BALKAN JOURNAL OF STOMATOLOGY ISSN 1107 - 1141

Pit and Fissure Sealants: Types, Effectiveness, Retention, and Fluoride Release: A Literature Review

SUMMARY

Sealing occlusal pits and fissures in teeth is a common and highly effective preventive method. The main purpose of sealing the pits and fissures is to prevent plaque microflora and food debris accumulation in the fissures where saliva cannot reach and clean the debris, re-mineralise initial lesions, and buffer the acid produced by cariogenic bacteria. Resin-based sealants, as well as glass ionomer materials, are used for pit and fissure sealing. The resin-based sealants require the use of acid for preparation of the enamel surface of the teeth, which is then rinsed and dried before the sealant material is applied. The success of this procedure depends on good isolation of the teeth and prevention of any contamination of the etched enamel surface by saliva or water. Tooth isolation may be achieved by the use of cotton rolls or rubber dam. Additionally it has been suggested that the benefit provided by protecting pits and fissures is based on good retention and the integrity of the sealant material. However, since the retention of the sealant is not permanent, this physical effect could be enhanced if the material simultaneously released fluoride. The durability of fluoride containing sealants would now appear to be comparable to conventional resin sealants. However, further long-term clinical trials are necessary to determine the clinical longevity of sealant retention is not adversely affected by the presence of incorporated fluoride. Also the clinical importance of fluoride in sealants in terms of caries prevention remains to be shown.

Key words: Pit Sealants; Fissure Sealants

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REVIEW PAPER (RP)
Balk J Stom, 2007; 11:151-162

Introduction

Dental caries is a disease that continues to affect the majority of people. Dental caries is a bacterially based disease that progresses when acid, produced by bacterial action on dietary fermentable carbohydrates, diffuses into the tooth and dissolves the mineral (demineralisation). Pathological factors including acidogenic bacteria (*Mutans Streptococci* and *Lactobacilli*), salivary dysfunction, and dietary carbohydrates are related to caries progression[1]. In addition caries is mainly a disease of pits and fissures[2]. Manton and Messer[3] reported that pit and fissure caries nowadays represent a greater proportion of coronal lesions than interproximal lesions. Thus there is a major need to protect the occlusal surface of teeth from the caries process. According to Williams[4], a fissure sealant is "a substance that is placed in the pit and fissure pattern of the teeth such that it prevents the ingress of plaque, bacteria and carbohydrate and in so doing prevents the onset of caries at those sites".

In order to intensify the caries protective benefits of sealants, several kinds of fluoride sealants have been developed over the years. 2 methods of fluoride incorporation are used; fluoride is added to unpolimerised resin in the form of a soluble fluoride salt, or an organic fluoride compound is chemically bound to the resin[5].

In this literature review, the early techniques used to prevent occlusal caries are discussed briefly and the history of fissure sealants is reviewed. The rationale of pit and fissure sealants used in caries prevention is analysed and the literature is reviewed regarding all the different types of sealants, their effectiveness in reduction of occlusal caries and the factors affecting sealant retention on pits and fissures of posterior teeth. Reference is made on sealant innovations: combination of their action with fluoride action in order to constantly release fluoride to the oral environment. The literature is reviewed regarding all the kinds of fluoride containing fissure sealants.

History of Modern Pit and Fissure Sealants

The high caries susceptibility of the pit and fissure surfaces of posterior teeth has been recognized for many years and a number of techniques have been proposed in order to prevent occlusal caries (Tab. 1). None of these attempts were successful until 1955, when Buonocore reported the use of acid to etch the enamel surface prior to the application of acrylic resin[10].

3 different kinds of plastics have been used as occlusal sealants: cyanoacrylates, polyurethanes and bisphenol A-glycidyl methylacrylate (Bis-GMA).

The first extensive clinical study of adhesive sealing using an acid etchant was that of Cueto and Buonocore[11] who employed methyl-2-cyano-acrylate monomer with filler to seal pits and fissures of permanent molars and premolars. This technique was soon proved unsatisfactory because the cyanoacrylates disintegrated after a slightly longer time[12].

Table 1. Techniques used for prevention of occlusal carries

Study	Technique
Wilson (1895) [6]	Placement of dental cement in pits and fissures to prevent caries
Hyatt (1923)[7]	Insertion of small restorations in deep pits and fissures before carious lesions had the opportunity to develop: "prophylactic odontomy".
Bödecker (1929)[8]	Deep fissures could be broadened with a large round bur to make the occlusal areas more self-cleansing: "fissure eradication".
Ast et al (1950)[9]	Attempted either to seal or to make the fissures more resistant to caries with the use of topically applied zinc chloride and potassium ferrocyanide and the use of ammoniacal silver nitrate; they have also included the use of copper amalgam packed into the fissures
Buonocore (1955)[10]	Use of acid to etch the enamel surface prior to the application of acrylic resin

The polyurethanes proved to be too soft and totally disintegrated in the mouth after 2 to 3 months[13]. Despite this problem, their use was continued for some time - not as a sealant but as a vehicle with which to apply fluoride to the teeth[14].

Dimethacrylates represent the reaction product of bisphenol A and glycidyl methacrylate (Bis-GMA), which is considered by its originator to be a hybrid between a methacrylate and an epoxy resin[15]. The most commercial sealants today are Bis-GMA[16]. They were first produced as a potential dental material by Bowen in 1962, although the first fissure sealant based on Bis-GMA was introduced to the profession in 1971 under the trade name Nuva-seal[14]. The initially claimed high retention rates with this ultraviolet photoactive material[17] were revised downwards when the same sealant was looked at over 5 years[18]. Commercially available sealants differ in whether they are free of inert fillers or are semi-filled, and whether they are clear, tinted, or opaque. A principal difference is the manner in which polymerization is initiated. The first marketed sealants, called first-generation sealants, were activated with an ultraviolet light source and they are no longer used. Second-generation sealants are auto-polymerizing and set upon mixing with a chemical catalyst accelerator system. The third-generation sealants are photo-initiated with visible light[19].

Rationale for the Use of Pit and Fissure Sealants

Tooth surfaces with pits and fissures are particularly vulnerable to caries development[3]. Ripa[19] observed that although the occlusal surfaces represented only 12.5% of the total surfaces of the permanent dentition, they accounted for almost 50% of the caries in school children. This can be explained by the fact that enamel forming pits and fissures do not receive the same level of caries protection from fluoride as smooth surface enamel[19-21]. Resin sealants are the most widely used and also have the greatest evidence of effectiveness[22]. The effectiveness of fissure sealants carried out in fluoridated and non-fluoridated areas, as part of public health measures and in private clinics, has been proved beyond doubt[19]. Brown et al[23] and Kaste et al[24] showed that in fluoridated communities over 90% of dental caries occurred in occlusal and buccal-lingual surfaces and represented, almost exclusively, pit and fissure caries, while from 1987 to 1991, interproximal caries was reduced by 25%, whereas pit and fissure caries decreased by 18%. The reason why fluoride is less effective in preventing caries in fissured surfaces may be related to the total depth of enamel on smooth surfaces compared with that underlying the fissure. The base of an occlusal fissure can be close to or within the underlying dentine, consequently lateral spread of the lesion along the enamel-dentine interface results in an increased rate of progression of the lesion, and therefore fluoride has relatively little time to increase demineralisation. On the contrary, fluoride ions have enough time to positively affect the demineralisation process in a smooth proximal surface, where the thickness of enamel is approximately 1mm[25,26].

Different Types of Pit and Fissure Sealants

Once pit and fissure sealants were judged to be caries preventive as long as they remained adherent to the teeth; the initial evaluation of sealant effectiveness by clinical trials comparing sealant treated and non-treated teeth was considered unethical. Clinical retention and longevity became the measure of sealant success[19].

First and Second Generation Pit and Fissure Sealants

Ripa[27] in 1985 reviewed the results of more than 60 studies on the effectiveness of first-generation (ultraviolet-initiated) and second-generation (chemical-initiated) sealants. The sealants were evaluated from 1 to 7 years after placement. He concluded that second-generation sealants provided superior retention and caries protection than first generation sealants, especially as the time increased between initial treatment and follow-up observation. Several studies reported the effectiveness of second generation sealants (Tab. 2). As a result of the better performance of chemically polymerized sealants (due to the change in the diluent in the Bis-GMA system from methyl methacylate to glycol dimethacrylate), and the increasing criticism for the use of ultra-violet light, first-generation sealants are no longer marketed[27].

Table 2. Studies for the effectiveness of second generation sealants

Study	Longevity of the study	Retention of sealants
Wendt and Koch (1988)[28]	10 years	94% partial and complete retention
Romcke et al (1990)[29]	10 years	41% complete retention 8% partial retention
Simonsen (1987)[30]	10 years	57% complete retention
Simonsen (1991)[31]	15 years	28% complete retention

Third Generation Pit and Fissure Sealants

Since third- and second-generation sealants compete with each other in the market place, clinical comparison of sealant types is fundamental for clinicians to make an informed selection. Ripa[19] reviewed numerous studies that have been carried out, comparing the retention between third and first and/or second generation sealants. The mean results indicate that the performance level for chemical initiated sealants and visible light photo-initiated sealants are similar within an observation period of up to 5 years. However, in 3 comparison studies of longer duration, greater longevity was reported for the chemically cured pit and fissure sealants[32-34].

Filled and Unfilled/Clear, Opaque and Tinted Pit and Fissure Sealants

The addition of filler particles to the sealant appears to have little effect on clinical results[35]. Filled and unfilled sealants penetrated the fissures equally well[36,37], demonstrated no difference in microleakage[38] and had similar retention rates[39-41].

Pit and fissure sealants are available as clear, opaque or tinted. No product demonstrated a superior retention rate, but the tinted and opaque sealants have the advantage of even better appreciation by the patient, and evaluation by the dentist at subsequent recalls[35]. Rock et al[42] found significant differences in the accuracy with which 3 dentists identified a clear and an opaque fissure sealant.

During the mid-1990's safety concerns were expressed regarding leaching of bisphenol-A (BPA) and bisphenol-A dimethacrylate (BPA-DMA) from sealants, and a possible oestrogenic effect. It is known that incomplete conversion of BPA during the setting reaction may allow this non-reacted monomer to be released into the oral environment[43]. Nathanson et al[44] analyzed 7 pit and fissure sealants and provided reassuring evidence regarding the safety of these materials. Soderholm and Mariotti[45] considered the dosages and routes of administration and the modest response of oestrogen-sensitive target organs, and concluded that the short-term risk of oestrogenic effects from treatments using bisphenol A-based resins is insignificant. Fung et al[46] showed that BPA released orally from a dental sealant may not be absorbed or may be present in non-detectable amounts in the systemic circulation.

Glass Ionomer Cement (GIC) Pit and Fissure Sealants

The use of GIC as a pit and fissure sealant was introduced more than 25 years ago[47,48]. Studies of the use of GIC's as a fissure sealant indicate significantly lower retention rates than resin-based pit and fissure sealants[49-51]. An interesting finding in the studies by Williams and Winter[52] and by Shimokobe et al[53] was that glass ionomer sealants seemed to exert a cariostatic effect after they had disappeared macroscopically. As retention of glass ionomer sealants is less dependent on good moisture control, this material has been suggested as an alternative to resins for sealing primary teeth[54]. Overbo and Raadal[55], comparing the extent of microleakage that occurred in GIC pit and fissure sealants and a diluted composite fissure sealant, concluded that extensive leakage occurred in the GIC throughout the material, and at the margin of the cement and the enamel. Birkenfeld and Schulman[56] concluded that etching prior to application of GIC enhances the bonding to fissure enamel. Therefore, although GIC's with their ability to release fluoride and adhere to enamel were initially worthy of consideration[57], clinical trials related to their effectiveness discouraged their use as pit and fissure sealants[35]. The use of GIC has been suggested for erupting teeth, where isolation from saliva is a problem[58].

Effectiveness of Pit and Fissure Sealants

Manton and Messer[3], in their review article in 1995, stated that sealant effectiveness can be evaluated by 4 measures: a) the per cent effectiveness, which compares the caries experience of sealed and unsealed teeth; b) the per cent retention, which reflects the number of sealants needing replacement, assuming a failed application requires replacement; c) the per cent sealed teeth/surfaces which become carious and/or restored; and d) the rate at which sealants require reapplication. Sealant effectiveness was measured initially by half mouth trials, but as the efficacy became established this approach became unethical and investigators changed to comparative studies of different sealant products[59].

Caries Prevention with Pit and Fissure Sealants

The ability of pit and fissure sealants to inhibit caries was first reported by Cueto and Buonocore[11], when they claimed an almost 100% reduction in caries over 1 year with the use of an acid etching technique. Romcke et al[29] reported a 10-year observation of more than 8000 sealants; complete sealant retention, without need for resealing, was 58-63% for 7 to 9 years and 41% at 10 years. They reported sealant success (freedom from caries) of 96% for the first year and 85% after 8-10 years (Tab. 3). Wendt and Koch[28] followed for 1-10 years 758 sealed surfaces, and the resulting examination showed 80% total sealant retention after 8 years. Another 16% of the surfaces were judged as partially retained. After 10 years only 6% of the sealed occlusal surfaces showed caries and restorations. Simonsen[31] conducted the longest clinical study to date on sealant retention and effectiveness. In children who received a single application of a white-coloured auto-cured sealant in 1976, 74% of the pit and fissure surfaces of permanent first molars were non-carious 15 years later. Chestnutt et al[60] reported on more than 7000 sealants after 4 years and 57% of the sealed tooth surfaces remained fully sealed with 18% scored as deficient or failed and 24% completely missing. 23% of the surfaces originally scored as deficient at baseline were scored as carious compared with 21% of surfaces not sealed. Only 14.4% of the sound/sealed surfaces at baseline became carious. Wendt et al[61] reported 95% complete or partial retention without caries in second permanent molars after 15 years and 87% complete or partial retention without caries in first permanent molars after 20 years. In a different study the same authors, reported that 74% of first permanent molars that had been sealed were caries free after 15 years[62].

Table 3. Pit and fissure sealants and caries prevention

Study	Longevity of the study	Percentage of sealed teeth without caries
Cueto and Buonocore (1967)[11]	1 year	100%
Romcke et al (1990)[29]	1 year	96%
	8-10 years	85%
Wendt and Koch (1988)[28]	10 years	94%
Simonsen (1991)[31]	15 years	74%
Wendt et al (2001)[61]	15 years	95% second permanent molars
	20 years	87% first permanent molars
Wendt et al (2001)[62]	15 years	74% first permanent molars

Factors Important for Retention

The retention and caries-preventive effects of pit and fissure sealants have been well documented for the past 20 years[27]. There is good evidence that teeth sealed very early after eruption require more frequent re-application of the sealant, than teeth sealed later[63,64]. Therefore, sealant placement may be delayed until the teeth are fully erupted, unless high caries activity is present. Sealant placement even in the absence of regular follow-up is beneficial[11,60]. The application procedure for a conventional sealant involves the placement of etching material, a waiting time, rinsing, and drying, followed by the application of the sealant and the exposure to the curing light. Thus, there are many time consuming steps involved, increasing the risk of saliva contamination during the procedure. Contamination by saliva after etching may have deleterious effects on bonding[65]. Consequent partial loss of material and/or micro-leakage and gaps may result in the formation of secondary caries around the sealed fissure. The annual incidence of caries development in sealed teeth is estimated to be approximately 2-4%[66]. The following parameters are important for fissure sealant retention: method of prophylaxis before sealant application, moisture control, use of etching gel or liquid, etching time, washing and drying times, and fissure sealant application itself[47,48,67,68].

Surface Cleaning

The need and method for cleaning the tooth surface prior to sealant placement are controversial. Usually, acid etching alone is sufficient for surface cleaning[69]. This is attested by the fact that 2 of the most cited and most effective sealant longevity studies by Simonsen[30,31] were accomplished without use of a prior prophylaxis. The use of prophy-pastes, especially those with fluoride, has been discouraged[69]. Garcia-Godoy and Gwinnett[70] and Garcia-Godoy and Medlock[71] showed in studies with SEM that pumice particles become lodged in the fissures and are not removed after rinsing with a stream of water. Additionally, treatment with fluoride before etching has been proposed to strengthen the enamel by reducing its solubility[72]. However, no significant differences were observed in bond strengths *in vitro* following the use of non-fluoridated or fluoridated pastes, a pumice slurry or water and bristle brush[73,74]. 2 clinical trials revealed similar retention rates between cleaning the debris of fissures with a prophy-brush and pumice or gently running a probe[75] and toothpaste[76], respectively.

Air polishing of the occlusal surface with special devices has been suggested[77,78]. *In vitro* studies with air polishing of the occlusal surface before acid etching demonstrated greater penetration[79], a greater number of resin tags for micromechanical retention[80], and higher bond strengths[81] than fissures cleaned with rotary instrumentation and pumice.

In recent years, a new technique for caries removal and cavity preparation has been introduced, i.e. laser irradiation. Lasers with a wide range of characteristics are available today and are being used in several fields of dentistry. Laser energy is absorbed by the dental enamel, promoting superficial modification, which may have clinical significance[82]. Several studies have been conducted to compare sealants placed on laser- or acid-conditioned enamel. In 1996, a split mouth clinical trial was undertaken to compare the retention of fissure sealants placed using both methods that found that, after a mean follow-up period of 14.5 months, the retention rate for CO_2 laser conditioning was greater than that for acid etching (97.9% versus 94.6%, respectively), although this difference was not statistically significant[83]. In the *in vitro* study, do Rego and de Araujo[84] compared the effect of different surface preparations on the micro-leakage of pit and fissure sealants, and found that Nd:YAG laser irradiation with an energy level of 120 mJ per pulse and an energy density of 1.4 Jcm^{-2} did not decrease the micro-leakage degree when using a fluoride resin-filled sealant and resin-modified GIC as pit and fissure sealants. It has been shown that occlusal surfaces treated exclusively by a very short pulsed Er:YAG laser (120 mJ at a frequency of 4 Hz under air-water spray for 30 s) showed poorer marginal sealing than those treated by acid etching alone[85].

Whatever the cleaning preferences, either by acid etching or other methods, all heavy stains, deposits, and debris should be removed from the occlusal surface before applying the sealant[69].

Isolation

Adequate isolation is the most critical aspect of sealant application[69]. Salivary contamination during or after acid etching allows rapid precipitation of glycoproteins onto the surface, greatly decreasing bond strength[61,62,86,87]. Silverstone et al[88] and Tandon et al[89] suggested that even a one second exposure to saliva can lead to the formation of a protein layer resistant to 30 seconds of vigorous irrigation, and they agreed that it would be necessary to repeat the etching procedure to ensure adequate bonding of a resin material.

In general, 2 methods of isolation from salivary contamination are used: rubber dam or cotton roll isolation. Several clinical studies have demonstrated that rubber dam isolation and cotton roll isolation provide comparable retention rates[90,91]. In the longest published comparison study, Lygidakis et al[90] found that after 4 years of application the complete retention rate was 81% for sealants placed using cotton roll isolation and 91% for sealants placed using rubber dam isolation. Rubber dam isolation is ideal but may not be feasible in certain circumstances. Clinical studies using Vac-Ejector moisture control, another alternative to the rubber dam, concluded that sealant retention is comparable to that with sealant placed under rubber dam or cotton roll isolation[92,93]. Interestingly, reports indicate that applying a halogenated bonding agent (Scotchbond®) after acid etching significantly increased the bond strength of sealant to saliva-contaminated enamel, and also to uncontaminated enamel[94,95].

It has been shown that sealants, placed soon after tooth eruption, are far more likely to need replacement. Additionally, tooth position in the mouth appears to be an important determinant for adequate isolation[63,96]. Many of the resin trials included premolar teeth, and sealant retention has been found to be superior for the more anteriorly placed teeth[17,97,98]. Sealants have been recorded as being more effectively retained on lower teeth than on upper teeth[99,100]. The cooperation of the patient, the skill of the operator[19], and the presence or absence of a dental assistant[101], altogether are important factors affecting sealant retention.

Etchants and Conditioners

The goal of etching is to produce an uncontaminated, dry, frosted surface[3]. Acids, such as phosphoric, maleic, nitric, or citric acid, are used with commercial dentine adhesive systems for partial or total removal of the smear layer and superficial demineralisation of the underlying dentine. Such liquids or gels are termed etchants and may also be called conditioners by some dental manufacturers. Etching implies the dissolution of the substrate, whereas conditioning involves cleaning, structural alteration, and increasing the adhesiveness of the substrate[102]. Resin-based fissure sealants are usually placed after cleansing and orthophosphoric acid etching of the fissure enamel[103].

Orthophosphoric acid. The most frequently used is orthophosphoric acid, provided that its concentration lies between 30 and 50% by weight, small variations in the concentration do not appear to affect the quality of the etched surface[35]. Orthophosphoric acid 36% is available as both a liquid solution and a gel. Numerous studies *in vitro*[104-107], found similar penetration of enamel, while *in vivo* studies[108] showed that gel etchant was as effective as the liquid form. The clinical disadvantage lies in the doubling of the rinsing time required with the gel form[33]. However, many clinicians prefer to use a gel because it is easily applied and controlled and because of its colour, easy to tell where it has been applied[34].

Variation in time during which the tooth enamel is exposed to the etching solution is more important. Several laboratory studies involving permanent teeth have shown resin-to-enamel bond strengths after 15-seconds to be comparable to those after 30- and 60-seconds etches[107,109,110]. Clinical studies comparing the same etching times (20 and 60 seconds) resulted in no statistically significant differences in retention rates[111,112]. Laboratory studies indicate that it may be more difficult to gain adequate retention by etching the enamel of primary teeth[113,114], but clinical studies[112] suggest it may not be necessary to increase the etching time when sealing primary molars. Redford et al[115] in the *in vitro* study showed that the etch depth increases between 60-120 seconds, but there was no corresponding increase in bond strengths. More recently, Duggal et al[116] showed no significant difference in retention of pit and fissure sealants after 1 year follow-up on second primary and first permanent molars when 15, 30, 45 or 60 seconds etching times were used.

After etching, the tooth is irrigated vigorously with both air and water for 30 seconds and then dried with uncontaminated compressed air for 15 seconds[3]. It has been suggested washing for 60 seconds if an etchant in solution is used and 90 seconds when a gel etchant has been applied. Compressed air is checked for contamination by directing the flow onto paper or a clean mirror surface; contaminants will appear as droplets of water or oil[117]. According to Waggoner and Siegal[35], exact washing and drying times are not as important as ensuring that both the washing and drying of the tooth are thorough enough to remove all of the etchant from its surface and give a chalky, frosted appearance.

Maleic acid. Combining acidic conditioners and resin primers began several years ago with the development of self-etching primers, such as those provided with Scotchbond 2® (2.5% maleic acid in 55% HEMA/water - 3M Dental Products), Syntac® (4% maleic acid in 25% TEGMA/water - Vivadent) and recently NRC® (maleic acid in itaconic acid and water - Dentsply). These primers are acidic enough to demineralise the smear layer and the very top of the intact underlying dentine. As they etch, they also infiltrate the exposed collagen with hydrophilic monomers, which then copolymerize with the subsequently placed adhesive resin. These primed surfaces are not rinsed with water, leaving solubilised mineral to re-precipitate within the diffusion channels created by the acid primers[102,118].

Fluoride and Pit and Fissure Sealants

Ripa[21], in his review article, stated that as fluoride becomes more ubiquitous in the UK, the difference in caries activity between smooth and pit- and fissure-surfaces becomes more pronounced and dental caries is becoming primarily a disease of the pits and fissures. Pit and fissure sealants were established as the only clinical regimen available for preventing occlusal caries[31]. In an effort to enhance the caries protective benefits of sealants, several kinds of fluoride fissure sealants have been developed over the years[119].

The addition of fluoride to pit and fissure sealants was considered more than 25 years ago[16,120-122] but were not found to reduce caries incidence perhaps because they were poorly retained on the tooth surface. Efforts to combine the 2 continue today[123,124]. According to Kadoma et al[125] the properties a fluoride containing sealant should have in order to replace a conventional one are listed in the table 4.

Table 4. The properties a fluoride-containing sealant should have in order to replace a conventional125

Better or at least comparable retention rates with the conventional sealant
Constant fluoride release for a prolonged period of time
Function as a reservoir of fluoride ion for enamel and to promote fluorapatite formation in enamel

Methods of Fluoride Incorporation in Pit and Fissure Sealants

Fluoride is incorporated into resins in 1 of 2 ways; the first utilizes a soluble fluoride salt which, after application, dissolves releasing fluoride ions, possibly compromising the integrity of the resin[19]. This method has been questioned, because fluoride release resulting from the dissolution of a soluble salt might weaken the sealant *in situ* and thereby might reduce its usefulness as a preventive agent[126]. The other system uses an organic fluoride that is subsequently released by an exchange with other ions in the system[19,127]. In this method (anion exchange systems), fluoride constitutes only a small amount of the total structure, and is replaced rather than lost. Thus, there should not be any significant decrease in the strength of the sealant[126].

Soluble Fluoride Salts Added to Unpolymerized Resins

Lee et al[120] were the first to formulate a polyurethane fluoride-containing sealant material that would release fluoride on the enamel surface for an extended period of 24h - 30 days. They concluded that Na_2PO_3F added to polyurethane reduced enamel acid solubility, increased fluoride uptake in enamel and released fluoride up to 1 month.

Swartz et al[122] conducted an *in vitro* study to test the feasibility of imparting anti-cariogenic properties by adding 2-5% NaF to BIS-GMA resin pit and fissure sealants. The findings revealed a reduction of enamel acid solubility and an increased enamel fluoride uptake. The physical properties of the resins remained the same. However, the greatest amount of fluoride was released during the first day or two, after which the amount rapidly diminished.

Based on the previous study, el-Mehdawi et al[128] studied, *in vitro*, the fluoride release of an ultraviolet fissure sealant (Nuva-seal) throughout a 3-week period by adding several concentrations of NaF to the sealant. They concluded that Nuva-Seal decreased fluoride release over the 3-week study period, while the quantity of fluoride ions increased when the concentration of the fluoride salt in the sealant increased.

In 1990, a commercially available sealant with fluoride was marketed that purportedly released fluoride. This product (FluoroShield) was a visible light-cured resin containing 2% NaF and 50% by weight inorganic filler[129]. Cooley et al[129] compared in their *in vitro* study, FluoroShield with a fluoride sealant (Helioseal). They found no significant difference between the 2 sealants in ability to penetrate fissures, but FluoroShield was found to have more leakage. All specimens of the FluoroShield released fluoride over the 7-day period; there was a ‘burst effect’ in which larger amounts of fluoride were released on the first and the second day, and then the release tapered off. Jensen et al[130] in the *in vitro* study, compared the size and depth of artificial caries lesions when using FluroShield or its non-fluoride containing analogue, PrismaShield. Lesion depth was found to be over 3-times greater in specimens that contained the conventional sealant compared with specimens that contained the fluoride-releasing sealant.

Hicks and Flaitz[119], in another *in vitro* study, compared the effects of FluroShield, PrismaShield and Ketac-Fil (GIC material) on initiation and progression of caries-like lesions around class V restorations. They concluded that FluroShield and Ketac-Fil showed less lesions than PrismaShield.

Park et al[38] compared FluroShield, PrismaShield and Delton pit and fissure sealants to each other through shear bond strength, scanning electron microscopy and microleakage. They concluded that the shear bond strength in FluroShield and PrismaShield was significantly higher than in Delton, better adaptation to the etched enamel with FluroShield and PrismaShield than with Delton, and no significant difference in microleakage among the 3 pit and fissure sealants.

Loyola Rodriguez and Garcia-Godoy[123] estimated the antibacterial activity and the fluoride release, of FluroShield, Helioseal and a new fluoride containing sealant Teethmate F. Only Teethmate F showed inhibition activity against all strains of *Mutans Streptococci* tested; there was no significant difference in the inhibition between strains of *S. Mutans* and *S. Sorbinus.* Teethmate exhibited higher fluoride release than FluroShield during the 7-day study period. During 2 days after setting, these materials showed their highest concentration of fluoride release, which decreased to approximately 50% (below 0.1 PPM F^-) at 7 days. Rock et al[124] came to similar results regarding fluoride release, *in vitro*, from FluroShield in comparison to a GIC material Baseline. They also found 70% complete retention of FluroShield in first permanent molars, *in vivo*, after a 3-year follow-up.

In another clinical study, Jensen et al[130] evaluated the retention and salivary fluoride release of FluroShield compared to its non-fluoride analogue PrismaShield. There was no significant difference in retention between the 2 sealants at 6 and at 12 months. However, fluoride release was significantly increased when compared to the baseline values, only at the 30 min post-sealant sampling interval. Rock et al[124] found 70% complete retention of FluroShield applied to contralateral caries-free first permanent molars in 86 children aged 7-8 years, after a 3-year follow-up. Do-Rego and de Araujo[131] found that 91.35% of FluroShield and 93.14% of Delton Plus sealants were intact after 2 years of follow-up.

Lygidakis and Oulis[132] evaluated the retention rate and the caries increment differences between FluroShield and Delton. The sealants were applied in a half-mouth design to all 4 caries-free first permanent molars of 112 children aged 7-8 years. At a 4-year follow-up, the complete retention for FluroShield was 76.5% and for Delton 88.8% - the difference being statistically significant.

Morphis and Toumba[133] evaluated the retention rates of 3 different sealants: a conventional sealant Delton, its recently marketed fluoride-containing analogue Delton Plus, and an experimental fluoride-containing sealant, which was prepared by adding fluoride-glass powder to Delton. The sealants were applied to 104 permanent molars in children aged 6-16 years, in a randomized way. Results showed no significant difference in retention among the 3 sealants after a 1-year follow-up.

Organic Fluoride Compounds Chemically Bound to the Resin (Anion Exchange System)

Instead of incorporating fluoride into an inert sealant material, ion exchanging resins were developed[134,125]. These resins have relatively high fluoride content and exchange fluorine ions from the sealant materials for hydroxyl and chloride ions in the oral environment. Inhibition of caries formation and re-mineralization of enamel caries have been shown to occur *in vitro* and *in vivo*. A significant level of fluoride is taken up by the sealed enamel. Both superficial and deep enamel layers incorporate the released fluoride, with fluoride levels of 3500 ppm and 1700 ppm reported for enamel biopsy depths of 10 μm and 60 μm, respectively, while the fluoride levels were 650 ppm and 200 ppm for the same enamel biopsy depths in contra-lateral control teeth[134]. Research of the anion exchange system-sealant is in progress but, to date, no commercial product is available[5].

Conclusions

Pits and fissures are recognised as highly susceptible to caries and least benefit by systemic or topical fluoride. Sealants do prevent caries[59] and are cost-effective[112]. Mertz-Fairhurst[59] reported in 1984 that at the end of 10 years 78% of those first permanent molars with a single application of sealant placed in pits and fissures were caries free compared with the unsealed matched pairs which had a caries free rate of 31.3%.

Fluorides also work in more than one way. They reduce enamel solubility and stimulate re-mineralization, actually reversing the course of caries during its early stages[126]. For these reasons fluoride has been incorporated into pit and fissure sealants. The rationale is that the sealants act as reservoirs from which the added fluoride is gradually released into the oral cavity[127]. It is essential that the effective levels of fluoride release are maintained for long periods of time, preferably at a constant rate, for at least 6 months since these materials are always subjected to leaching by saliva[135].

Despite the fact that no anti-caries clinical studies have been reported[21], *in vitro* studies indicate that a fluoride releasing sealant substantially reduces the amount of enamel demineralization adjacent to it[130]. However, the main problem with the existing fluoride releasing sealants is that they give no lasting effects on salivary fluoride concentration levels[124, 129, 130].

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