BioCoat™

Part 2. Pit-and-Fissure Sealant Incorporating SmartCap™ Technology

Introduction

An estimated 23% of children 2 to 5 years-of-age and 56% of children 6 to 8 years-of-age in the United States have dental caries in their primary dentition.1 Among adolescents 12 to 19 years-of-age and adults 20 to 64 years-of-age in the United States, an estimated 58% and 91%, respectively, have experienced dental caries in their permanent dentition.[1,2] Caries experience for children from age 6 through adolescence is estimated at a worldwide average of 70%.[3] Of significance for pit and fissure sealants, occlusal caries is estimated to represent 44% of all carious lesions in primary molars and 80% to 90% in permanent posterior teeth.[4] Pit-and-fissure sealants help prevent and arrest dental caries by preventing cariogenic bacteria from accessing pits and fissures, and preventing bacteria already present from accessing fermentable carbohydrates and metabolizing these to produce the acid that demineralizes tooth structure as part of the caries process.[4,5] Sealants may also help to lower salivary levels of cariogenic bacteria (mutans streptococci) following placement in caries-free oral environments.[6]

Success rates

Caries reductions of 86%, 78.6% and 58.6% have been observed 1, 2 and 3 years, respectively, following resin-based sealant placement.[5] Sealants were found in one randomized trial to reduce the incidence of occlusal caries in children and adolescents by 76% at 4 years post-placement on sound occlusal surfaces, with reapplication as required.[7] At 9 years, with no further reapplications, a caries reduction of 65% was observed.[7] Caries reductions are also observed when sealants are placed over incipient occlusal caries.[8,9] In one meta-analysis of 6 studies comparing caries progression of incipient (non-cavitated) caries lesions on occlusal surfaces, 2.6% of sealed surfaces progressed (median annual percentage) versus 12.6% of unsealed surfaces.[9] Sealants have also been found to be more effective than fluoride varnishes for caries prevention on occlusal surfaces.[7,10,11] Sealants should be monitored regularly after placement and teeth should be resealed if necessary.

Current recommendations

The American Dental Association and the American Academy of Pediatric Dentistry issued joint recommendations in 2016.[5] These evidence-based recommendations support the use of pit-and-fissure sealants in primary and permanent molars with sound or non-cavitated carious occlusal surfaces in children and adolescents.

Types of materials

Four types of sealant materials were considered, based on the evidence, when the recommendations were formulated. Glass ionomer (GI) and resin-modified glass ionomer (RMGI) sealants contain a mix of fluoroaluminosilicate glass and an aqueous polyacrylic acid solution. RMGIs additionally incorporate resin. GIs and RMGIs set through an acid-base reaction, do not require acid-etching of the enamel, and adhere with formation of a hybrid layer. They are moisture-tolerant, release high levels of fluoride, recharge with fluoride, and offer lower shrinkage on setting and thermal expansion than resin-based sealants (RBS).[12] However, they have a greater risk of loss of retention, offer lower tensile strength, are more soluble and susceptible to desiccation. Compomers contain resin material and are poly-acid modified. They are in effect hybrids between RBS and GI materials, offering some characteristics of both.

RBS contain urethane dimethacrylate (UDMA) or bisphenol A-glycidyl methacrylate (bis-GMA) and fillers, require acid etching of the occlusal surface adjacent to the pit/fissure prior to placement (and depending on the sealant, also bonding), and set through polymerization.[13] They are stronger than GIs and RGMIs, offer greater retention, less expansion associated with water sorption, and have low susceptibility to drying. However, they are not moisture-tolerant, release less or no fluoride and they do not have recharge capability. In addition, polymerization is a potential source of shrinkage, albeit less than for bulkier resin-based materials.

Ideal properties

The success of sealants relies on their long-term durability. An intact seal prevents the ingress of cariogenic bacteria and carbohydrates, microleakage and, subsequently, caries. Therefore, high tensile strength, compressive strength, dimensional stability, wear resistance and lack of solubility in the oral environment are all important physical properties of an ideal pit-and-fissure sealant. Flowability and adaptability must also be optimal for sealant penetration and a lack of voids at the time of placement. The resulting surface should be smooth to help prevent build-up of biofilm on and adjacent to the sealant. Moisture tolerance is also desirable in situations where a dry field is difficult or impossible to achieve – e.g., a GI may be placed for a high caries risk patient while teeth are not yet fully erupted. Ideal biochemical properties of sealants include sustained and controlled release of calcium, fluoride and phosphate to help prevent demineralization and promote remineralization, and the ability to replenish these ions are also desirable. Finally, the sealant must be biocompatible. (Table 1)

Table 1. Ideal physical and biochemical properties of pit-and-fissure sealants

Complete penetration of pits and fissures
Long-duration seal to enamel
Dimensional stability during and after placement
High shear bond strength (tensile strength)
High compressive strength
Wear resistance
Low solubility in presence of oral fluids and low pH
Moisture tolerance
Smooth surface
Sustained release of fluoride, calcium and phosphate ions
Ability to replenish fluoride, calcium and phosphate ions
Biocompatibility

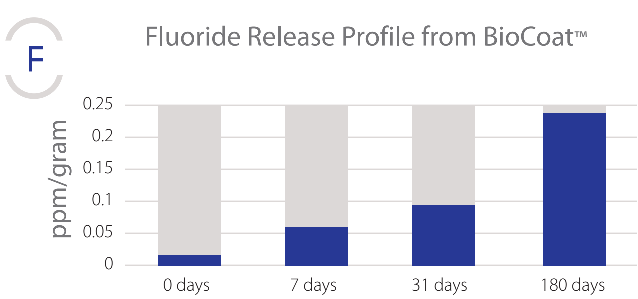
Properties of a novel resin-based sealant containing microcapsules

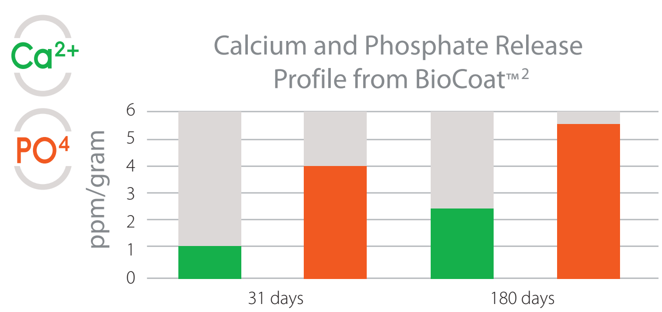
A new RBS, 'BioCoat™ Bioactive Resin Pit and Fissure Sealant,' contains microcapsules developed using SmartCap™ Technology. This technology results in distinct advantages in an RBS, due to incorporation of the microcapsules. Controlled ion release, high enamel fluoride uptake, ion recharge, and high shear bond strength have all been confirmed in laboratory studies on pit-and-fissure sealant formulations containing this novel technology.[14-18]

Ion release

Fluoride, calcium and phosphate ion release from RBS formulations containing microcapsules with aqueous solutions of the respective salts has been demonstrated. In one laboratory study, microcapsules containing an aqueous solution of 1) 0.8 molar sodium fluoride (NaF); 2) 5 molar calcium nitrate (Ca(NO3)2); or, 3) 6 molar potassium phosphate (K2HPO4), were incorporated into commercially available sealants.[19] Significant release of fluoride, calcium and phosphate was observed for the respective formulations. Each release profile was performed separately to show the accurate release of each ion. A fourth sealant was formulated containing three types of microcapsules, each with one of three aqueous solutions (2% w/w 0.8 molar NaF, 2% 5 molar Ca(NO3)2 or 1% w/w 6 molar K2HPO4). Significant ion release was observed for all three ions from this sealant.[19] (Figure 1) As a result, these ions would be available to help prevent demineralization and to promote remineralization. Note that measurement of fluoride release is suppressed by simultaneous release and complexing with calcium ions. It is also well-recognized that all dental resin composite materials are porous to some degree.[20] In addition, it is advantageous that the microcapsules freely permit the movement of water into and through them, such that the structural volume of the microcapsules remains essentially unchanged over time. The porosity of the resin material (substrate) allows ions to move through in both directions: from the microcapsules to increase the concentration at the tooth-material interface, and into the microcapsules to replenish ions from external sources (such as rinses or toothpastes).

Figures 1a-b.





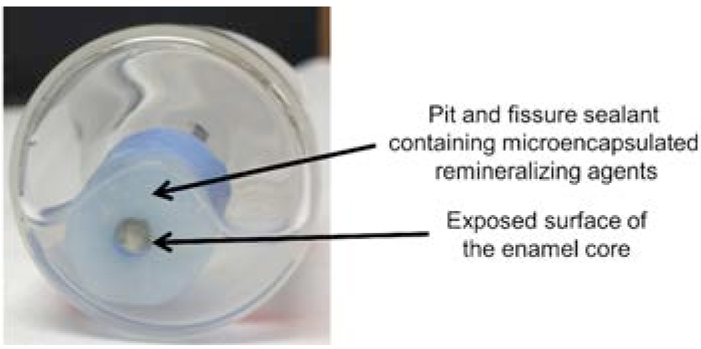
A second study of a similar formula confirms sustained release of fluoride, calcium and phosphate ions for a sealant formulation.[24] Additionally, research confirmed ion release from experimental glaze formulations.[21-23]

Enamel Fluoride Uptake

Enamel fluoride uptake into demineralized enamel adjacent to an RBS was compared for three formulations: 1) 5%

w/w microcapsules with an aqueous solution of 0.8 molar NaF; 2) a mix of microcapsules each with either 2% w/w with an aqueous solutions of 5 molar Ca(NO3)2, 2% with 0.8 molar NaF, and 1% w/w 6 molar K2HPO4; and, 3) A RBS with no microcapsules, as a control.[24] A modified method for measuring bioavailable fluoride (FDA Method 40) was used for 12 sets of bovine enamel for each of the 3 formulations. Enamel samples were prepared, set in acrylic, and placed in a demineralizing solution for 24 hours. Enamel fluoride and depth of etch were then evaluated. For each specimen, the respective sealant was then placed on the acrylic surrounding the enamel (Figure 2), and the specimens were soaked in nanopure water for 90 days before again measuring enamel fluoride and depth of etch.

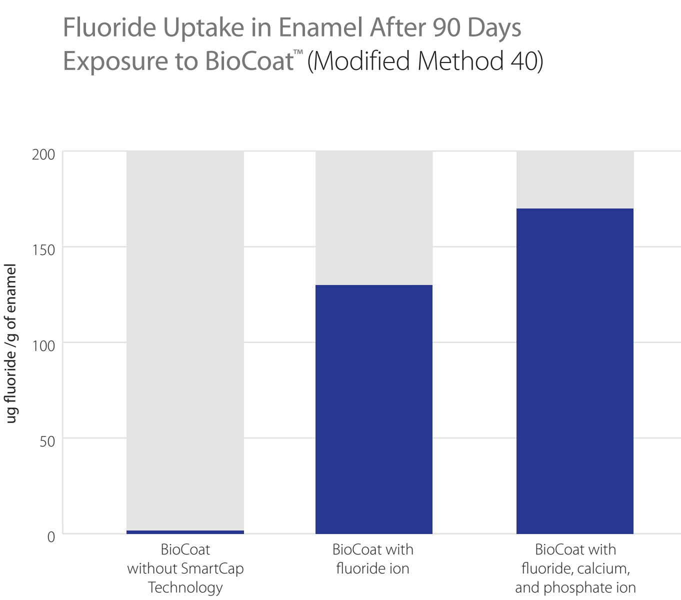
Figure 2. Specimen design



Significantly greater decreases in depth of etch were observed for the formulations containing microcapsules, demonstrating their remineralization potential.

Increases in enamel fluoride were significant for the formulations containing microcapsules and, in contrast, negligible for the control sealant. Greater enamel fluoride uptake was also observed for the sealant containing the mix of microcapsules. This suggests that the presence of calcium and phosphate increases enamel fluoride uptake or precipitation of a protective fluoride-rich surface layer.[24] (Figure 3)

Figure 3. Enamel fluoride uptake



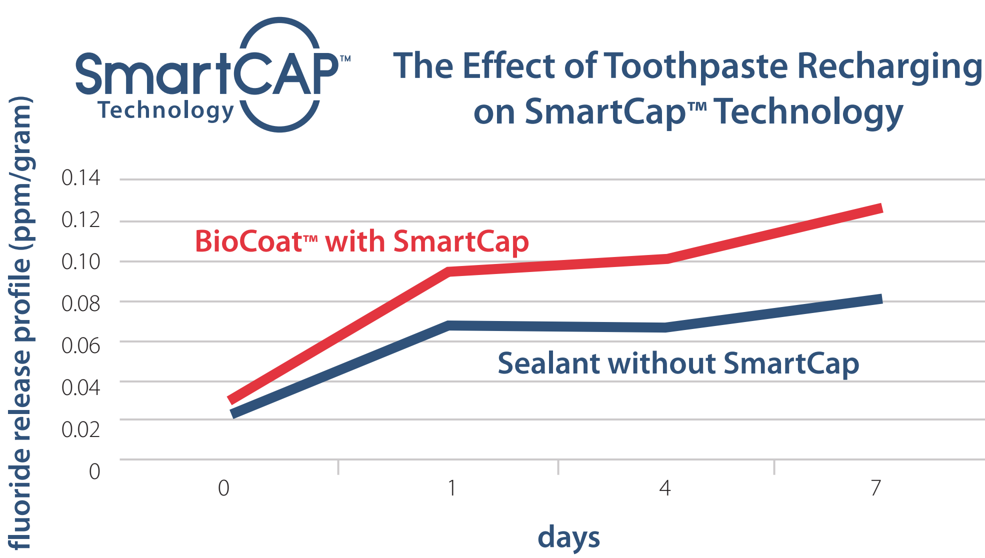
Fluoride adsorption/absorption and recharge

The ability of a material to adsorb fluoride (onto its surface)/absorb fluoride (into the material) and to later release this is advantageous for protection against dental caries. Fluoride released following its adsorption/absorption from a fluoride toothpaste slurry (50% w/w toothpaste and 50% w/w water) was measured for a film of RBS material with no microcapsules and for one with 7% w/w microcapsules containing only nanopure water.[25] The film surface was brushed for 2 minutes with 0.4 ml of the slurry, and this was repeated 40 times, each time with fresh toothpaste slurry. (Figure 4) The samples were subsequently rinsed free of toothpaste slurry, dried and placed in nanopure water. Samples of the fluid were taken over 2 weeks to measure its fluoride ion concentration to evaluate fluoride ion release from the samples.

Figure 4. Brushing toothpaste slurry on the film surfaces

Significantly more fluoride was released from the sealant containing microcapsules, believed to be attributable to the ability of the microcapsules (which previously only contained nanopure water) to incorporate fluoride.[25] (Figure 5)

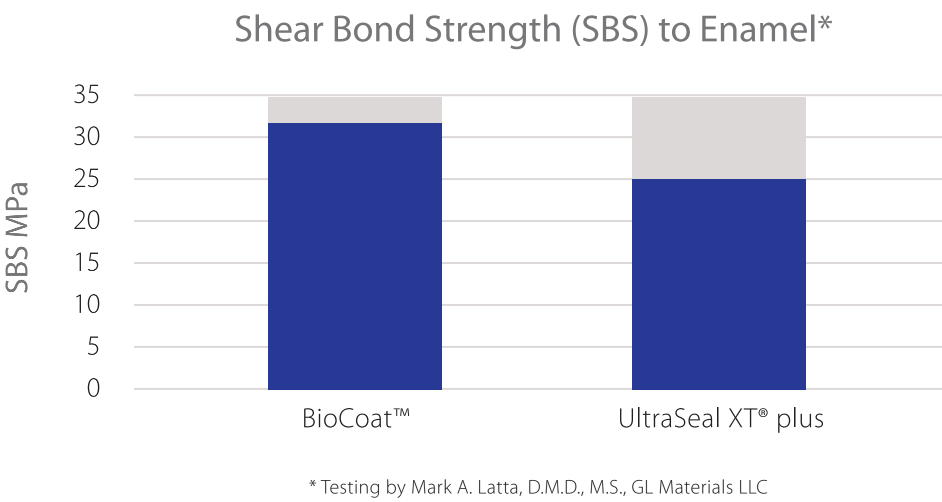
Figure 5. Evaluated fluoride ion release from sealant material with and without microcapsules



Superior Shear Bond Strength for greater retention

Shear bond strength (SBS) has been compared for the BioCoat sealant and a leading commercially available RBS (UltraSeal XT, Ultradent).[26] Flat surfaces were prepared on extracted teeth, acid etched for 30 seconds, and then rinsed with water for 10 seconds and dried. The respective sealant was then applied to the enamel surface and light-cured for 30 seconds with a Spectrum 800 QTZ curing light (800 mW/cm2). After storing the specimens for 24 hours in distilled water at 37°C, SBS was measured using an Ultradent fixture with a notched chisel against and parallel to the bonding sites. Each cylinder was placed under continuous loading at 1 mm/minute until fracture occurred. SBS was significantly greater for the BioCoat sealant at 31.7 MPa (± 4.0) vs. 24.9 MPa (± 3.3) for the RBS without microcapsules. The entirety of the formulation, including the microcapsules, small particle size and choice of monomers contribute to the superior SBS compared to a leading pit and fissure sealant, which is advantageous for durability.[26] (Figure 6)

Figure 6. Shear bond strength (MPa)



The influence of toughening monomer content on shear bond strength

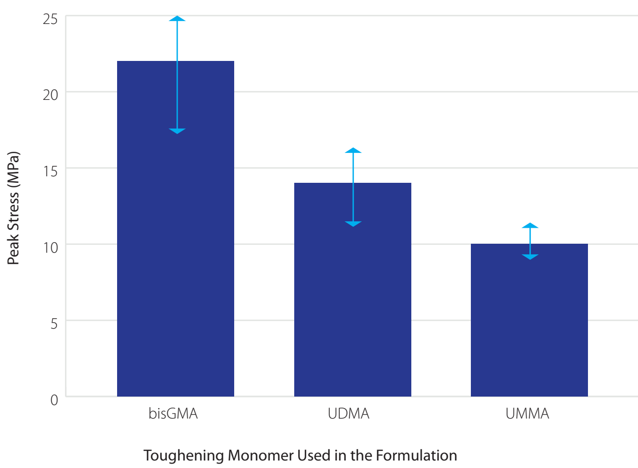
In earlier research, the influence of alternative toughening monomers on SBS was investigated for sealant formulations containing microcapsules.[27] Formulations with high, medium and low TEGMA content (41-55%, 31-40% and 20-30%, respectively) and containing either bisGMA, UDMA or UMMA at the same ratios to the TEGMA were evaluated. Glass and fumed silica levels as variables in the formulation were also investigated. As a result, more than 100 formulations were tested.[27] (Table 2).

Table 2. Variables in the experimental pit-and-fissure sealant formulations

Toughening Monomer	TEGMA Content (Defined as % of the Continuous Phase)	Glass Loading (Defined as w/w% of the formulation)	Fumed Silica Loading (Defined as w/w% of the formulation)
bisGMA	High (41-55%)	High (50-60 w/w%)	High (2.1-3.0 w/w%)
UDMA	Medium (31-40%)	Medium (20-49 w/w%)	Medium (1.1-2.0 w/w%)
UMMA	Low (20-30%)	Low (3-19 w/w%)	Low (0.1-1.0 w/w%)

Flat surfaces were prepared on intact bovine teeth, and the surfaces were acid etched, rinsed with water and dried. The respective sealant was applied to prepared flat surfaces of bovine enamel samples, which were then stored for 7 days in distilled water at 37°C, before measuring SBS in the same manner as described above. When all other variables were held constant (TEGMA content, glass loading and fumed silica loading), SBS was greatest for the formulation containing bisGMA. (Figure 7)

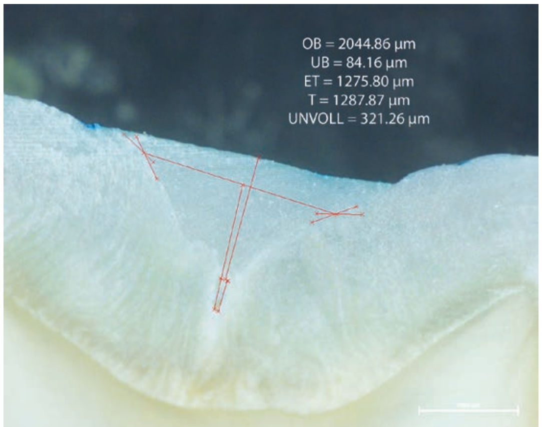
Figure 7. Shear bond strength as a function of the toughening monomer



Filler Content

BioCoat pit and fissure sealant has a 56% filler content. A high level of filler increases compressive strength and wear resistance, and lowers shrinkage. As a result, this formulation aids dimensional stability and long-term durability by reducing the risk of loss of an intact seal and microleakage. The consistent small micron size filler improves the movement of the sealant allowing for access into very tight areas and develops intimate contact with the enamel. Furthermore, initial research on resin-based glaze formulations containing microcapsules, and with filler loads ranging from 0% to 30%, confirmed that higher filler loading not only has no negative impact on ion release, it results in greater ion release from the microcapsules.[22] In addition, this novel sealant containing microcapsules is thixotropic, flowing well into pits and fissures and adapting well to their configuration. This results in precise adaptation, as confirmed in dye-penetration laboratory testing where no dye penetration was observed at the sealant-enamel interface.[28] (Figure 8)

Figure 8. Precise penetration and marginal adaption (dye-penetration laboratory testing)



Discussion

Existing pit-and-fissure sealants are effective in helping to control caries.[29-32] Up until now, none of the materials on the market have been able to meet all the requirements of an ideal sealant material. SmartCap Technology has enabled the development of a novel RBS that incorporates microcapsules and offers distinct physical and biochemical advantages compared with other RBS.

Fluoride release and replenishment of fluoride are potentially beneficial characteristics for pit-and-fissure sealants. However, while there are studies on fluoride release from GI and RMGI materials, fluoride release from traditional resin-based fluoride-releasing materials is less and there is no ability to recharge these (other than, possibly, de minimus fluoride adsorption/absorption associated with their porosity). There is also a paucity of data on the influence of monomers and fillers such as glass on the release of remineralizing ions (fluoride, calcium and phosphate) from resin-based materials such as sealants.

In contrast, in vitro studies for resin-based formulations containing microcapsules developed using SmartCap Technology, including sealants, have demonstrated significant remineralizing ion release and fluoride uptake into adjacent enamel as well as significant fluoride charge/recharge capabilities.[33] Laboratory studies have confirmed their ability to release fluoride, calcium and phosphate ions in a controlled and sustained manner with the potential to help prevent demineralization and to promote remineralization. In addition, ion release was shown in other research to be influenced by the counterion, concentration, temperature, monomer component and filler content.[16,22,23,24] Through continual release of these ions, it is also possible to maintain a higher level of these ions at the tooth surface compared to within the tooth structure, creating a concentration gradient. This discourages loss of ions from the tooth and encourages the diffusion of these ions into tooth structure. In addition, it has been demonstrated that fluoride recharge into the microcapsules can be achieved when brushing with a fluoride toothpaste.

The high filler content increases ion release and the influence of monomers is understood as a result of in vitro studies. Studies have also confirmed that an RBS containing microcapsules and a high filler content offers excellent penetration and marginal adaptation into pits and fissures through its thixotropic nature. Superior shear bond strength compared to a leading resin-based pit-and-fissure sealant, as well as increases in fluoride, calcium and phosphate release, while improving physical properties of the sealant were also confirmed.

Conclusions

Pit-and-fissure sealants have been shown in systematic reviews to be effective in preventing occlusal caries. Nonetheless, to date the ideal sealant material has been elusive. SmartCap technology has enabled the development of a novel RBS incorporating microcapsules loaded with bioavailable fluoride, calcium, and phosphate ions. Research results are promising, and the 'BioCoat™ Bioactive Resin Pit and Fissure Sealant' offers distinct properties that are unique and advantageous for a resin-based pit-and-fissure sealant.

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