Review Article

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# Pit and Fissure Sealants in Caries Prevention: Materials, Techniques, and Evidence-Based Outcomes

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## ABSTRACT

Dental caries is among the most common chronic diseases in the world that is disproportionately present in the occlusal surfaces of the posterior teeth with complex morphology of pits and fissures where there is the presence of biofilm and conducive demineralization by acid. Pit and fissure sealants are one of the prevention measures that serve as a strategy due to their ability to cause a barrier between the exposed tooth surface and the oral environment, and hence the prevention of bacterial colonization and consequent carious lesions. This narrative review focuses on the current evidence on the topic of pit and fissure sealants, including the history of sealant materials, the mechanisms of their application, their retention, their caries-preventive effectiveness, and their cost-effectiveness. The review combines the results of clinical trials, systematic reviews, meta-analyses that were carried out during a number of decades to present an all-encompassing evaluation of the purpose of sealants in modern preventive dentistry. Some of the key themes covered are comparative efficacy of resin-based and glass ionomer sealants, effects of isolation and surface preparation methods on the retention of sealants, the use of sealants over incipient carious lesions and new bioactive materials. The literature is consistently in favor of the efficacy of pit and fissure sealants in preventing the occlusal caries by 60 to 90 percent when properly retained, and best results are noticed in the high risk groups. Nevertheless, there are some gaps in terms of long-term follow up data, the best choice of material to use in different clinical settings, and what should be done to enhance sealant programs in underserved communities. The review shows that the application of sealants must be incorporated into an overall plan of managing caries and also provides an insight into the future opportunities in material science and policy development.

## Introduction

Dental caries is a biofilm-based disease that is multi-factorial in nature and consists of gradual demineralization of the hard tissues of the tooth due to the metabolic activity of the acidogenic microorganisms in the tooth plaque ecosystem [1]. Although there has been great progress in the oral health sector, caries has been the leading chronic disease in the world, having an estimated 2.4 billion with untreated lesions in permanent teeth and 621 million affected children with diseased primary teeth [2]. Pre-occlusions of premolars and molars are especially susceptible as they constitute about 8090 percent of all caries in permanent dentition in children and adolescents [3]. This weakness can be explained by the

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fact that pits and fissures have a complex shape as it offers a sheltered habitat of bacteria that would otherwise be inaccessible to the standard procedures of oral hygiene and the protective value of salivary clearance and exposure to fluoride [4].

The theory of sealing pits and fissures to prevent caries was initially suggested by Hyatt in 1923 using the term prophylactic odontotomy (although the contemporary era of sealant application dates back to Buonocores seminal work on acid etching of enamel in 1955 followed by subsequent work by Cueto and Buonocore on the development of the first resin-based sealant in 1967 [5,6]. Ever since, pit and fissure sealants have been among the best-established and evidence-based preventive interventions in the dentistry field, recommended by multiple professional bodies such as American Dental Association (ADA), American Academy of Pediatric Dentistry (AAPD) and the World Health Organization (WHO) [7,8].

Although there is strong evidence that is in support of their effectiveness, the use of sealants is still less than optimum especially in populations with highest risk of being affected by dental caries. According to national surveys in the United States, a small proportion of children aged 6 11 years old of about 42 per cent have sealants on their permanent molars with high socioeconomic and racial variations in access [9]. There are still controversies over the best sealant material, need and nature of surface pretreatment, suitability of sealing over existing early carious lesions, and cost-effectiveness of sealant programs in the long-term [10].

This narrative review aims to critically evaluate the existing literature on pit and fissure sealants, which include material science, clinical pro cedure, caries-preventive effects, and health consequences in the community. In particular, this review will attempt to: (1) compare the properties and clinical performance of the available sealant materials; (2) determine the impact of the application techniques on retention and clinical performance; (3) review the evidence on sealing incipient carious lesions; (4) discuss the cost-effectiveness and implementation issues; and (5) provide the emerging materials and future research directions.

## Pit and fissure Susceptibility Morphological Basis.

The anatomical structure of the occlusal pits and fissure is the main factor of the susceptibility to caries on those surfaces. Nagano defines five different fissure morphologies, including V-shaped, U-shaped, I-shaped, IK shaped and inverted Y shaped where narrow, deep fissures (I and IK types) are especially prone to caries, as they cannot be efficiency cleansed with a toothbrush and their penetration is not easily hindered by fluoride and salivary buffers [11]. Histological examination has confirmed that fissure depths may extend to 1.0 1.5 mm with base widths as small as 0.1 mm which is too small to fit even an individual toothbrush bristle [4].

Also, enamel that coats the fissure walls is in most cases, less mineralized, thinner and more uneven, compared to those in smooth surfaces, making them more vulnerable to acid dissolution [12]. The ecology of fissures is conducive to the growth of aciduric and acidogenic species, especially Streptococcus mutans and Lactobacillus type of species that inhibit the caries process via the production of acid [1]. All these morphological and microbiological attributes collectively support the specific usage of sealants as a specific preventative tool on the surface.

## Sealant Materials: Typology and Characteristics

The sealant materials that have become most common and are extensively studied are the resin-based sealants (RBS). They are mainly made up of bisphenol A-glycidyl methacrylate (Bis-GMA) or urethane dimethacrylate (UDMA) monomers which harden when activated to form a strong coating on the prepared enamel surface [13]. Recent RBS are proposed in both autopolymerizing (self-curing), and photopolymerizing (light-curing) versions, the latter being more desirable because of better working time regulation and better adjustment [14].

RBS can also be categorized as either filled or unfilled and filled sealants have much higher resistance to wear but slightly less fissure penetration because of increased viscosity [15]. It has been examined whether the incorporation of fluoride into certain resin-based systems can improve their caries-preventive capabilities, although the data regarding the presence of fluoride-releasing action of these materials is not extensive [16,17].

The main benefit of resin-based sealants is their great retention that has been regularly associated with caries-preventive effectiveness.

## Glass Ionomer Sealants

Glass ionomer cement (GIC) sealants, such as the traditional and resin-modified glass ionomer (RMGIC) types are a significant substitute to resin-based materials. GIC sealants have the benefits of chemical bonding to enamel, prolonged fluoride release and recharge capacity, ability to be used with moisture and being biocompatible [18]. The characteristics of these sealants render them especially useful in fieldwork as well as in patients where sufficient moisture management is unable to be attained like partially erupted molars of young children [19,20].

Ironically, although they have less retention, some studies have reported that even when the material has been lost clinically, the caries-preventive effect of GIC sealants may still be maintained, perhaps because of lingering material of fluoride-enriched substance within the fissure crevices and the shielding effect of fluoride ions on adjacent enamel [21,22]. The meta-analysis provided by Mickenautsch and Yengopal (2011) did not allow concluding that there was statistically significant difference between the caries-preventive effectiveness of GIC and RBS sealants, which refutes the hypothesis that the caries-preventive effectiveness is solely determined by macroscopic retention [23].

## Emerging and Bioactive Materials

The latest developments in the field of material science have presented new sealant formulations that have a superior bioactive quality. They are amorphous calcium phosphate (ACP)-containing sealants, bioactive glass particles, and antimicrobial agents that encompass quaternary ammonium compounds and chlorhexidine [24-26]. The justification behind these innovations is to develop sealants which not only act as passive physical barriers but also have active effects of encouraging remineralization and discouraging bacteria proliferation. Nevertheless, the clinical validation of these new materials is still in its early phase and no long term performance in vivo has been established yet.

# Application Techniques and How they affect Retention.

## Isolation and Moisture Control.

Sufficient moisture regulation at the time of sealant application has been universally known to be the most critical influence on retention and, hence, clinical effectiveness [27]. Salivary pollution of the acid-etched enamel surface impairs the development of resin tags in the demineralized enamel prisms, which leads to lower bonding strength and early loss of sealants [14]. The most effective way to control moisture is with the use of rubber dam isolation but its application in pediatrics and community-based care might be difficult. Continuous suction and cotton roll isolation is another alternative that is practical and mostly used.

## Surface Preparation

The traditional method of applying resin-based sealants is by conditioning enamel using 37 percent phosphoric acid in 15 to 30 seconds which forms a microretentive pattern that the sealant substance mechanically interlocks [6]. Other and adjunctive ways of preparing have been studied, such as mechanical preparation using air abrasion or bur enameloplasty, or even using self-etching adhesive systems.

A review of the findings on the different pretreatment modalities by Feigal and Donly (2006) found that though air abrasion and minimal enameloplasty may offer a slight advantage in terms of the sealant retention when compared to conventional acid etching alone, the added value relative to the added cost and armamentarium is insignificant [28,29]. The implementation of bonding agents which work as intermediate in the connections of etched enamel and the sealant material has demonstrated success in enhancing retention especially in unfavorable circumstances.

## Technique Sensitivity and Operator Factors

Application of sealants is a technique sensitive procedure though it is conceptually simple. It has been found that retention rates among various operators and different clinical environments can differ considerably, which explains the significance of training, standardization, and quality assurance [30]. Evidence on school-based sealant programs has demonstrated that dental hygienists and expanded function dental auxiliaries can yield the same retention rates as the dentist, and as a result of delegating sealant placement, it is suggested that certain schools should delegate it as a strategy to enhance access [31-34]

## Seal of Over Incipient Carious Lesions

The application of sealants over carious lesions that are not caved or non-cavitated at the early ages is one of the highly controversial issues in ealant therapy. Historical issues were focused on the fear of entrapment of viable bacteria under and behind the material, which might enable the development of caries to continue without being detected. Nonetheless, there is a significant amount of evidence that underlies the practice of therapeutic or even preventive resin restorations over incipient lesions.

Existing evidence-based practice recommendations by the ADA and the AAPD support the use of sealants in the position of the non-cavitated caries lesion, and the position of sealants should be evaluated periodically to maintain intactness [7,8]. Such a direction is consistent with the general shift in paradigm to minimally invasive dentistry, where biological treatment is prioritized over surgical one.

## Economic and Health-Related factors

The cost-effectiveness of pit and fissure sealant program has been widely tested especially with regard to school-based and community-based preventive programs on high-risk groups. Weintraub (2001) summarized the economic data and concluded that the sealant applied to permanent first molars of high-risk children saved money compared to the expense of the restorative treatment provided later [35,36].

High-quality evidence of effectiveness in the prevention of dental caries, especially among low-income families children who may otherwise not have access to regular preventive dental care, has led the Community Preventive Services Task Force of the United States to recommend school-based sealant delivery programs [37]. Notwithstanding these suggestions, the barriers to implementation still exist, such as staffing issues, the lack of financing, the lack of parental consent, and regulatory limitations on dental auxiliary scope of practice [9].

## Discussion

The evidence surveyed in this article has solidly defined pit and fissure sealants as one of the best and most supported interventions in preventive dentistry. The mechanism of protection, which is based on the physical isolation of the vulnerable fissure anatomy in relation to the oral environment, is conceptually simple, and the clinical data shows consistent significant decreases in incidences of occlusal caries in sealed teeth [17].

A number of relevant themes come to mind in this review. To start with the discussion of resin-based versus glass ionomer sealants, the idea of sealants is more intricate than the data of retention would have indicated. Although it is evident that RBS exhibit a better level of macroscopic retention, the supposed parity in caries-preventative between GIC sealants in some studies indicates that the fluoride release and retention of the microscopic materials in fissures are significant in protection [23]. Clinical implications of this discovery are extremely important, especially in areas where moisture control cannot be effectively established, e.g., partially erupted teeth or in field-based programs in low-resource areas [19].

Second, the sealant placement evidence in comparison to the non-cavitated carious lesions is a significant development in clinical practice. The fact that sealing can be effectively used to arrest early lesions by starving the underlying biofilm with substrates is consistent with modern concepts of least invasive caries treatment, as well as biologic disease control [33,34]. Nevertheless, this measure requires effective monitoring equipment to identify sealant failure and possible lesion development that may be very difficult in the community where residents lack access to follow-up dental services.

Third, there are still major gaps in the literature. There are few long-term data, more than 5 years and 10 years old, available, and the high attrition rate and heterogeneity of methods makes most studies difficult to synthesize using meta-analytic methods [17]. Very little is known about the performance of emerging bioactive sealant materials in clinical environments since much of the evidence is based on in vitro and short term in vivo investigations [26]. Moreover, although cost-effectiveness was proved on the population level, individual-level cost-benefit analysis is critically dependent on baseline caries risk that requires proper risk assessment instruments still to be standardized on the universal scale [10].

Another area that needs to be addressed is that of incorporation of sealant therapy into a wider caries management system like Caries Management by Risk Assessment (CAMBRA). Sealants are not to be perceived as solitary measures but as a part of a multimodal preventive approach which involves exposure to fluoride, dietary education, biofilm control, and frequent professional follow-up [38]. Such an approach could be one reason why sealants have not been fully used even with strong evidence of their usefulness.

Lastly, the considerations of equity are the most important. The groups who are most likely to gain benefits of sealant programs, namely, children in low-income families, racial and ethnic minorities, and those residing in underserved communities are the least likely to have the programs [9,37]. To resolve this gap, it is necessary to take some policy-based measures, legislation about dental auxiliaries scope of practice expansion, new models of service delivery, including the use of teledentistry, and long-term funding of health policies.

## Conclusion

The two most prevalent diseases in the oral cavity are dental caries and periodontal disease having a common etiological factor, dental plaque. [39] Dental caries development is considered to involve a triad of indispensable factors, which can be concluded as bacteria in dental plaque, carbohydrates in diet and susceptible teeth. [40,41] Early stages of dental caries are reversible and can be modified or eliminated by protective factors such as fluoride exposure. [42] Endodontic therapy is a common dental technique used to repair teeth whose pulp tissues have become permanently irritated or decaying as a result of caries. By utilizing biocompatible materials such as living cells, hydrogels, and growth factors, 3D bioprinting has the potential to create functional, biologically integrated constructs that can mimic the natural architecture 3d-printed scaffolds in GTR exhibited superior clinical and radiographic outcomes compared to conventional GTR alone in the treatment of Combined endo-perio lesions. [43-45] Prevalence of dental caries as the primary reason for primary tooth extraction in Indian children. Gender-specific differences were observed in extraction reasons, and maxillary teeth were more frequently extracted than mandibular teeth. The significant difference observed in immediate postoperative discomfort following pulpotomy highlights the importance of considering the specific nature of procedures in managing postoperative pain. [46,47] Body mass index (BMI) helps assess nutritional status. The association between body mass index (BMI) and dental caries has been widely studied, but its relationship with caries activity remains unclear. With changing lifestyles, rising obesity, and dietary shifts, both high BMI and dental caries are increasing concerns in children. BMI is also associated with recurrent apthous ulcer. [48,49] Orthodontic treatment is a widely embraced intervention aimed at enhancing dental aesthetics and

correcting malocclusions among adolescents. However, concerns persist regarding its potential impact
on oral health, particularly on the development of dental caries. Orthodontic treatment can alter the oral environment, leading to plaque accumulation and changes in microbial colonization. This study aimed to assess microbiological changes in 10 to 16-year-old children undergoing fixed orthodontic treatment. Resin-based sealants applied on occlusal surfaces of permanent molars are effective for preventing caries in children and adolescents. Corrosion of alloys of orthodontic bracket like nickel increases in the presence of *S. mutans*, which increases the risk of caries. Demineralization around the cemented orthodontic bands can be reduced by using fluoride releasing cements which impairs plaque formation and helps to remineralize enamel [50-55]

Rampant caries has been defined by Massler as "a suddenly appearing, widespread, rapid burrowing type of caries, resulting in early involvement of the pulp and affecting those teeth usually regarded as immune to ordinary decay. [56,57] Silver diamine fluoride and pit and fissure sealant may be successfully used to reduce rampant caries. [58] Combination of retention is stronger in resin-based sealants, whereas, glass ionomer sealants have a good alternative in difficult clinical situations, and both types of material have shown significant caries-preventive advantages. The development in application methods, such as bonding agent and surface preparation, has enhanced clinical results, and the evidence is strongly advanced to support placing the sealants over carious lesions that are non-cavitated as one of the conservative methods of managing these lesions. The positive perception of sealant use for prevention was associated with educational, professional, and technical factors. Social media can play great role in improvement of oral health and reduce caries by spreading awareness of pit and fissure sealants [59] Nanotechnology has unique physical, chemical and biological properties that can be used to overcome the shortcomings of traditional dental treatments. Study showed pit and fissure sealant containing nano-CaF2 and dimethylaminohexadecyl methacrylate with double benefits of fluoride release and antibacterial function and reduce caries incidence. [60,61] Novel bioactive materials can be used in improving the therapeutic capabilities of sealants beyond physical barriers. Nevertheless, there exist notable obstacles to converting the evidence into equitable application at the population level and future studies should work on long-term clinical trials of new materials, risk-based protocols of sealant application, and new models of delivery to serve underserved groups. Finally, sealant therapy must be incorporated in comprehensive, individualized caries management strategies to ensure the greatest possible contribution toward oral health.

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