Pit and Fissure Sealants in Children - Current Concepts and Emerging Innovations: A Narrative Review

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Abstract:
Pit and fissure sealants continue to play a key role in the prevention of dental caries in pediatric dentistry. In recent years, developments in material science—such as the incorporation of nano-fillers, amorphous calcium phosphate (ACP), and bioactive glass—together with refinements in adhesive techniques, advances in diagnostic imaging, and the expansion of school- and community-based preventive programs, have broadened their clinical use and potential benefits. This narrative review brings together current evidence on the clinical performance of sealants, emerging material innovations, and the role of diagnostic adjuncts in caries detection and management. Bioactive and ion-releasing sealants have demonstrated encouraging outcomes in laboratory investigations and short-term clinical studies, particularly with respect to enamel remineralization, reduction of microleakage, and arrest of early carious lesions. Nevertheless, there remains a need for well-designed, long-term randomized controlled trials to confirm the durability of these effects and to guide evidence-based clinical decision-making.

Keywords: Amorphous Calcium Phosphate, Bioactive Glasses, Nano-Hydroxyapatite, Narrative Review, Pediatric Dentistry, Pit and Fissure Sealants.

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INTRODUCTION:

Occlusal surfaces of posterior teeth are disproportionately affected by dental caries due to complex fissure morphology and plaque retention. Pit and fissure sealants create a physical barrier that prevents cariogenic biofilm ingress and have been shown to reduce occlusal caries incidence in children and adolescents when properly applied and maintained. Systematic reviews consistently report that sealants are effective for caries prevention on permanent and primary teeth under appropriate conditions[1,2].

Historically, resin-based sealants (unfilled or filled) have been the standard due to favourable retention and handling. However, concerns such as technique sensitivity, moisture contamination effects, marginal micro leakage, and material biocompatibility (e.g., BPA derivatives) have stimulated research into hydrophilic/resin-modified materials, ion-releasing fillers (ACP, nano-hydroxyapatite), bioactive glass-based formulations, and diagnostic tools to better identify lesions suited for sealing. Concurrently, advances in 3D and digital imaging, and minimally invasive approaches, enable more precise decision-making and patient selection.[3]

This review synthesizes contemporary evidence focused on clinical effectiveness, material innovations (nano- and bioactive approaches), surface conditioning and application strategies,diagnostic adjuncts, safety and regulatory concerns, andpublic-health and economic considerations.

MATERIALS AND METHODS:

This narrative review is based on a focused search of recent, high-quality literature published up to 2025, including systematic reviews, meta-analyses, clinical trials, and relevant in vitro studies related to pit and fissure sealants and associated technologies. Literature was identified through searches of PubMed/PMC, leading dental journals, and recently published systematic reviews. The review primarily concentrates on the clinical effectiveness of sealants, developments involving nano-hydroxyapatite (nHAp), amorphous calcium phosphate (ACP), bioactive glass and other ion-releasing materials, as well as advances in etching techniques such as laser and alternative surface conditioning methods. In addition, emerging diagnostic tools, including three-dimensional imaging, and considerations related to cost-effectiveness were also explored.

RESULTS:

1. Clinical effectiveness and evidence synthesis

Multiple systematic reviews and meta-analyses have reinforced the effectiveness of pit and fissure sealants in preventing occlusal caries in permanent teeth and, to a lesser extent, primary teeth; outcomes are strongly influenced by retention and follow-up duration. Systematic reviews through 2024 support sealant use as a non-inferior and often superior intervention compared with no treatment or fluoride varnish for occlusal caries prevention in school-aged children[1].

Comparative effectiveness between different sealant formulations (filled vs unfilled, hydrophobic vs hydrophilic) shows variable retention patterns; hydrophilic materials may offer advantages in less ideal isolation, while hydrophobic resins can offer better long-term retention in well-isolated conditions. A contemporary 2025 meta-analysis discussed these trade-offs and categorized sealants by retention and moisture-tolerance[4].

2. Nano-hydroxyapatite (nHAp)

nHAp has been extensively reviewed for remineralization potential in dentifrices and restorative materials. In vitro and in situ studies show nHAp can promote remineralization of early enamel lesions and increase surface microhardness. When incorporated into sealant formulations, nHAp and nACP improve mineral delivery to adjacent enamel and may reduce demineralization underneath sealants. These findings are supported by multiple scoping and systematic reviews on nHAp and by targeted in-vitro sealant studies[5].

3. Amorphous Calcium Phosphate (ACP) – ion-releasing sealants

ACP-containing sealants have been shown in laboratory studies and some clinical trials to release calcium and phosphate ions, aiding in remineralization and limiting subsurface demineralization adjacent to sealants. A number of controlled in-vitro studies and at least one clinical retention trial (trial registries and smaller RCTs) support ACP sealants' potential to protect enamel; however, the strength of long-term clinical evidence remains moderate and larger RCTs are warranted[6].

4. Bioactive glass and other bioactive materials

Bioactive glass (fluoride-containing 45S5 derivatives and others) incorporated into low-viscosity resins or as separate glaze materials has demonstrated ion-release, enamel protective effects, and potential to occlude micro-gaps at the tooth–material interface. Recent in-vitro and a few clinical evaluations indicate enhanced protective effects comparedwith conventional sealants; broader RCT evidence is emerging[7].

5. Antimicrobial additives (silver nanoparticles, chlorhexidine, etc.)

Antimicrobial-loaded sealants (e.g., silver nanoparticles) have shown in vitro reductions in cariogenic bacteria; clinical data are limited but suggest potential benefit in high-risk populations. The long-term effect on bacterial ecology, resistance, and staining needs careful assessment[8].

6. Surface conditioning and alternative etching (laser etching)

Er,Cr:YSGG and other laser etching techniques have shown comparable or improved marginal adaptation and microleakage profiles for sealants compared with conventional acid etching in several in-vitro studies, and can be useful in patients where traditional isolation is difficult. Clinical adoption is limited by equipment cost and training requirements; more clinical outcome data are needed[9].

7. Diagnostic adjuncts and digital imaging

3D scanned imaging and other optical/digital caries detection systems (including near-infrared transillumination and quantitative light-induced fluorescence) improve detection of early occlusal lesions and help clinicians avoid sealing over cavitated or established lesions. These technologies therefore support evidence-based selection for sealing vs restorative interventions[10].

8. Cost-effectiveness and public health programs

Economic evaluations indicate that sealants are cost-effective relative to untreated caries and often compare favourably to fluoride varnish programs when retention and re-seal strategies are considered. Community sealant programs remain an important component of school-based preventive care[11,12].

DISCUSSION:

Contemporary sealant research is increasingly focused on combining reliable mechanical retention with added therapeutic benefits, such as ion release and antimicrobial activity. The incorporation of nano-fillers, including nano-hydroxyapatite (nHAp) and nano-amorphous calcium phosphate (nACP), as well as bioactive glass formulations, has shifted sealants from being purely passive occlusal barriers to materials that actively interact with the tooth surface. These newer formulations have the potential to promote remineralization of adjacent enamel and may help arrest early carious lesions. However, while in-vitro findings are encouraging, their translation into consistent and sustained clinical caries reduction remains uncertain, underscoring the need for large, well-designed randomized controlled trials with follow-up periods of at least 2–5 years.

Careful case selection remains a critical determinant of long-term success when using pit and fissure sealants. Ideal candidates include sound fissures, particularly in newly erupting first permanent molars in children at increased risk of dental caries. During the eruption phase, these teeth are especially vulnerable due to partial eruption, difficulty in maintaining hygiene, and plaque accumulation, making sealant placement highly beneficial. The use of modern diagnostic adjuncts—such as three-dimensional surface scanning, near-infrared transillumination, and other advanced optical detection techniques—can further support clinical decision-making by allowing more accurate differentiation between non-cavitated early lesions suitable for sealing and lesions that have progressed and require preventive resin restorations or definitive treatment. In situations where moisture control is suboptimal, hydrophilic resin-based sealants and glass ionomer sealants provide practical alternatives. Although their retention may differ from conventional resin sealants, they offer distinct advantages in challenging clinical conditions and may function effectively as interim or, in selected cases, long-term preventive measures based on individual caries risk.

Despite extensive research, the current body of evidence on pit and fissure sealants has several important limitations. Many newer material innovations are supported largely by laboratory studies, with relatively few high-quality clinical trials available to validate their long-term effectiveness in routine practice. There is also marked heterogeneity among existing studies, including differences in outcome measures—such as an emphasis on sealant retention versus true caries prevention—as well as variations in follow-up periods and comparator materials. Moreover, although advanced diagnostic technologies show considerable promise in improving lesion detection and case selection, their uptake in everyday practice remains inconsistent due to factors such as cost, availability, and varying levels of clinician familiarity. Collectively, these issues limit the ability to draw standardized and universally applicable conclusions.

Future research should prioritize robust randomized controlled trials that compare bioactive and nano-enhanced sealants with contemporary resin-based materials over extended follow-up periods, with greater emphasis on clinically meaningful outcomes such as caries reduction rather than retention alone.

In addition, real-world studies conducted within school-based and community programs are needed to evaluate the performance of emerging materials and digital diagnostic tools under practical conditions. Ongoing assessment of biocompatibility and potential environmental implications will also be essential as newer additives and technologies continue to be introduced into clinical practice.

CONCLUSION:

Pit and fissure sealants remain a well-established and evidence-based approach for the prevention of occlusal caries in children, especially among those at higher caries risk. Recent advances in material science have gradually moved sealant development beyond reliance on mechanical retention alone, with increasing emphasis on multifunctional materials that offer additional therapeutic benefits, including ion release, remineralization potential, and antimicrobial properties. These developments are intended not only to improve protection of the enamel surface but also to enhance sealant durability and overall clinical performance. At the same time, improvements in diagnostic technologies—such as refined visual assessment methods, digital imaging, and optical caries-detection systems—have contributed to more accurate identification of early occlusal lesions and better-informed decisions regarding sealant placement. Evidence from public-health assessments and economic evaluations consistently supports the cost-effectiveness of sealant programs, underscoring their importance within community-based preventive dentistry. For pediatric clinicians, keeping pace with evolving material innovations, applying sealants based on appropriate caries-risk assessment, and adhering to sound clinical protocols for placement and follow-up remain critical for optimizing sealant success and achieving sustained caries prevention.

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