned in conjunction with non-invasive approaches such as dietary modifications, remineralization therapies, and effective plaque control.[4,7,10,12] Despite promising clinical results, systematic reviews emphasize that current evidence remains insufficient to strongly endorse the RI technique; however, this is attributed to the scarcity of high-quality, long-term clinical studies rather than a lack of efficacy in the method itself.[10,13]

SONIC AND ULTRASONIC APPROACHES

Within the framework of minimally invasive caries management, sonic and ultrasonic approaches represent conservative alternatives to rotary instrumentation, enabling selective caries removal while preserving sound dental tissues. These techniques support minimally invasive cavity preparation principles by allowing controlled dentin removal with reduced mechanical trauma.[14]

SONIC SYSTEMS

Sonic systems are air-driven oscillatory devices operating at approximately 5-6 kHz. The elliptic oscillations generated by diamond-coated tips allow minimally invasive slot-type cavity preparations, particularly on proximal surfaces, while reducing the risk of iatrogenic damage to adjacent teeth.[16] However, limited cutting efficiency in harder dentin may prolong treatment time; therefore, the clinical use of sonic systems should be guided by lesion characteristics, including hardness, depth, and location.[14]

ULTRASONIC SYSTEMS

Ultrasonic systems are tissue-preserving approaches that operate via a piezoelectric mechanism and generate vibrations typically within the 20-40 kHz range, enabling selective removal of caries-infected dentin. Linear oscillations of diamond-coated tips allow controlled dentin removal without conventional mechanical cutting.[15]

Ultrasonic preparation has been associated with reduced noise, vibration, pressure, and heat generation, thereby improving patient comfort and, in certain cases, reducing the need for local anesthesia, particularly in pediatric patients.[14] Lower frequencies are considered more suitable for the removal of softer carious dentin, whereas higher frequencies may enhance cutting efficiency in harder dentin.[15]

Although smear layer formation may occur, dentin surfaces prepared using ultrasonic systems have demonstrated clinically acceptable bonding performance with contemporary adhesive protocols and offer particular advantages for precise caries removal in narrow pits and fissures.[16]

LASER

Laser applications in minimally invasive dentistry are primarily emphasized in three main areas: (i) assisting in early diagnosis and lesion monitoring, (ii) increasing the resistance of enamel tissue against acid demineralization and potential synergy with fluoride applications, and (iii) improving patient comfort during cavity preparation and/or the removal of carious tissue.[17] To briefly summarize the areas of use for lasers (Table 1).

TABLE 1: Clinical applications of lasers in caries management

Laser application	Irradiation effects	CO_2 laser	Diode laser	Er,Cr:YSGG laser	Er:YAG laser	Nd:YAG laser
Caries diagnose	Detection of dental caries		✓			
Caries prevention	• Modification of dental hard tissues • Enhancement of acid resistance • Increased fluoride uptake					
Caries treatment	• Removal of carious lesions • Cavity preparation • Enhancement of adhesion	✓		✓	✓	

Er,Cr:YSGG, erbium, chromium-doped yttrium scandium gallium garnet; Er:YAG, erbium-doped yttrium aluminum garnet; Nd:YAG, neodymium-doped yttrium aluminum garnet

LASERS IN THE DIAGNOSIS OF DENTAL CARIES

The basis of laser caries diagnosis approaches involves measuring the optical response of the tissue to light directed onto the tooth surface and interpreting the signal changes associated with caries. DIAGNOdent and DIAGNOdent-Pen, which are frequently used among laser fluorescence systems, utilize laser light at a red wavelength of approximately 655 nm to stimulate fluorescence in carious tissues. It is stated that, since the fluorescence signal originating from porphyrin-like structures associated with bacterial metabolic products can increase in caries lesions, the signal intensity -which is low in sound tissue- may be related to the presence or severity of the lesion. However, the fact that conditions such as the presence of restorations, secondary caries, plaque, calculus, and surface staining can affect measurements is among the significant limitations of the method. Therefore, it is recommended that laser fluorescence be positioned not as a primary diagnostic tool, but as a complementary adjunct supporting conventional examination.[18]

In addition to fluorescence-based systems, optical imaging techniques based on near-infrared light transillumination (NILT) have been introduced for caries detection. Using a camera-based system (DIAGNOcam) operating at a wavelength of approximately 780 nm, crack lines, occlusal marginal discrepancies or defects, and areas of early proximal demineralization can be detected with relative ease, particularly in proximal regions where visual inspection is limited.[17]

Evidence from comparative studies indicates that diagnostic performance varies according to lesion depth and surface. ICDAS has demonstrated high diagnostic accuracy and reproducibility, while fluorescence-based systems are more useful for non-cavitated lesions. DIAGNOdent Pen has shown good performance in detecting deeper non-cavitated and residual dentinal caries, although it may overestimate caries in certain clinical situations.[19,20]

LASERS IN THE PREVENTION OF DENTAL CARIES

Evidence from systematic reviews and meta-analyses indicates that laser applications for caries prevention have been evaluated in various clinical scenarios, including newly erupted first permanent molars, pits and fissures, restoration margins, and enamel adjacent to orthodontic brackets. Overall, meta-analysis findings support the demineralization-reducing effect of CO_2 lasers, while emphasizing that clinical outcomes are highly dependent on application parameters and the sequence of adjunctive fluoride use.[21]

The long-term clinical success of fissure sealants depends on reliable adhesion at the enamel-resin interface and sustained retention, with one-year retention rates reported to range between approximately 70% and 90%.[22] In a clinical study by Durmuş et al., enamel surface preparation using Er: YAG laser followed by acid etching resulted in significantly higher fissure sealant retention at 12 and 18 months compared with acid etching alone, although no significant difference was observed in caries incidence between groups.[23] Systematic reviews and meta-analyses of randomized clinical trials indicate that laser application alone does not provide a clear advantage over conventional acid etching in terms of sealant retention; however, adjunctive laser use in combination with acid etching may enhance retention, albeit based on evidence with a high risk of bias.[21]

LASER-ASSISTED REMOVAL OF CARIOUS TISSUE

Laser-assisted caries removal is based on the absorption of laser energy by water molecules within dental tissues, leading to rapid vaporization and micro-explosive ablation of the substrate, enabling selective ablation of carious dentin. Due to the risk of excessive thermal effects associated with CO_2 and Nd:YAG lasers, Er:YAG lasers (2940 nm) are more commonly preferred in pediatric dentistry, as they allow effective caries removal with minimal damage to sound tissues.[17]

Evidence from meta-analyses indicates that Er:YAG laser use significantly reduces pain perception compared with conventional rotary instruments, thereby improving patient comfort.[17] In line with these findings, Eren et al. reported lower pain scores and improved behavioral cooperation in children treated with laser-assisted cavity preparation.[24] Clinical studies have also demonstrated a marked reduction in the need for local anesthesia when Er:YAG lasers are used.[25]

Overall, laser-assisted caries removal offers a minimally invasive approach that preserves sound tooth structure, reduces pain perception, and enhances patient cooperation. However, its clinical application necessitates careful case selection, adequate training, and strict safety measures, given limitations such as prolonged treatment time in deep lesions, technical challenges in posterior regions, high equipment costs, and potential risks related to aerosol generation and ocular exposure.[17]

OZONE

Ozone (O_3) is a triatomic oxygen molecule with strong oxidative capacity and broad-spectrum antimicrobial activity and has gained increasing attention as a biologically based adjunct in minimally invasive caries management.[26] While traditional caries treatment relied on restorative interventions, contemporary minimal intervention dentistry emphasizes preservation of sound tooth structure and biologically driven repair processes, within which ozone therapy has emerged as a supportive approach.

Ozone may be applied as ozonated water, ozonated oils, or ozone gas. Its antimicrobial effect is mediated by oxidative damage to microbial cell membranes, leading to rapid inactivation of cariogenic microorganisms and reduction of biofilm load.[27] Host tissues show relative resistance to oxidative stress due to endogenous antioxidant defense mechanisms, supporting the biocompatibility of ozone.

Beyond its antimicrobial action, ozone has been reported to facilitate remineralization by promoting mineral diffusion into demineralized enamel and dentin. Clinical studies have demonstrated reductions in dentinal hypersensitivity and pain following ozone application, particularly in deep or nearly exposed carious lesions.[28] When combined with remineralizing agents, ozone may exert synergistic effects, enhancing resistance to demineralization and supporting lesion stabilization.[29] Overall, current evidence supports ozone therapy as a biologically driven adjunct within individualized, multimodal caries management rather than as a standalone treatment.[26,27]

SILVER DIAMINE FLUORIDE (SDF)

Silver Diamine Fluoride (SDF) is regarded as one of the most important agents developed for caries management within the field of minimally invasive dentistry.[12] This topical agent combines the antimicrobial properties of silver with the remineralizing effects of fluoride, providing a dual-action mechanism for arresting and preventing caries progression.[30]

SDF exerts its antimicrobial effect through the formation of silver-protein complexes that inhibit bacterial activity, while fluoride ions promote remineralization of enamel and dentin tissues.[31] Numerous clinical studies have confirmed the effectiveness of SDF in arresting caries progression, demonstrating caries arrest in approximately 80% of treated lesions.[32,33] These characteristics render SDF particularly valuable for young children and individuals with limited access to oral health care services.[34]

In 2021, the World Health Organization (WHO) included SDF in its list of essential medicines, together with clinical guidelines recommending the use of a 38% SDF solution.[35] Approximately 62% of SDF consists of water, and it is an alkaline solution with a pH range of 10-13, containing 44-800 ppm fluoride.[35] In the oral environment, metallic silver releases silver ions, which exert antimicrobial activity through disruption of bacterial cell wall structure, denaturation of cytoplasmic enzymes, and inhibition of microbial DNA replication.[36]

The clinical advantages of SDF include its noninvasive and painless application, high effectiveness in arresting and preventing caries, cost-effectiveness, and suitability for community-based oral health programs, as well as its ease of use in children with special health care needs or limited cooperation.[30,31,37] Nevertheless, the most frequently reported limitation of SDF is the black discoloration of carious lesions, which is particularly problematic in anterior teeth where esthetics are a primary concern. In addition, the need for repeated applications to maintain long-term effectiveness may affect patient compliance, and potential adverse effects such as soft tissue irritation and contraindications including silver allergy should be carefully considered.[30]

Current evidence indicates that, although SDF demonstrates high effectiveness in arresting dental caries, there is a need to strengthen standardized clinical protocols and practice-oriented training in order to increase its widespread adoption in routine clinical practice.[38] The use of SDF has been increasing worldwide, particularly within school-based programs and community-oriented oral health initiatives. Evidence demonstrating its long-term effectiveness when combined with periodic reapplications suggests that SDF may serve as an important public health tool for reducing the burden of untreated dental caries.[37]

SILVER MODIFIED ATRAUMATIC RESTORATIVE TREATMENT (SMART)

The integration of silver diamine fluoride (SDF) with atraumatic restorative treatment (ART) techniques has led to the development of Silver Modified Atraumatic Restorative Treatment (SMART), which is regarded as an important advancement in the management of dental caries within the framework of minimal intervention dentistry.[39] This approach combines the cariostatic and remineralizing effects of SDF with the biocompatible and non-invasive restorative properties of glass ionomer cements (GIC), thereby offering an effective treatment alternative, particularly for patients with limited cooperation.[39] In the SMART technique, the carious lesion is conservatively excavated, SDF is applied, and the cavity is subsequently restored with a GIC.[40] This combination has been reported to be advantageous for arresting deep cavitated carious lesions, preserving tooth function, and maintaining pulpal health.[40]

The primary objective of SMART is to arrest caries progression without additional loss of tooth structure, suppress bacterial activity, and restore the lesion functionally.[39] Key clinical advantages of this approach include preservation of pulpal vitality through minimal caries removal, control of residual carious tissue via the antimicrobial and remineralizing effects of SDF, and effective sealing achieved with GIC restorations.[39-41] Moreover, SMART represents a painless and patient-friendly procedure, and no serious adverse effects have been reported in clinical studies.[41]

Although SDF can biologically arrest caries, it does not restore lost tooth structure, and open cavitated lesions may remain susceptible to plaque accumulation.[41] Therefore, restoration following SDF application is recommended, particularly in cavitated lesions extending into dentin.[39]

In vitro studies have demonstrated that remineralization can occur in dentin lesions restored with GIC following SDF application.[42,43] Clinical studies have shown that, in the short to medium term, the restorative success of SMART is comparable to that of ART or conventional GIC restorations, while SMART offers superior outcomes in terms of patient behavior, treatment tolerance, and pain perception.[40,44] In teeth affected by molar-incisor hypomineralization (MIH) and other hypomineralized molars, SMART has been reported to provide similar or more favorable results regarding hypersensitivity control and prevention of caries progression.[45] Although long-term follow-up studies have demonstrated that SMART protocols can achieve effective caries control for up to 36 months, systematic reviews and meta-analyses emphasize the need for well-designed clinical studies with standardized protocols to clearly establish long-term clinical effectiveness.[41,44]

The principal limitation of SMART is SDF-related esthetic discoloration, which may restrict esthetic acceptance, particularly in anterior teeth.[39] This limitation should be carefully considered during case selection and treatment planning, especially when esthetic demands are high.

PIT AND FISSURE SEALANTS

Occlusal surfaces of permanent molars represent the most vulnerable sites for caries development in children and adolescents. Epidemiological studies consistently show that the majority of new carious lesions occur in pits and fissures rather than on smooth surfaces, primarily because their complex anatomy provides sheltered niches for plaque retention, limits self-cleaning by saliva, and reduces the effectiveness of toothbrushing. Preventing occlusal caries is therefore a critical priority in pediatric dentistry, and pit and fissure sealants have been established as one of the most effective evidence-based measures.[46]

Cochrane systematic reviews have consistently demonstrated that sealants effectively prevent occlusal caries in permanent molars and provide superior caries-preventive effects compared with fluoride varnishes applied to occlusal surfaces.[47] These findings underscore the pivotal role of sealants in contemporary preventive strategies.

Sealants act by creating a micromechanical barrier that isolates pits and fissures from the oral environment, preventing microbial colonization and fermentation of dietary carbohydrates. By transforming a retentive, plaque-prone surface into one that is smooth and easily cleansable, sealants disrupt the ecological niche necessary for lesion initiation. In addition, many sealant materials -particularly glass ionomer-based formulations- release fluoride, further enhancing their protective effect.[46]

Resin-based sealants remain the gold standard, with strong clinical evidence supporting their superior retention rates and long-term caries-preventive benefits. These materials require adequate isolation to achieve proper adhesion, making rubber dam or careful cotton-roll isolation crucial during application. When optimal moisture control cannot be achieved, as in newly erupted molars with partially covered occlusal surfaces, glass ionomer sealants provide a practical alternative. Although less durable, they release fluoride and can serve as an interim protective measure until resin placement becomes feasible.[46]

The AAPD strongly advocates the placement of resin-based sealants on permanent molars in children and adolescents at risk for caries, ideally as soon as the tooth is fully erupted and moisture control can be achieved.[46] The EAPD similarly recommends sealants for high-risk children, noting that their use is justified even on sound occlusal surfaces when risk is elevated.[48] The IAPD further emphasizes the role of sealants as a cost-effective preventive strategy that should be incorporated into both individual clinical care and community-based programs, particularly in populations with high caries prevalence.[49]

Overall, pit and fissure sealants constitute a safe, minimally invasive, and highly effective adjunct to fluoride-based prevention and remain a cornerstone of contemporary pediatric caries management.

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