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THE USE OF FISSURE SEALANTS IN SCHOOL BASED PREVENTIVE DENTAL PROGRAMS

SIRIANDER DEVI SHARMA
BDS (Singapore)

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Department of Preventive Dentistry
Faculty of Dentistry
University of Sydney

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SUMMARY

The pits and fissures of occlusal surfaces are the tooth sites where caries most commonly begins; and fissures are also the sites which least benefit from fluorides. The unique form and depth of pits and fissures is responsible for the high caries susceptibility of these tooth surfaces.

The changing epidemiological pattern of dental caries is elevating the relative importance of pit and fissure caries. There is therefore a need for protecting the pit and fissure surfaces of both first and second permanent molars and premolars; especially in children with considerable previous occlusal caries of primary and permanent teeth.

Pit and fissure sealants prevent dental caries by forming a physical barrier between the oral environment and the depths of pits and fissures. They are a very conservative method of overcoming the problem of occlusal caries, as it involves a minimum of operative, non invasive procedures. Fissure sealants have been used for a number of years in the prevention of occlusal caries.

This thesis is purely a literature review, mainly concerned with the types of materials used and the criteria of patient selection for the application of fissure sealants, together with a discussion of the common problems encountered. Some school based fissure sealant programs have been selected from the literature for discussion to ellicit the effectiveness and implications of the use of fissure sealants in school based preventive programs.

The use of pit and fissure sealants has had a major positive impact on dental caries prevention in fluoridated and nonfluoridated communities. Using the cost effectiveness analysis, fissure sealants are the most expensive among preventive programs. However, when compared to the application of a restoration, the cost of applying a single application of pit and fissure sealant to a group of children, and reapplying sealant one time to all missing areas that occurred over a 10 year period, is approximately two thirds (0.63) the cost of treating the caries that occurred in the matched group of unsealed children over the same 10 year period (Simonsen 1989).

The cost effectiveness of sealants can be improved by using dental auxiliaries to apply sealant, and by utilising good criteria for patient and tooth selection. However, there is a need for methods that will permit better targeting of children at high risk to dental caries so as to identify those children who stand to benefit most from the sealant application. Sealants, undoubtedly have a place in the caries preventive programs of community based or school based programs, and when their use is combined with the most effective use of fluoride, the combination can prevent dental decay entirely in children.

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1 INTRODUCTION

Dental caries is probably the most prevalent chronic disease affecting the human race. It is also the most prevalent affliction of childhood. It is a microbial disease which affects the calcified tissue of teeth, beginning with a localised dissolution of the inorganic structures of a susceptible tooth surface by acids of bacterial origin and leading to the disintegration of the organic matrix over time (Newbrun 1989).

Dental caries is a localised multifactorial disease requiring the simultaneous presence of three factors:

1. Microflora
2. A susceptible host or tooth surface
3. A diet for the microflora

While all of these are present to some extent in most mouths, the outcome of their interaction in terms of caries is entirely dependent upon the time factor. The frequency and duration of this interaction makes the difference between the tooth surface remaining sound, a carious lesion developing, and a carious lesion arresting.

The major strategies currently directed at reducing and eliminating caries are:

1. to reduce the amount of microbial plaque on teeth
2. to decrease the susceptibility of teeth to caries attack
3. to modify or control dietary practices

The external factors, the microflora and the diet are alterable by changes in

the behaviour of the host, through programs of personal oral hygiene, plaque removal and plaque control, and by diet control with restriction of sucrose-containing foods and beverages.

The intrinsic factors relating to the tooth are also modifiable. The anticaries effectiveness of fluoride, taken either systemically during the period of tooth formation and mineralisation or applied topically after eruption are well established (Newbrun 1986).

Numerous articles published have reported that systemic fluorides, obtained through fluoridated water supplies and tablets are very effective in preventing dental decay in children. Fluoride protection can also be obtained topically, through toothpaste, mouth rinses and professionally applied fluorides (Newbrun 1986).

The surfaces of the teeth that are most caries susceptible, the occlusal and proximal surfaces, are also the areas that are least easily cleaned by tooth brushing and are least accessible to the protective effects of saliva. The protection by fluorides is greatest on the smooth surfaces of the teeth; it is least effective in protecting pits and fissures of the teeth.

Another method of increasing tooth resistance is by application of a physical barrier on the vulnerable pits and fissures by the use of fissure sealants. This is one of the most promising means of reducing caries incidence as long as

the sealants are retained. The effectiveness of sealants is directly related to sealant retention (Mertz-Fairhurst 1984; Rock 1984).

School based dental care systems of prevention and treatment have long been recognised as truly effective dental public care systems for the provision of dental services for children (Jones 1984). Well planned and executed dental health plans starting at the earliest school grades, could greatly accentuate the decline of caries. Preventive programs in schools have focussed on fluoride mouthrinses, fluoride tablets, operator applied topical fluoride, school water fluoridation, prophylaxis and dental health education (McCormack-Brown, Clark, McDermott 1989). Pit and fissure sealants have also been incorporated in school based dental programs especially for children with moderate to high risk of dental caries.

Such a fissure sealant program was started in Malaysia in 1985 as a pilot project in the Federal Territory of Malaysia. This project, however, was discontinued temporarily because of insufficient funds and priorities for other target groups. Other states in Malaysia have also started this program in stages. Presently a few pit and fissure sealant programs are carried out in all the states but not on an extensive basis. The topic of this thesis was evolved from a desire to gather more information on the use of pit and fissure sealants in school based dental programs to determine their value and whether it should be a higher priority program.

Aims and Objectives

The principal aims of this thesis are to review the literature and discuss:

1. The criteria of patient selection, the materials used and the methods of application, for some commonly used fissure sealants and the common problems encountered
2. The effectiveness of the use of fissure sealants and their implications for school based dental programs

2 PIT AND FISSURE CARIES IN CHILDREN

Pit and fissure caries is a major problem in children as can be discerned by the epidemiology of pit and fissure caries, coupled with the morphology of these surfaces, which makes these sites more susceptible to caries. These factors will be discussed here leading to the efforts to overcome this problem, which have led to the development and use of fissure sealants.

2.1 EPIDEMIOLOGY OF PIT AND FISSURE CARIES

The pattern of dental caries has changed significantly among children during the last two decades. Approximately 44 per cent of children between 6 and 11 years of age were considered to be caries free when examined in 1974 for a caries prevalence study conducted by the National Centre for Health Statistics in the United States of America (Hicks 1988). In the 1980 National Caries Prevalence Survey conducted by the National Institute of Dental Research (NIDR), 57 per cent of children were found to be caries free.

In 1974, less than 10 per cent of adolescents in the USA were clinically caries free in the 12-to-17 year-old age group. A decade later, more than 17 per cent of adolescents were considered to be caries free (Hicks 1988). Results from the cross-sectional 1986-1987 NIDR National Survey of the oral health of school children indicate that 50 per cent of the 5-17 year-olds were caries free and two-thirds of carious or filled surfaces were occlusal surfaces (Johnson 1988).

With the increasing proportion of children and adolescents that remain caries free, there has also been a reduction in the number of decayed, missing, and filled surfaces (DMFS) for those affected by caries in many countries (Brunelle, Carlos 1982; Fejerskov, Antoft, Gadegaard 1982; Koch 1982; Brown 1982).

The occlusal surface is particularly vulnerable to caries development. According to both the National Preventive Dentistry Demonstration program completed in 1984 and the 1980 NIDR National Caries Prevalence Survey, caries involving occlusal surfaces accounts for 54 per cent of the total caries experience in children and adolescents. This apparent increase in the proportion of caries experience attributed to occlusal caries is due to a 53 percent reduction in caries prevalence in interproximal surfaces that occurred between 1974 and 1980. Compared to the similar 1979-1980 NIDR national survey, in 1986-1987 the prevalence of occlusal, buccal, and lingual caries or filled surfaces had declined 32 per cent, and carious or filled interproximals had declined 54 per cent (Johnson 1988). Occlusal surfaces actually represent only 12.5 per cent of the total number of tooth surfaces exposed to cariogenic challenge. This means that the pits and fissures are approximately eight times as vulnerable as the smooth surfaces (Hicks 1988).

It has been shown that school-going children who are born and raised in an area with natural or artificial fluoridation will experience 50 per cent less caries than equivalent non-fluoridated subjects. However most protection, approximately 75 per cent, is confined to the smooth surfaces (Backer-Dirks,

Houwink, Kwant 1961). Only 25-30 per cent protection is obtained in the stagnation sites of the grooved pit and fissure areas. Hence the concept of fissure sealing evolved whereby an acid-resistant plastic resin could be applied to these caries-susceptible surfaces.

A report from the Hastings fluoridation project after 16 years found that there was a 91 per cent reduction of caries on gingival tooth surfaces, a 76 per cent reduction on approximal surfaces, but only a 46 per cent reduction on occlusal surfaces for 13 year old children in New Zealand (Ludwig 1971).

Lewis and Hargreaves (1975) found that 70 per cent of the first permanent molars of children residing in the non-fluoridated area of the Isle of Wight, in the United Kingdom, had pit and fissure decay within one year after eruption. This study demonstrated the need for early treatment of all pit and fissure areas. King, Shaw and Murray (1980) later found that 92 per cent of first permanent molars and 68 per cent of second molars were decayed, missing or filled by age 15 in a sample of 276 Buckinghamshire and 1106 Berkshire children, in England.

Occlusal caries represents a disease process that has an early onset. Approximately one third of children between the ages of 1 and 3 years have experienced dental caries in the primary dentition, with 67 per cent of the lesions being occlusal caries. With the permanent dentition, 65 per cent of first molars in 12-year-old children either have been restored because of occlusal

caries or presently have occlusal caries. Pit and fissure caries accounts for 90 per cent of all lesions in first permanent molars as shown among elementary children from a fluoridated community (Bohannan, Disney, Graves, Bader, Klein, Bell 1984; Hennon, Stookey, Muhler 1969; Graves, Burt 1975; Ripa 1985).

2.2 MORPHOLOGY OF SURFACES WITH PITS AND FISSURES

The pits and fissures of occlusal surfaces are the tooth sites where caries most commonly begins; and fissures are also the sites which least benefit from fluorides. The unique form and depth of pits and fissures is responsible for the high caries susceptibility of tooth surfaces with pits and fissures. Attempts have been made to provide an elaborate classification system for pits and fissures as they show an enormous complexity. However three principal types of pits and fissures are described by Nagano (1961). They are shown in Figure 1 a, b, and c.

1. a V-type fissure; shallow and wide at the top and gradually narrowing towards the bottom
2. a U-type fissure; of medium depth and almost the same width from top to bottom
3. an I-shaped fissure; deep and with an extremely narrow slit

Figure 1: **Optical photomicrograph showing**
a V-type fissure
b U-type fissure
c I-type fissure
Source: Buonocore (1975)

a

b

c

The deep, narrow, I-shaped fissure is quite constricted and may resemble a bottleneck in that the fissure may have an extremely narrow slit appearance with a larger base as it extends towards the dentino-enamel junction. These fissures may also have a number of different branches. The typical fissure usually contains an organic plaque composed of reduced enamel epithelium, microorganisms forming a dental plaque, and oral debris. The fissure provides a niche for dental plaque accumulation that is difficult to remove. The speed with which dental caries occurs in the surface is related to the fact that the depth of the fissure is in close proximity to the dentino-enamel junction and to the underlying dentine, which is highly caries susceptible (Nagano 1961; Galil, Gwinnett 1975a; Hicks, Flaitz 1986). Whereas enamel thickness in most tooth locations is approximately 1.5 to 2.0 millimetres, it is only 0.2 millimetres or less under deep fissures (Newbrun 1989).

The morphology of occlusal surfaces varies from tooth to tooth and from individual to individual. In general, a premolar will have a single fissure with usually three or four pits. In upper and lower molars the fissures are extremely variable both in number and configuration with as many as ten separate pits which may be present in primary, secondary, and supplemental fissures. In addition, when examined microscopically, certain surface porosities are apparent which are not noticeable clinically (Buonocore 1975). The teeth themselves differ in their susceptibility to decay. Their morphology, position in the arch, chemical composition and degree of maturation are all factors that affect their fate after eruption.

Buonocore (1975) has also noted that deciduous teeth have been shown to have fewer pits and fewer deep constrictive fissures. Usually a shallow, wide or narrow "V" configuration exists.

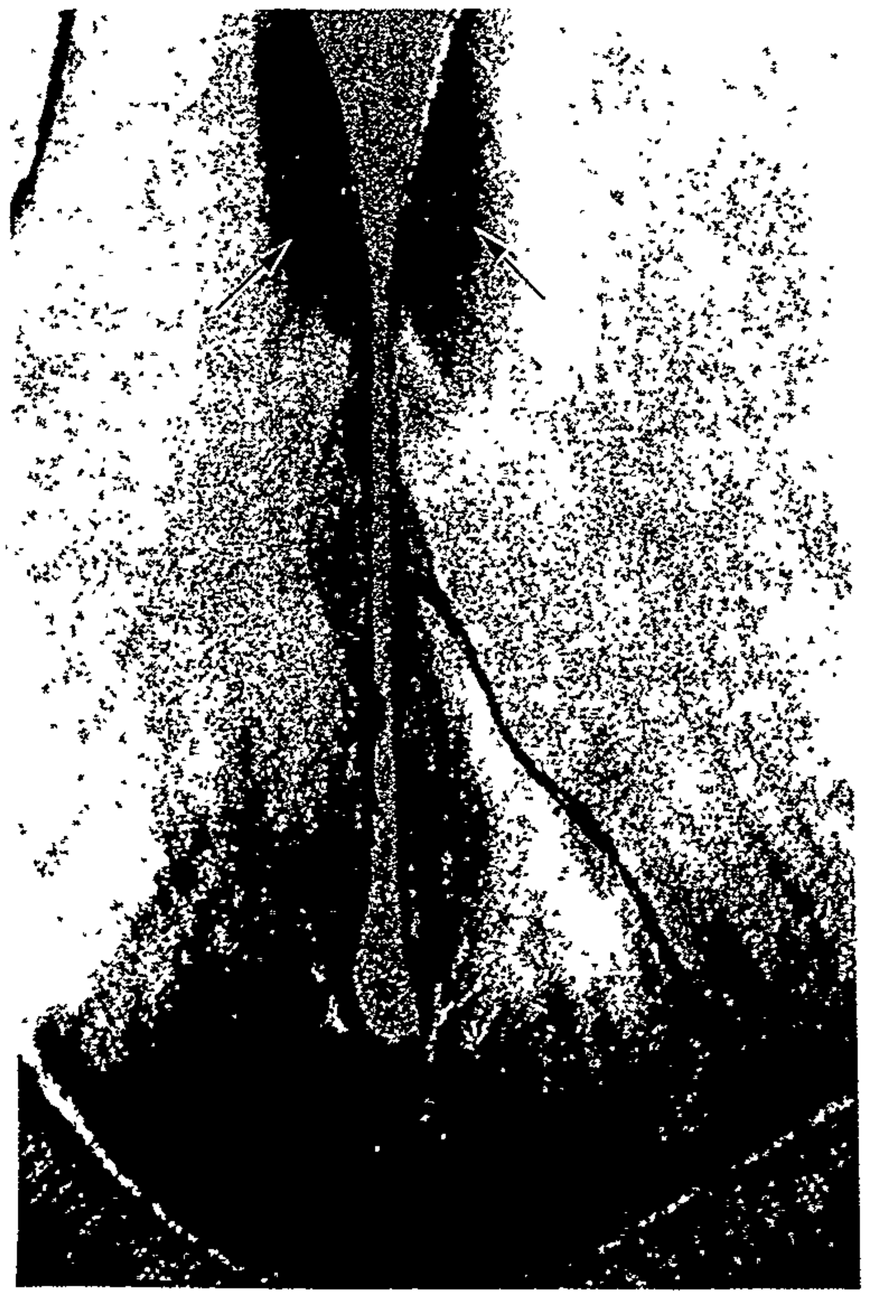
Generally the primary lesion of caries starts at the top of the pits and fissures more often than at other levels, especially in the case of the I-type fissure. The inclines forming the walls of the fissures are affected first by the caries process. The first histologic evidence of lesion formation is found at the orifice of the fissure and is usually represented by two independent bilateral lesions in the enamel composing the opposing cuspal inclines as shown in Figure 2. As the lesion progresses, the fissure walls become involved and coalescence of the two independent lesions into one lesion occurs at the base of the fissure (Hicks 1988).

The enamel present at the base of the fissure is affected to a greater degree than that of the cuspal inclines, and the lesion spreads both laterally within the enamel adjacent to the fissure and readily towards the dentino-enamel junction (Hicks, Flaitz 1986).

The reason why fluoride appears to be less effective in preventing caries in fissured surfaces may be related to the total depth of enamel on smooth surfaces in comparison with that underlying the fissure (Hicks, Flaitz 1986; Silverstone 1984). The pit and fissure surfaces are also less available to mechanical cleansing with fluoride toothpastes and to salivary buffering.

Epidemiological data have shown that in pits and fissures, pre-carious lesions are formed almost immediately after eruption (Lee, Orlowski 1975). These lesions, if left untreated, will progress to frank caries in the majority of teeth within a few years after eruption. The results suggest that the high caries susceptibility of occlusal surfaces is probably representative of conditions in many parts of the world and points out the need for protecting pits and fissures against caries. The highest incidence of dental caries is during the early post eruptive years. During this initial stages of enamel mineralisation, the enamel matrix is relatively porous. The greatest efforts in the prevention of occlusal decay are thus directed towards children (Gwinnett 1971; Weintraub 1989).

Figure 2. **Histologic appearance of pit and fissure caries (polarised light microscopy; water imbibition). Caries formation (arrows) begins in the cuspal inclines just above the fissure orifice. The darkened appearance at the base of the fissure is due to the organic material present.**
Source: Hicks (1988)



2.3 HISTORICAL PERSPECTIVE OF THE PREVENTION OF PIT AND FISSURE CARIES.

The high caries susceptibility of the pit and fissure surfaces of posterior teeth has been recognised for many years. Different techniques to prevent caries specifically on occlusal surfaces have been attempted.

Extension for prevention

M.H.Webb introduced the concept that cavity preparations on teeth under treatment for occlusal caries be extended to eliminate noncarious fissures and extension into less caries susceptible areas. This principle was subsequently popularised by G.V.Black and this procedure is still widely accepted and practised today (Newbrun 1989).

Prophylactic odontomy

Hyatt (1923) recognised the significance of pits and fissures to the development of occlusal lesions. He recommended their eradication by prophylactic odontomy, a technique which required drilling of all pits and fissures and then their filling with amalgam before the appearance of clinical signs of decay.

Fissure eradication

Bodecker (1929) recommended shaping non carious pits and fissures into wide, non retentive grooves rather than placing restorations. He contented that any dentine exposed by the grinding procedures would undergo secondary changes and become resistant to caries. He also reported filling certain fissures with a thin mix of oxyphosphate cement.

Application of impregnating solutions

Ammoniacal silver nitrate solutions were applied to sterilise tooth surfaces. The material has been reported to diffuse into enamel and dentine and increase the resistance of the area by forming complexes with the protein components and by depositing reduced silver by Howe in 1917 (Newbrun 1989). Klein and Knutson (1942) did controlled clinical studies and showed no significant cariostatic effects of this procedure. Applications of silver nitrate precipitated with saturated calcium chloride were reported by Younger in 1949 with dramatic caries reductions (Newbrun 1989). Another solution, consisting of zinc chloride and potassium ferrocyanide was also reported to be effective in reducing caries. This was known as the Gottlieb method, introduced in the late 1940's. The use of impregnating solutions was based largely on the theory that the primary route for the initiation of caries was by proteolytic action of organisms on organic structures in enamel. This was again shown to have no significant cariostatic effect (Ast, Bushell, Chase 1950). A procedure involving fissure modification followed by chemical treatment with acetic acid and chromic anhydrite has been tried with little success (Walder, Moriera 1971).

Application of non adhesive dental materials

Zinc phosphate and copper cement (Miller 1951) were among some of the numerous dental materials that were used in an attempt to physically block pits and fissures. These substances, however had limited value due to their high solubility in oral fluids and poor retention to tooth structure.

Development of pit and fissure sealants

The search for a non-operative method for increasing the resistance of pits and fissures has focussed on developing materials capable of adhering to tooth structure. It was not until the advent of the acid-etch technique by Buonocore in 1955 that a viable means of long term pit and fissure protection became possible. The discovery of the etching of enamel with phosphoric acid to increase the retention of resin restorative materials and improve the marginal integrity of the material, led to the development of pit and fissure sealants. With this option, a liquid plastic is flowed over the occlusal deep fissures to fill areas that cannot be cleaned with a tooth brush. The hardened sealant represents a barrier between the tooth and hostile oral environment.

The first sealant material that utilised the acid-etch technique was introduced in the mid-1960's and was a cyanoacrylate material. Several clinical trials of occlusal sealing utilising cyanoacrylates were described in the literature (Cueto, Buonocore 1967; Buonocore 1970,1971; Ripa, Cole 1970; Takeuchi, Shimizu, Kizu, Eto, Nakagawa, Ohsawa 1971). Cyanoacrylates were not suitable as sealant materials, because of their difficult handling characteristics and bacterial degradation of the material in the oral cavity over time. The cyanoacrylates are presently marketed as superglues and have a variety of useful applications.

The polyurethanes are another class of adhesive resins. They were tested in laboratory animals and in a few clinical trials. It was found that they do not appear to have the retentive qualities necessary to physically seal occlusal pits and fissures. Fluoride has been added to the formulation of certain commercial products in order to chemically protect subjacent tooth enamel (Buonocore 1975).

By the late 1960's, a number of different resin materials had been tested and a viscous resin was found to be effective and produced a tenacious bond with etched dental enamel. This liquid resin was introduced and called by the acronym Bis-GMA. This resin is formed by reacting bisphenol A with a monomer glycidyl methacrylate producing a dimethacrylate (Bis-GMA) (Bowen 1982). Bis-GMA resin-based pit and fissure sealants form the vast majority of the commercially available sealants today. Examples of some sealants available are Nuva-Seal (LD Caulk), Kerr Pit and Fissure Sealant (Kerr/Sybron), and Delton Pit and Fissure Sealant (Johnson & Johnson).

Other pit and fissure coatings which have been used with varied success in the prevention of pit and fissure caries include a variety of dental cements- such as oxyphosphate, copper cements, silicophosphate cements, glass-ionomer cements, glass-cermet cements, and Duraphat - a varnish preparation containing sodium fluoride.

The glass-ionomer cements were invented by Wilson and Kent in 1972 in the laboratory of the Government Chemist, London. Their use for pit and fissure sealing was advocated by McLean and Wilson in 1974. Glass-ionomer cements possess some interesting qualities which justify their use as pit and fissure sealants.

A major benefit of fluoride therapy has been the reduction of smooth surface caries. This changing epidemiological pattern of dental caries is elevating the relative importance of pit and fissure caries. There is therefore a need for protecting pit and fissure surfaces of both first and second permanent molars and premolars, especially in children with considerable previous occlusal caries of primary teeth. It follows that while dentistry must maintain its emphasis on the various forms of fluoride, the protection of the fissure surfaces by sealant materials represents another discrete step towards greater caries prevention.

3 FISSURE SEALANT MATERIALS

The term pit and fissure sealant is used to describe a resin material that is introduced into the occlusal pits and fissures of caries susceptible teeth, thus forming a mechanical physical protective layer against the action of caries-producing bacteria and substrates (Simonsen 1981a).

Fissure sealing is a very conservative method of overcoming the problem of occlusal caries, as it involves a minimum of operative procedures. These include, polishing of the teeth to remove plaque and food debris, and slight chemical and physical modification of the enamel surface to render it more receptive to bonding by etching with acid prior to the painting of the sealant on to the tooth.

The sealant acts as a physical barrier preventing oral bacteria and dietary carbohydrates from aggregating within the pits and fissures, thereby preventing the production of acid which results in the carious destruction of the tooth (Horowitz 1982).

Pit and fissure sealants can be grouped into two categories:

1. Physical sealants

   A physical sealant is a layer of inert material that blocks the fissure entrance and so prevents stagnation

2. Chemical sealants

   A chemical sealant is a vehicle for the long term fluoridation of the enamel lining the fissure (Rock 1975)

Conventional pit and fissure sealants such as the Bis-GMA derivatives are adhesive resins but the glass-ionomer cements have also been advocated by McLean and Wilson in 1974 for pit and fissure sealing. One of the main advantages in clinical practice in the use of glass-ionomer cements relates to their ability to bond chemically to enamel and dentine. This, in conjunction with active fluoride release into the surrounding enamel, has led to the development and evaluation of glass-ionomer cements as alternate fissure sealant systems. These two separate materials will be considered in greater detail in this chapter.

3.1 ADHESIVE RESINS

Adhesive resins are sealants which act as a physical barrier to seal pits and fissures and thus prevent the advent of caries in these areas.

An adhesive, according to a definition of the American Society for Testing Materials, is a substance capable of holding materials together by surface attachment. There is some divergence of views as to the mechanisms of adhesion covered by such a definition. Some authors include both mechanical interlocking and interfacial bonding through molecular attraction, others consider the latter mechanism. In practice both mechanisms probably contribute to the strength of a bonded joint but one or the other predominates (Smith 1975).

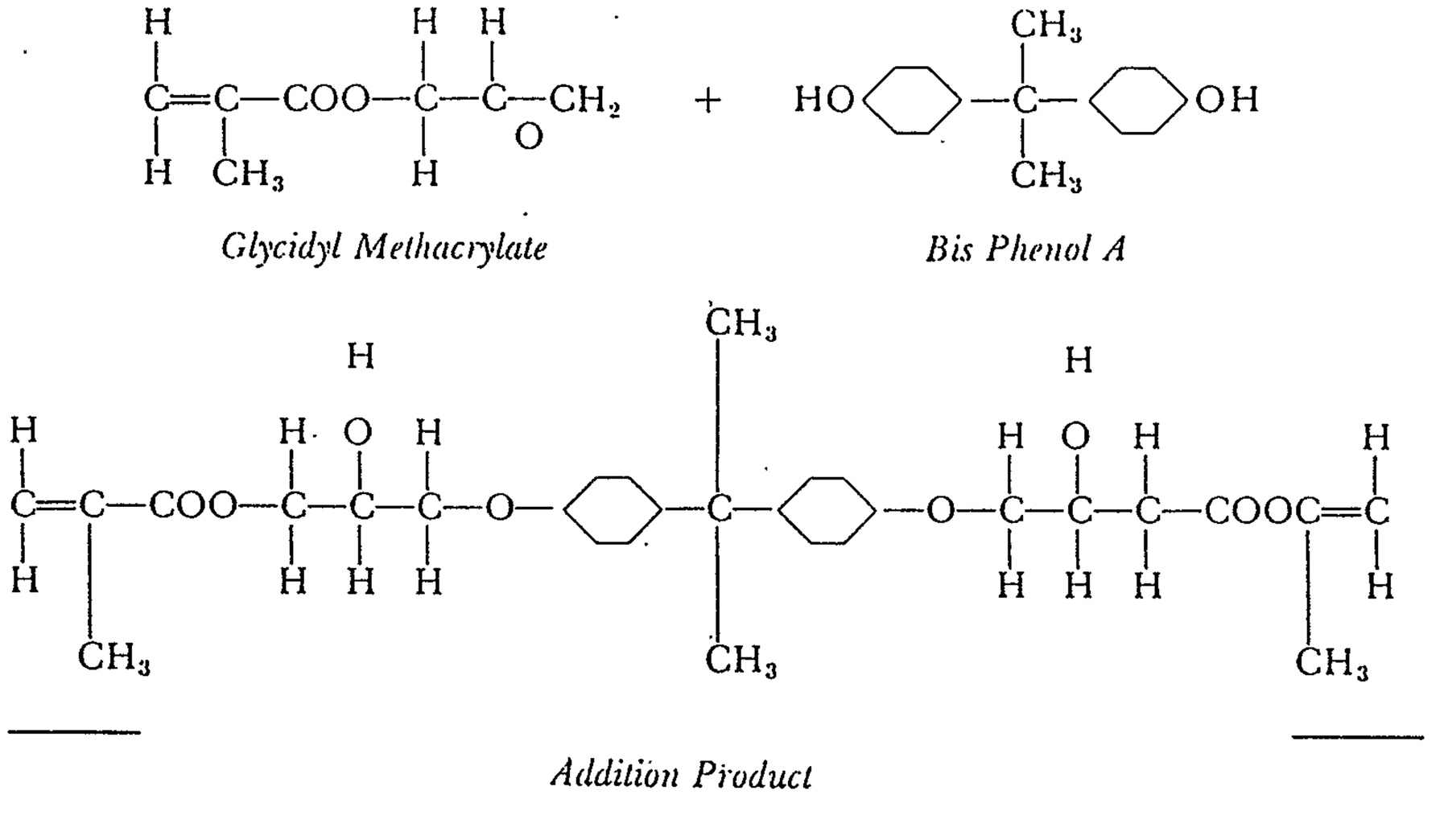
Resins are complex, amorphous mixtures of organic substances, which are characterised by specific physical behaviour rather than by any definite chemical composition. Natural resins are mostly obtained from trees and plants (kauri, dammar) and there are some synthetic resins (epoxy resins, polyurethanes) (Peyton, Craig 1971).

Conventional pit and fissure sealants are adhesive resins. Three types of adhesive resins have been clinically evaluated within the past three decades and have been commercially available for clinical use. The most successful formulation of adhesive resins was the one developed by Bowen sometimes known as Bowen's resin. This class of resins is known as dimethacrylate (Bis-GMA).The vast majority of pit and fissure sealants available today are based upon the Bis-GMA formulation.

3.1.1 Composition and properties

Most of the conventional pit and fissure sealants can be classified as dimethacrylate compositions. This product was first produced as Bis-phenol A-Glycidyl Methacrylate Adduct (Bis-GMA) and was used as the base monomer for some of the original composite restorative materials. The equation for the formulation of the monomer is shown in Figure 3.

Figure 3: **Reaction formation of Bis-GMA.**
Source: Buonocore (1975)



Bis-GMA is a large molecular weight monomer of relatively high viscosity. In order to be used as a sealant material, its viscosity is lowered by the addition of diluents such as methyl methacrylate. The various brands of fissure sealants currently available are all based on Bis-GMA, the only differences being related to the diluent monomers added to the basic Bis-GMA (Silverstone 1986).

The commercial products will possess somewhat different physical and mechanical properties including thermal expansion coefficient, water absorption, compressive and tensile strength, modules of elasticity and dimensional stability, because of formulation differences. Some of these

properties will be discussed with the experimental results in Chapter 4. However, there are some differences between the materials which have direct clinical implications. These are:

1. Method of polymerisation
2. Presence of fillers
3. Presence of tinters or opaquers
4. The concentration of acid etchants

1. Method of polymerisation

There are two methods of polymerisation. The first is the chemically cured or autopolymerised system. This involves the mixing of two resin components, a base resin and catalyst resin such as benzoyl peroxide (initiator), and 50 per cent organic amine (accelerator). The material sets by an exothermic reaction usually within 1-2 minutes. In the second system, the resin is photoactivated or light cured. This polymerisation is achieved by the inclusion of either benzoin methyl ether in a phthalate ester carrier for ultraviolet(U-V) sensitive materials or the incorporation of a diketone and an aliphatic amine for the materials sensitive to visible blue light (Nikiforuk 1985).

Initially, U-V light of 3650 angstroms was used to initiate the setting reaction. This procedure demanded a bulky U-V light source in the oral cavity with an exposure time of 60 seconds to ensure complete polymerisation. However, owing to the inconsistency of the wavelength of light and possible retinal damage with long term use, photoactivation of sealant materials with exposure

to a visible light source of 4400-4480 angstroms was introduced. Use of visible light sources also requires eye protection, owing to the intensity of the light created.

The advantages of the light cured system are:

1. Setting of the sealant occurs in only 10-20 seconds
2. There is no mixing of resins thus eliminating the incorporation of air bubbles that may occur with chemical cured sealants
3. The viscosity of sealant remains constant during the infiltration of the etched enamel pores, and the sealant does not set until it is light initiated

The disadvantage of the light cured sealant is the cost of the visible light unit, as a number may be needed in a dental practice if sealants are placed by auxiliaries (Nikiforuk 1985).

2. Presence of fillers

Most sealants are either unfilled, they contain no filler particles, or are semifilled, contain few filler particles, which makes the hardened sealant more resistant to abrasion. Kerr Pit and Fissure Sealant (Kerr/Sybron) contains 40 per cent quartz filler and is chemically activated. Nuva-Cote (LD Caulk) contains 64 per cent lithium aluminium silicate filler in a resin based on an isocyanate modified Bis-GMA and a diluent monomer. It is polymerised by U-V light (Nikiforuk 1985).

In a two year study the retention on smooth surfaces was better for filled than unfilled resins (Stephen, Kirkwood, Main, Campbell, Gillespie 1983). An unfilled resin however, has the advantage of being quickly worn down by the patient's own occlusion so that equilibration by the operator is unnecessary.

3. Presence of tinters and opaquers

A polymerised material may be clear, white or tinted. The tinted materials are usually either opaque white or transparent pink, where a small amount of opaquing agent, such as titanium oxide, is incorporated. The advantages of coloured sealants over clear sealants are the following:

1. Coloured sealants are easier to apply
2. They are easier to check for complete coverage and polymerisation
3. They give a more accurate assessment of sealant presence and therefore markedly decrease examination time at recall
4. They are a helpful motivational agent in the overall dental preventive health program because it becomes convenient to explain the concept of a sealant to a patient or parent as being a type of caries-preventive restoration

Fluorescent sealants have been developed and tried by using dyes such as Fluoral 7GA, Fluorescein-dicaprylate. This dye additive gives a yellow-green fluorescence to the sealant and is advocated as a promising diagnostic aid for determination of pit and fissure sealant retention (Derouen, Rawls 1986).

4. Acid concentration

Phosphoric acid is the etchant in all commercial sealant systems. Buonocore (1955) used 85 per cent phosphoric acid solution to etch enamel prior to the use of acrylic restorative materials in order to improve the edge adaptation. Silverstone (1974) found that the depth of histological change was greatest at weaker acid concentrations. Concentrations of the acid in the range of 30 to 40 per cent phosphoric acid used with 60 second exposure periods produced the most evenly distributed etching patterns (Silverstone 1974;1975). Pyruvic, polyacrylic, lactic and citric acids have also been used to etch enamel, prior to the application of resin. However, although etching of the enamel was achieved with these various solutions, the bonding of resins to enamel was less satisfactory compared with that achieved using phosphoric acid (Silverstone 1975). The concentration of phosphoric acid packaged with commercially available resin systems falls in the range of 30-50 per cent. It is dispensed either as a solution or gel. Clinical sealant trials done by Stephen, Kirkwood, Main, Campbell, Gillespie (1983), support a recommendation for shorter etching times such as 20 seconds.

The first generation sealants

The results with a fissure sealant consisting of Bowen's resin and methyl methacrylate monomer were reported by Roydhouse (1968). This sealant was polymerised by a peroxide-amine catalyst-accelerator system and used on unetched enamel surfaces. A single application after three years produced a 29 per cent caries reduction on a limited sample of teeth.

Buonocore did a one year study using the material Nuva Seal (LD Caulk) in 1970. None of the treated teeth developed caries, whereas 42 per cent of the control permanent teeth developed occlusal caries. Two years later there was a 99 per cent occlusal caries reduction in the permanent teeth and an 87 per cent reduction in the primary teeth. Eighty seven per cent of the permanent occlusal surfaces and 50 per cent of the primary occlusal surfaces showed sealant retention (Buonocore 1971).

Nuva Seal was the first pit and fissure sealant introduced commercially in 1971. It was polymerised by a fixed quartz rod U-V light source. The first generation sealants were polymerised with U-V light at a wavelength of 3650 angstroms. In Nuva Seal the catalyst benzoyl peroxide was substituted with benzoin methyl ether in the Bis-GMA system to produce a material which set on exposure to U-V light . The ultraviolet light activates the production of free radicals that induce polymerisation.

Rock in 1973 and 1974 carried out clinical trials with Nuva Seal (LD Caulk). He reported higher significant results in retention of adhesive (80 per cent) and effectiveness in caries prevention (97 per cent) with Nuva Seal after 2 years in 1974.

Epoxylite 9075 (Lee), a conventionally polymerised self-curing resin system is also based on Bowen adduct or a homologue. The catalyst used was benzoyl peroxide. A 52 per cent retention and 65 per cent caries reduction after two years utilising this material was reported by Rock (1974).

The Nuva Seal system was improved with the introduction of the recommended light source - Nuva Lite (LD Caulk). However, Nuva Lite did not always have a uniform output and the intensity of light produced from lamp to lamp was often below the minimum value needed for proper polymerisation of the resin with a full 60 second exposure. The light source was also bulky and the area of the light beam was small. Newer U-V lights, such as Lee-lite (Lee) emerged which were assessed to have high outputs and had broad light guides to ensure exposure to all the sealant (Main, Cummings, Moseley, Stephen, Gillespie 1983).

Another sealant introduced had a fluid resin system containing 2 parts of 2-hydroxypropyl methacrylate to 1 part of 2,2,4 trimethyl hexamethylene di-iso-cyanate with added dimethacrylate of 1.3 butane diol as a diluent and cross-linking agent. A small quantity of tinopal dye is incorporated into the resin so that it fluoresces blue in U-V light which also polymerises it. It was marketed under the name TP 2206 and later as Alpha Seal (AD International) (Murray, Williams 1975). Caries reduction and retention of TP 2206 was similar to Nuva Seal (LD Caulk). Alpha Seal excessively absorbed U-V light and hence prevented complete polymerisation of the sealant at its depth. The Alpha lite has a high intensity, but the diameter of the fibre-optic tip was far too small (2.5 millimetres), and hence some parts of the sealant were only partially polymerised (Wei 1988).

A Bis-PMA (Bis-Polymethyl methacrylate) resin has also been used as a fissure sealant. Two per cent benzoin methyl ether is used in the basic resin to polymerise it under U-V radiation. This material is less viscous but more hydrophobic in nature than the Bis-GMA materials. It was marketed in a tube under the name of ESPE 717 (ESPE). This was superseded by ESPE 71729 with a slight modification to the hydrophobic material (Murray, Williams 1975).

The new U-V light polymerising systems introduced since 1977 include Lee Bond (Lee), with the Lee U-V Curing Light System. A similar system has been introduced by Kulzer. The U-V light unit is known as Duralux U-V 300 and the sealant, Estilux Glaze (Kulzer) (Silverstone 1985).

The second generation sealants

The second generation sealants were introduced with much better formulations and were generally self cured or chemically cured without the need of an external light source. Most of the self cured resins are unfilled, but they may be transparent, tinted or opaque by inclusion of white pigment or a tint for better visualisation. The successful and widely used self cured resins include the commercial products, Concise White Sealant System (3M), Delton (Johnson and Johnson) and Contact Seal (Vivadent).

The filled, self cured resins include Kerr Pit and Fissure Sealant (Kerr/Sybron) and Nuva Cote (LD Caulk), a modified version of Nuva Fil. The filled resins were found to have a much higher wear and abrasion resistance than unfilled resins and yet maintain the same bond strength, setting times, and retention rates as the unfilled resins (Wei 1988).

The third generation sealants

Visible blue light at a wavelength of 4300 - 4900 angstroms was used to light cure the third generation sealants. These sealants are also classified as filled or unfilled, with or without tint or opaquer. Most of the unfilled resins are coloured white such as Delton Opaque (Johnson and Johnson), Helioseal (Vivadent), and Light Cured White Sealant (3M). A few unfilled, clear resins are also available such as Status Armor (Healthco). Visio Seal (ESPE Premier) is an unfilled resin that is tinted pink.

The filled light cured resins are either clear such as Status Armor 2 (Healthco), yellowish white such as Prisma Shield (LD Caulk) or tan such as Estiseal-LC (Kulzer).

Variations in the formulation and the technique of polymerisation give rise to different results in clinical trials of these materials and also in measurement of their properties. The changes in formulation have improved current performances compared to past results. The visible light source is far more compact and cheaper than the original U-V light. Many visible light sources are now available with the sealant products, such as Prismalite (LD Caulk), ESPE Elipar (ESPE), Translux (Kulzer), Heliomat (Vivadent), Aristolite (Litema KG), and Luxor (ICI), all having different wavelength spectra and intensity outputs over the required range.

The enamel sealant bond strengths, depth of polymerisation and setting times of three visible light curing sealants (Prismashield, Helioseal and Estiseal LC) polymerised with four different light sources (Prismalite, Heliomat, Translux and ESPE Elipar) were studied. It was concluded that these materials had adequate enamel sealant bond strengths and polymerised sufficiently at depths, provided an adequate exposure was used. The setting time experiments showed that mis-match problems could be encountered where the light from one manufacturer was used with another manufacturer's sealant. It was recommended that a 60 second exposure be used in all cases to overcome this problem and to ensure good bonding and depth of polymerisation (Strang, Cummings, Stephen, McMenemy, Wyper 1983; Strang, Cummings, Stephen 1983).

The filled resins are preferred to the unfilled because of their greater wear resistance. All the light cured filled resins are theoretically rated superior as compared to both the light cured unfilled and self cured unfilled resins. The light cured resins are expected to perform clinically better than their self cured counterparts manufactured by the same company (Wei 1988).

Release of fluoride by chemical sealants

The chemical sealants available contain fluoride salts as the active agents in a polyurethane base. These are probably considered as hybrids between fissure sealant and topical fluoride agents. The important mode of action here is to modify the chemical composition of the enamel lining the pits and fissures so that it becomes more resistant to acid attack (Rock 1973). The polyurethanes appear to be good vehicles for the sustained release of fluoride, since they are sufficiently permeable when properly formulated to permit the free interchange of ions with the saliva. Polyurethane material was then marketed primarily as a means of applying and retaining fluoride. The fluoride disodium monofluorophosphate is incorporated in the material and slowly leaches out to combine with the enamel during the time that the material is in contact with it. This material was called Epoxylite 9070 (Lee) (Rock 1974). Elmex Protector (Vivadent), another material developed in Switzerland, contains the hydrofluoride of cetylamine. Carbon dioxide is evolved during the setting of the polyurethane and this gives this material a porous, bubbly appearance. This porous coating allowed other ions to pass from the oral cavity into the enamel and, on dissolution, calcium and phosphorous ions would pass in the opposite direction. These coatings were very poorly retained by the enamel surface with total loss of both materials after a 2 year trial by Rock (1974).

Buonocore (1975) presented a technique of sealing fluoride in fissures, in which pits and fissures could be filled with topical fluorides such as stannous or sodium fluoride and allowed to dry. These are then coated with adhesive fissure sealant. This may be useful for long term sealing of fluorides in pits and fissures. *In vitro* studies showing the ability of fissure sealants to release fluoride ion which increases with time and concentration have been documented (El-Mehdavi, Rapp, Draus, Miklos, Zullo 1985). More recently, a commercially available sealant with fluoride has been marketed that releases fluoride. This product, FluroShield (LD Caulk), is a visible light cure resin containing sodium fluoride and 50 percent (by weight) inorganic filler. *In vitro* studies for penetration into fissures, resistance to microleakage by dye immersion, and fluoride release showed no statistical difference between a non-fluoride sealant, Helio Seal (Vivadent), and the fluoride containing sealant, FluroShield (LD Caulk), in its ability to penetrate fissures. FluroShield adapted and penetrated the fissures and its microleakage may not be clinically significant considering its ability to release fluoride over time (Cooley, McCourt, Huddleston, Casmedes 1990).

Biocompatibility of fissure sealants

There is very little published evidence on the toxicity of fissure sealants. It is generally assumed that these materials are non irritating to the tissues based on the use of similar formulations containing Bis-GMA in composite restorative materials tested by implantation and pulp reaction. Allergic response to methyl methacrylate and similar monomers is extremely rare (Smith 1985).

A study was reported that aimed to evaluate the oral soft tissue response to pit and fissure sealants. This study showed that the chemically cured sealants were better tolerated by the oral soft tissue than the visible light cured sealants. The difference was shown to be statistically significant ($P < 0.05$) (Farias, Banks, Adrian, Soni 1985).

Other properties of adhesive resins, namely the penetrativity, microleakage and wear, have been linked to its effectiveness in preventing dental caries and these will be discussed in chapter 4.

3.2 GLASS-IONOMER CEMENTS

3.2.1 Composition and properties

The glass-ionomer cement has been described as a hybrid of dental silicate cements and polycarboxylate cements. It is actually a dental glass polyalkenoate cement (Wilson and Kent 1972). It is a member of the class of hybrid materials known as ionic polymers, which are characterised by macromolecular entities containing both ionic and covalent bonds. The polymer chains are preformed and setting is by ionic cross linking and not by polymerisation. A glass-ionomer is a composite material which has an ion-leachable glass powder dispersed in a crosslinked polyacrylate matrix. The compositions of glass-ionomer cements are complex and varied. The material was invented in 1969, later fluoride was incorporated into it and given the tradename ASPA (AD International). This material is derived from alumino silicate polyacrylate. The material has undergone compositional changes over the years with the first clinical trials done by McLean in 1970.

In 1974, the improved material ASPA 1V (AD International) was used for Class 1 restorations and fissure sealing. Clinical tests were done in 1974 and showed an 84 per cent retention after 1 year and only 1 per cent of treated teeth became carious. After 2 years, 78 per cent of the material was still intact, however, only fissures where a probe could enter a definite pit or crack (about 300 micrometers in width) were considered suitable for fissure sealing. If a fissure was less than 300 micrometers, it was widened with a bur by judicious prophylactic odontomy within the enamel layer and then cement applied

(McLean and Wilson 1974). It had the advantage of truly bonding to enamel and releasing fluoride. In the conventional form, the powder was simply ground glass, and the liquid contained the polyacid and tartaric acid in solution. The major problem of the material was the instability of the polyacrylic acid solutions and an extended setting time. The new presentation of the glass-ionomer cement consists of the dried polyacid which is mixed with the glass to form a powder blend. The liquid is then either water, where the tartaric acid is incorporated into the powder blend, or a solution of tartaric acid. This led to the development of ASPA V (AD International) (Prosser, Powis, Brant, Wilson 1984).

The glass-ionomer cement system consists of the following four basic constituents:

1. glass
2. polyacid
3. tartaric acid
4. water

1. Glass

The glasses used in glass-ionomer cements are ion-leachable calcium aluminosilicates, which provide ions to crosslink the polyacid chains. Fluoride is an essential constituent of glass-ionomer cements. It lowers the temperature of fusion, improves the working characteristics of the cement paste, increases markedly the strength of the set cement, in moderate amounts enhances translucency and most of all contributes to the therapeutic value of the cement by releasing fluoride over a prolonged period (Wilson, McLean 1988).

The types of calcium fluoroaluminosilicate glasses that are employed in glass-ionomer cement formulations are:

SiO_2 - Al_2O_3 - CaF_2

SiO_2 - Al_2O_3 - CaF_2 - $AlPO_4$

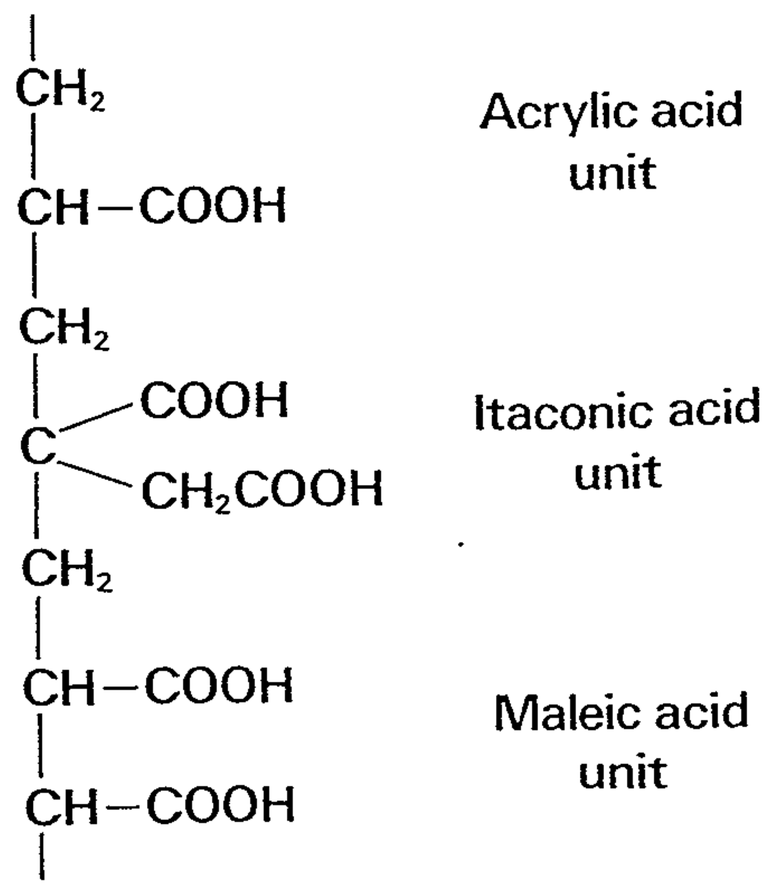
SiO_2 - Al_2O_3 - CaF_2 - $AlPO_4$ - Na_3AlF_6

The aluminosilicates dissolve in acids and release ions. The glass composition affects working time, resistance to erosion, aesthetics and cement strength. Another important factor is the particle size of the glass powder. The finer the particle size, the more rapid the setting and the stronger the cement will be (Wilson, Prosser 1982; Wilson, McLean 1988).

2. Polyacids

The polyacids in glass-ionomer cements include the homopolymer or copolymers of unsaturated carboxylic acid. The more important carboxylic acids in the ionomer system include acrylic, maleic and itaconic acid (Wilson, Prosser 1982). The polyacid may be either in the form of a concentrated aqueous solution (40 to 50 per cent by mass) or freeze-dried and blended with the glass powder. They are generally prepared by polymerisation of the appropriate monomers in aqueous solution using an initiator, such as ammonium persulphate, a chain transfer agent. Essentially, these polymers consist of linear chains, with no cross-linking but with pendant acid groups as shown in Figure 4.

Figure 4: **A co-polymer of polyacid.**
Source: Wilson and Prosser (1982)



3. Tartaric acid

Tartaric acid reacts preferentially with the glass-ionomer to form a complex at pH 3. It prevents the early formation of polyacrylate salts and hence improves cement workability (Wilson, Crisp, Fenner 1976). The incorporation of the tartaric acid also enables the fluoride content of the glasses to be reduced, which led to the production of clear or slightly opal glasses with enhanced translucency (Wilson, McLean 1988).

4. Water

Water is the reaction medium for the glass-ionomer cements though not considered a constituent. It plays a role in hydrating reaction products, the metal poly (alkenoate) salts when present and silica gel. Too much water in the system results in weak, slow-setting cements (Prosser,Powis,Wilson 1986).

The glass-ionomer cements are divided into three types:

1. Type 1 - luting agents
2. Type 11 - aesthetic filling materials or its cemet derivatives for Bis-reinforced filling materials
3. Type 111 - lining, base and fissure sealing materials

Strength and radiopacity are important when a glass-ionomer cement is to be used as a lining, base or fissure sealant. Some commercial fissure sealant materials presently available include ASPA (AD International), Chem-Fil 11 (LD Caulk) and Fuji Ionomer Type III (GC International).

A formulation of a typical glass-ionomer cement is shown in Table 1.

Table 1: **Formulation of a typical glass-ionomer cement.**
Source: Wilson and Prosser (1982).

POWDER		LIQUID	
Fusion mixture composition	% m/m	Composition	% m/m
SiO_2	29.0	Poly(acrylic/itaconic acid)	47.5
Al_2O_3	16.6	Tartaric acid	5.0
CaF_2	34.2	Water	47.5
$NaAlF_6$	5.0		
AlF_3	5.3		
$AlPO_4$	9.9		

Fluoride release and antimicrobial properties

Glass-ionomer cements have high amounts of fluoride content, about 23 per cent. The mechanism of fluoride release is complex but is dependent on time. It is leached from the hardened glass-ionomer cements for a sustained period of time - at least 18 months. Substantial amounts of fluoride are taken up by enamel which becomes more resistant to acid attack (McLean, Wilson 1988). This happens even in cases where cement is lost from the fissure.

In a study by Williams and Winter (1981) using glass-ionomer cement as a sealant, sealant loss was higher for glass-ionomer cements than for resin, but there was no significant difference in caries incidence between teeth sealed with these two materials. However, glass-ionomer cements seemed to exert a cariostatic effect, even after they had disappeared macroscopically. Fluoride released from glass-ionomer and taken up by enamel may give prolonged protection against caries (Retief, Bradley, Denton 1984; Shimokobe, Komatsu, Kawakami, Hirota 1986; Forss, Seppa 1990). Microscopic examination of occlusal surfaces showing partial or total loss of sealants revealed that in most cases, residual material was observed in the bottom of the fissures (Seppa, Forss 1991).

3.3 BONDING MECHANISM TO ENAMEL

Bonding is the term used to describe the attachment of dental adhesives to enamel and dentine. This is based on the fact that it describes an observed attachment without necessitating a commitment as to whether the attachment is due to adhesion and/or to mechanical retention (Buonocore 1975).

Adhesion is defined as the attraction exerted between the molecules at the surfaces of different materials when these surfaces are brought into contact. These forces of attraction involve physical and chemical forces. Physical forces refer to van der Waal's forces, hydrogen bonding, adhesive forces and cohesive forces. Chemical forces result from formation of ionic, covalent and metallic bonds (Buonocore 1975).

Mechanical bonding is the attachment of two phases by mechanical means and the varying degrees of bonding range from gross means of retention to retention by microscopic and submicroscopic surface irregularities. When an adhesive is applied to a dry etched enamel surface, it is likely to be attracted to it by the physical forces of adhesion, namely van der Waal's forces, filling in the microspaces by strong capillary action. After the adhesive hardens, the multitude of projections of adhesive which have penetrated into the microscopic capillaries, voids and crevices also serve to hold the resin firmly in close proximity to the enamel surface. The physical forces of attachment can be displaced by water and as such cannot be maintained in the aqueous oral environment, which results in disruption of these bonds. The mechanical retention endures (Buonocore 1975).

3.3.1 Structure of enamel

Enamel is the hardest tissue in the body. It's chemical composition consists of three components:

1. the inorganic component
2. the organic component
3. water

1. The principal inorganic component of enamel is calcium hydroxyapatite which comprises approximately 95 per cent of enamel. The empirical formula of calcium hydroxyapatite is $Ca_{10}(PO_4)_6OH_4$. With fluoridated water, or where individuals receive topical fluoride therapy or fluoride supplements, the hydroxyl group in the hydroxyapatite structure may be replaced in part to form fluorapatite.

2. The organic component constitutes approximately 1 per cent of enamel. The exact chemical composition of this remains unclear. The principal organic component of enamel is protein but this shows features of both keratin and collagen during amino acid essays. Carbohydrate has also been identified in enamel.

3. Water constitutes about approximately 4 per cent of enamel. It is present in both a loosely bound, or free form and a firmly bound state. The loosely bound water is readily replaceable and is removed at room temperature and is that water which is lost during air-drying under clinical

conditions. There is a dynamic flow of fluid through the dentine and across enamel, and within an hour of initial drying, the enamel would essentially be rehydrated by flow of fluid from the pulp (Buonocore 1975).

The microscopic picture of enamel consists of units called prisms or rods. There are approximately twelve million prisms in enamel and each measures approximately 6 microns in diameter. The prism configuration is referred to as a keyhole structure, consisting of a central core or head region and a peripheral or tail region, which is an extension of the core between the head regions of adjacent prisms to form interprismatic material (Buonocore 1975).

The prisms start from the amelocemental junction and run outwards and upwards to the enamel surface but do not usually run a straight course. This tortuous course may start of in the initial segments as a more or less straight one, then it curves to the left in their progression and then assume a straight course again. Thus, in the inner two thirds of enamel, there is considerable decussation or crossing of groups of prisms so that in longitudinal section some may appear to be cut transversely, while neighbouring groups appear to be cut obliquely. The outer third of enamel shows a much more regular arrangement of prisms in which these units lie parallel to each other, approaching the enamel surface at a slightly obtuse angle.

'Prismless' enamel refers to that area of enamel where the prisms bend abruptly or curve at the surface. This region is devoid of the usual prism markings and measures approximately 25 microns in thickness in permanent teeth. It is found most commonly in the cervical region and to a lesser extent on the smooth tooth surfaces and in the region of pits and fissures. It is slightly more radiopaque than the underlying enamel as it is better mineralised.

At an ultramicroscopic level of examination, enamel is seen to be composed of a multitude of long rodlets or crystallites embedded in a scant organic framework. The crystallites are preferentially oriented in the prisms with an inclination away from the cusps towards the cervical region with well-defined boundaries between prisms or rods. This results in poor crystalline packing and the spaces are taken up by organic material and associated water. In the 'prismless' layer, the crystallites are oriented parallel to each other and perpendicular to the enamel surface. Such an arrangement results in good crystallite packing and fewer pores. Hence, the enamel appears to be more dense (Gwinnett 1975a; Gallil, Gwinnett 1975b).

3.3.2 Acid etching of enamel for adhesive resins

Enamel is a permeable tissue. Mature enamel contains micropores, many of which are intercommunicating and are located at the periphery of the enamel prisms. This porous tissue acts as a molecular sieve, allowing for the selective passage of small ions and excluding larger molecules. Larger molecules as of the adhesive resins can be infiltrated into the enamel only by enlarging the naturally occurring micropores by modification of the outer enamel layer (Buonocore 1975).

Proteins from saliva, as well as organic products from other sources, may be adsorbed by the enamel surface, producing a nonmineralised organic covering called pellicle. The reaction of the outer enamel with various ions and salivary proteins from this pellicle leads to the enamel surface becoming relatively inert and of low surface energy. This outer fully reacted layer can be made more conducive to bonding by modification with acid treatment. This etching removes the reacted surface (Gwinnett 1975b).

The use of an acid solution to etch the enamel surface is an essential prerequisite for the successful bonding of resin to the hard tissue. The concentration of phosphoric acid packaged with commercially available resin systems falls within the range of 30-50 per cent.

It has been shown that the acid solution produces changes to the enamel surface in two distinct ways:

1. Etching removes the plaque, surface and subsurface cuticles or pellicle and the chemically inert crystallites in the surface enamel and the hypermineralised aprismatic surface
2. The remaining enamel surface is rendered porous by the acid solution to a depth of 5-25 micrometers. It is in this porous region that the resin is able to penetrate and so bond with the enamel

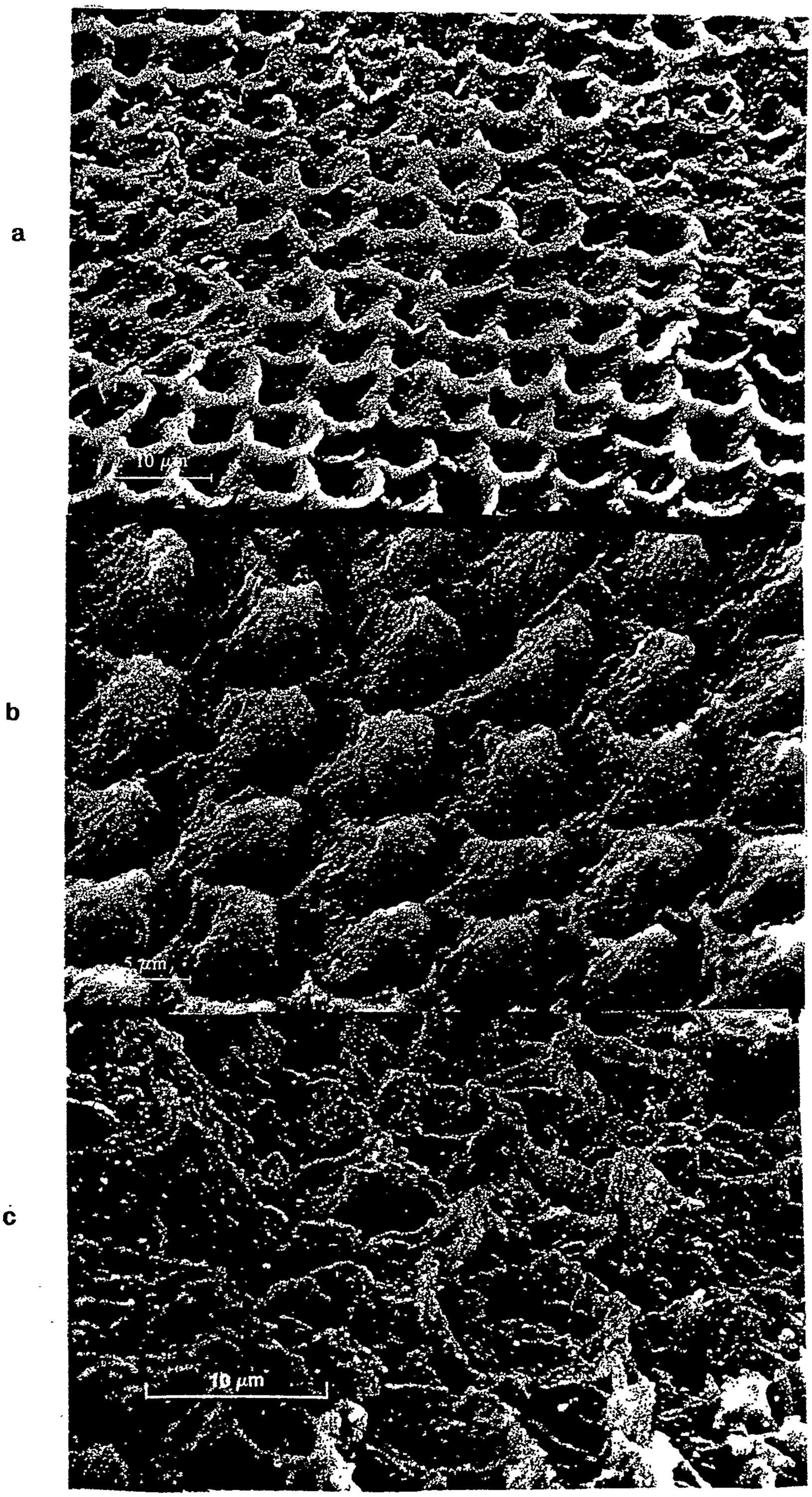
A one minute etch time appeared to result in an adequate etch pattern, provided sufficient time for the acid to penetrate, and lift off organic pellicles and dissolved thin calcified deposits not removed by the prophylaxis (Buonocore 1975; Silverstone 1975). Presently, an etch time of 15-20 seconds is recommended by the manufacturers of the commercially available sealant systems. In deciduous enamel, a satisfactory etch pattern was not produced by the application of acids with concentrations between 20-50 per cent for one minute. However, with a 30 per cent phosphoric acid solution and 120 seconds exposure, a clear etching pattern is seen (Silverstone 1975).

Morphological and chemical differences in the enamel contribute to a variety of dissolution patterns of the enamel. If the enamel prisms are perpendicular to the surface, selective decalcification will create capillaries but if the rods or prisms are parallel, selective decalcification of either cores or peripheries will produce long shallow groves instead (Ibsen, Neville 1974).

The etching raises the surface free energy of the enamel which favours wetting by the adhesive resin, and it creates minute interstices into which the adhesive may penetrate to provide mechanical interlocking between plastic and it increases the surface area across which the adhesive forces may interact. Calculations based on approximate measurements indicate a possible ten-to twenty-fold increase in surface area available for bonding as a result of acid etching (Silverstone 1975).

Microscopically the etched region of enamel shows a surface pitting and distinct pattern. Three basic patterns have been described and observed when acid in the concentration of 20-60 per cent is applied on the enamel surface as shown in Figure 5 a, b, and c.

Figure 5: **Scanning electron micrograph of etched human enamel showing**
a Type 1 etching pattern
b Type 11 etching pattern
c Type 111 etching pattern
Source: Silverstone (1975)



Type 1 etching pattern: preferential removal of prism cores. The histological change noted is the dissolution of prism rod cores producing crater-like depressions with the peripheral areas forming the walls of the crater (Figure 5a).

Type 11 etching pattern: preferential removal of the prism rod peripheries. The prism cores appear relatively intact with the peripheral areas dissolved (Figure 5b).

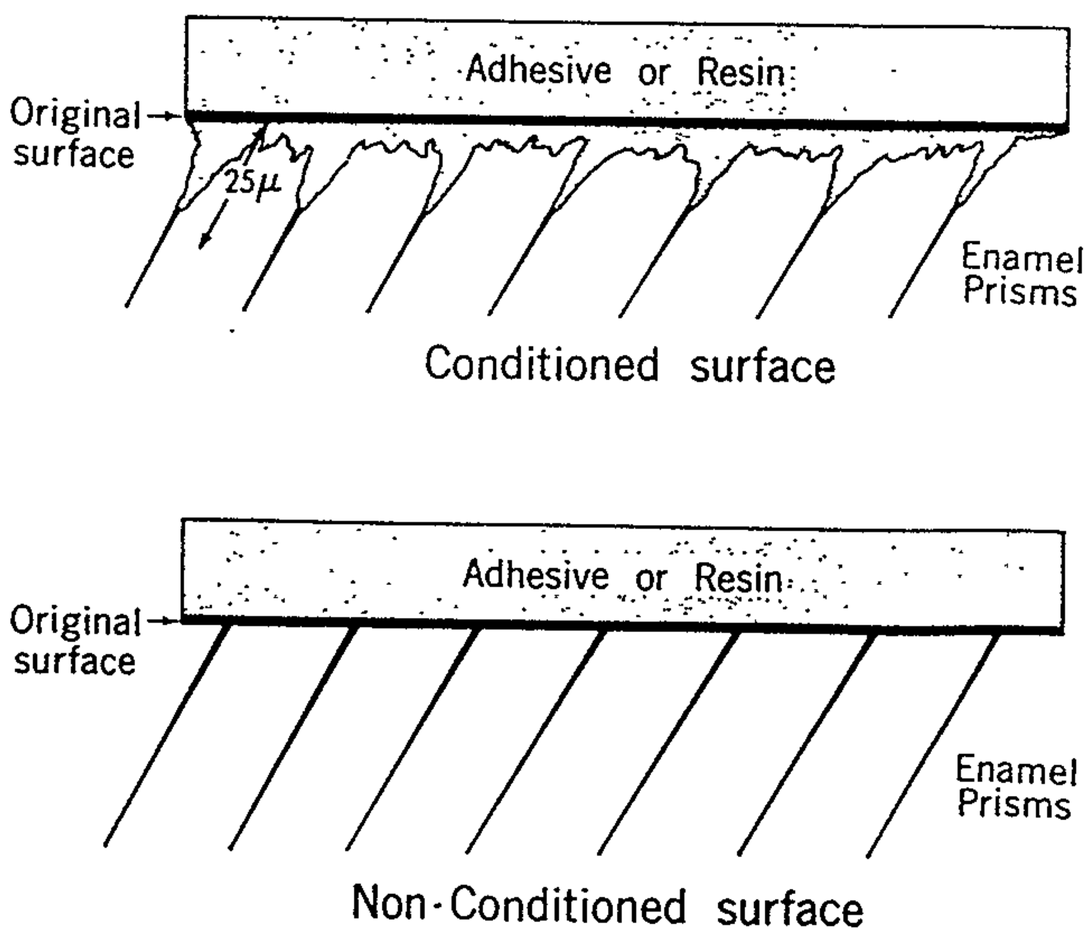
Type 111 etching pattern: the etched surface bears no resemblance to the enamel morphology. Both prism cores and peripheries were dissolved at the same rate resulting in relatively flat, pitted areas (Figure 5c).

All these types of patterns can occur on a single tooth surface, and be produced by the one acid solution with a gradual transition from one pattern to another. Good bonding phenomena occurred between resin and enamel irrespective of the etching pattern produced (Silverstone 1975; Silverstone, Saxton, Dogen, Fejerskov 1975). Acid etching of prismless deciduous enamel produces approximately the same gross loss of surface as it does on permanent teeth. Penetration of the acid, however, is restricted so that the in-depth change occurs to a much smaller degree and there is merely a random distribution of finer micropores (Buonocore 1975).

Enamel/resin interface

When an adhesive resin is applied over an etched enamel surface, it penetrates into the porosities created by etching, forming comb-like structures or tags. This forms a mechanical lock on polymerisation. Examination of the enamel/resin interface demonstrated that, provided a satisfactory initial etch had taken place, a good bond occurred between the enamel and resin irrespective of the material used. These tags can be more clearly seen if the enamel is dissolved away by strong acids *in vitro.* The resin tends to fill the microspaces by capillarity, entrapping and encapsulating the organic matter present as shown in Figure 6. The more fluid the adhesive, the greater the likelihood of penetration and tag formation (Buonocore 1975).

Figure 6 : Diagrammatic representation of an adhesive bond to an acid-conditioned enamel surface.
Source: Buonocore (1975)

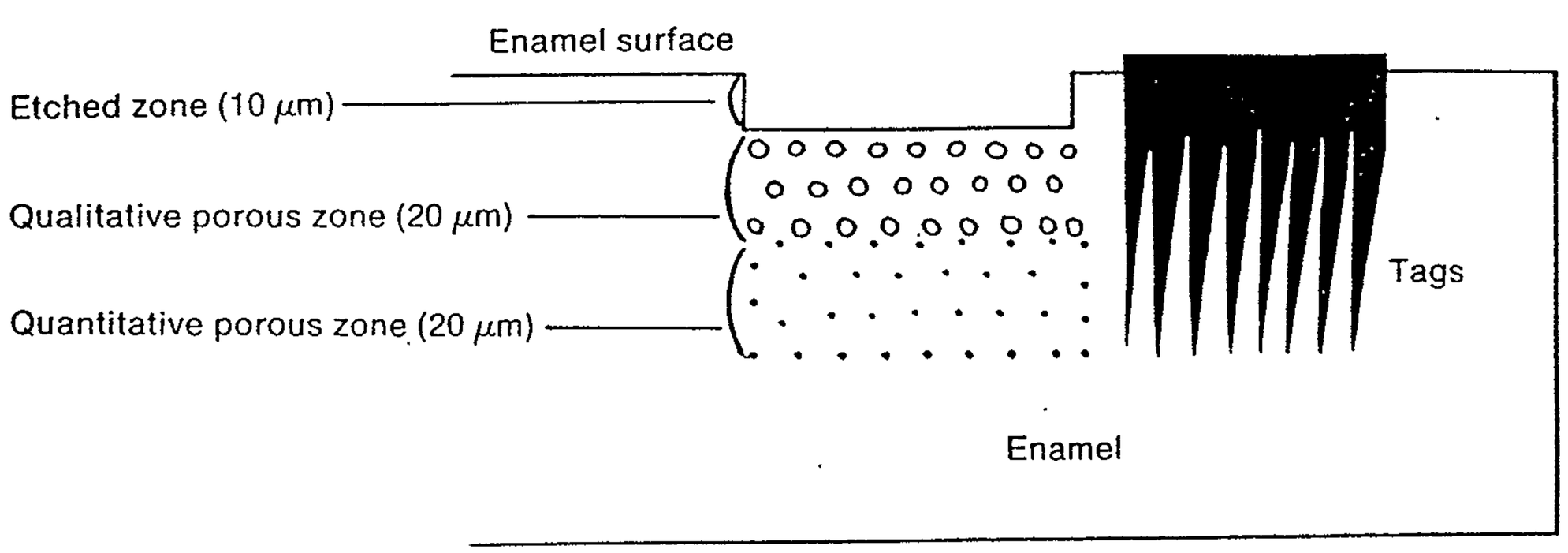


Silverstone (1975) showed that after etching with phosphoric acid the enamel is affected in advance of the regions identified by qualitative microscopy as being porous. Thus enamel surfaces etched with phosphoric acid appear to be affected at three levels and may be described in terms of three specific zones as shown in Figure 7.

1. A narrow zone of enamel some 10 micrometers deep that is lost by etching (etching zone)
2. A zone some 20 micrometers deep that is rendered porous as demonstrated by qualitative examination with the polarising microscope (qualitative porous zone)
3. A deeper zone about 20 micrometers thick and indistinguishable from sound enamel by qualitative examination that is rendered slightly porous as a result of the acid solution (quantitative porous zone). Into this third zone the tags of resin extend from the enamel surface. The penetration of resin into etched enamel and the subsequent bonding mechanism both occur at a molecular level (Silverstone 1975; 1985).

The retention of the resin is dependent on the number of tags, their depth of penetration, their rigidity and partially on their strength properties (Ibsen and Neville 1975). Teeth from highly fluoridated areas appear to be more resistant to the action of the acid etch, thus bonding to heavily fluoridated teeth appears to be less durable than on *normal* teeth, using the same etching times (Buonocore 1975).

Figure 7: **Etched and porous enamel surfaces; three distinct zones and subsequent penetration of tags of resins**
Source: Silverstone (1985).



Caries susceptibility of acid etched enamel

Results from *in vitro* studies have shown that etched enamel is definitely more susceptible to both acid dissolution and artificial caries formation than sound enamel (Silverstone 1984; Hicks, Silverstone 1982). This is because etched enamel has a greater degree of porosity and an increased surface area. However, if etched enamel is exposed to saliva for a 24 hour period and to an artificial cariogenic challenge, the extent of artificial lesion formation in both etched and sound enamel are comparable. The exposure of etched enamel to saliva for a relatively short period of time allows for remineralisation of the etched surface to occur (Hicks, Silverstone 1982). Clinical studies have shown significant reductions in caries where partial or even total loss of sealant from the teeth have occurred. The loss of sealant does not result in enamel which is more susceptible to caries, but may provide protection against the caries process due to the presence of resin tags in the enamel (Hicks, Silverstone 1982).

3.3.3 Chemical bonding of glass-ionomer cements

Glass-ionomer cements have been shown to permanently adhere to untreated enamel and dentine under the moist conditions of the mouth. The cement may adhere to the acquired pellicle or penetrate this layer and so bond directly to enamel. They also adhere to base metals, such as stainless steel, tin oxide, plated platinum and gold alloy (Wilson, Prosser 1982).

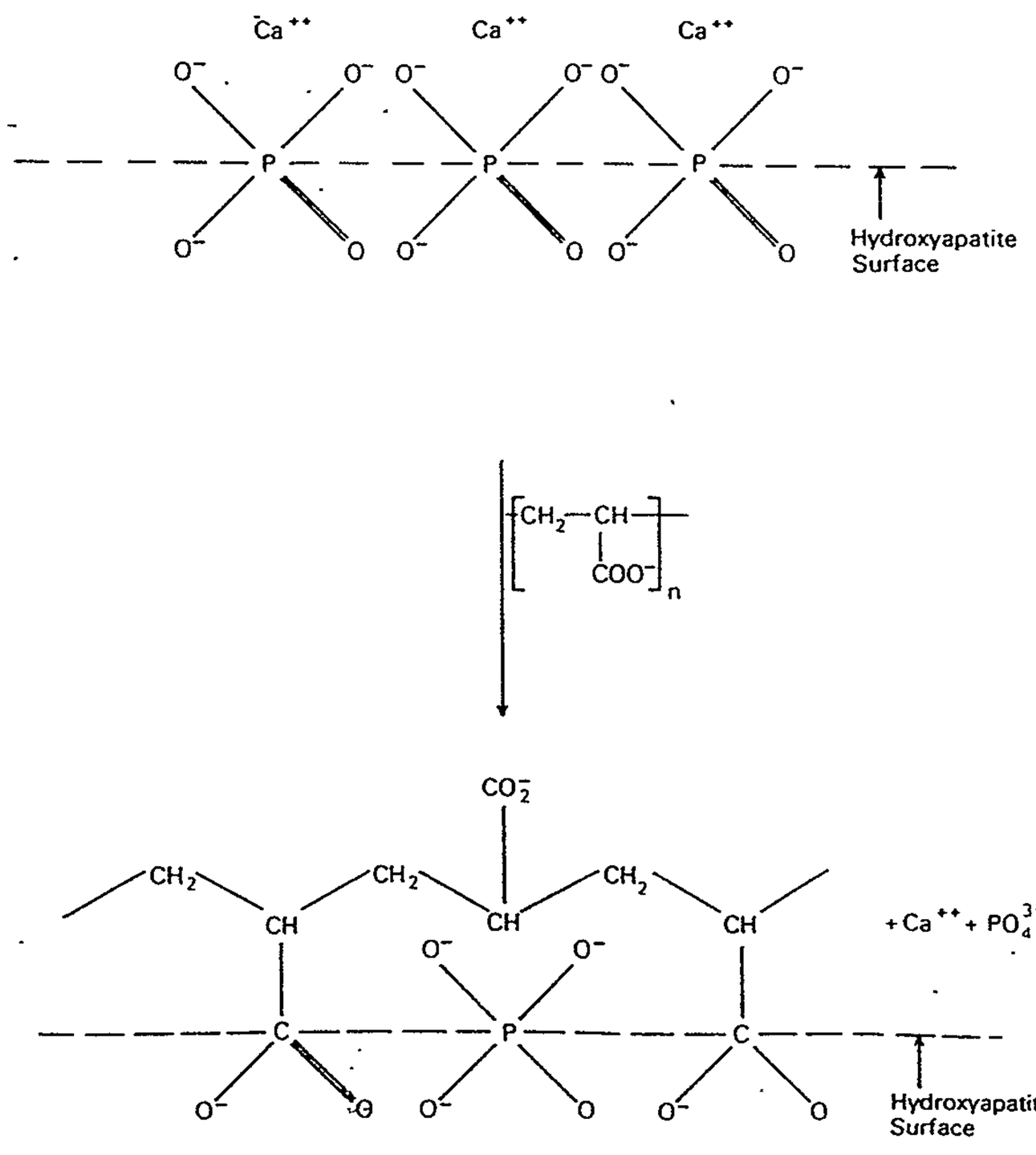
The bonding of glass-ionomer cements to enamel is of a chemical rather than a mechanical nature. The glass-ionomer cement is a highly ionic polymer that can compete successfully with water because of multiplicity of its carboxyl (-COOH) groups which can form strong hydrogen bonds to enamel apatite. The interaction between apatite and polyacrylic acid produces polyacrylate ions which then form strong ionic bonds with the surface calcium ions of apatite in enamel and dentine (Wilson, McLean 1988).

It has been postulated that during adsorption the polyion chains of the polyacrylate enter the molecular surface of hydroxyapatite, displacing and replacing surface phosphate and calcium ions as part of a complex series of ionic exchanges (Wilson, Prosser, Powis 1983). It is agreed now that bonding to enamel results from ionic and polar forces and glass-ionomer cements do not bond to collagen as illustrated in Figure 8.

Adhesion may be greatly improved by surface conditioning, not acid etching, as rough tooth surfaces are contraindicated. The smoother the surface, the

stronger the bond, and the surface conditioner actually smoothens the cut dentine or enamel surfaces. The smoothing of surface irregularities may be necessary to prevent air entrapment and to minimise sites where stress concentration could occur. Citric acid (50 per cent) was used as an effective cleansing agent to remove pellicle and debris. However, citric acid is a potential irritant. Alternative treatments which are less irritant to tissues and more effective at promoting adhesion both to enamel and dentine are now used. These include aqueous solutions of tannic acid, poly acrylic acid and dodicin. Enamel surfaces are only slightly etched. Adhesive bonding almost equals the tensile strength of the cement (Wilson, Prosser 1982).

Figure 8: **Schematic representation of a mechanism for adhesion of a polyelectrolyte cement to enamel apatite.**
Source: Wilson, Prosser, Powis (1983)



The two commonly used fissure sealant materials, Bis-GMA derivatives and glass-ionomer cements have undergone technological development over the years. The Bis-GMA derivatives permit mechanical obturation of pits and fissures for caries prevention. The use of glass-ionomer cements as a sealant may perhaps be viewed as a further improvement in the technique. One of their main advantages is their ability to bond chemically to dentine and enamel. They also have the ability to actively release fluoride into the surrounding enamel. However because of the poor physical properties of the glass-ionomer cements, the Bis-GMA materials still remain the materials of selective choice for the prevention of pit and fissure caries.

4 EFFECTIVENESS OF FISSURE SEALANTS IN PREVENTING DENTAL CARIES

The technique in which fissures are sealed with a polymeric material is now an accepted method of great potential in preventive dentistry. However, sealants prevent dental caries in pits and fissures only where the sealant is applied and retained. The first report of a successful clinical trial using sealing to prevent occlusal caries was presented in 1965 by Cueto and Buonocore. Since that time other clinical trials have been reported in which significant caries reductions have been obtained using this technique.

It is also evident that a suitable adhesive material should be a liquid of reasonably low viscosity which wets and spreads on clean tooth surfaces under oral conditions and which solidifies chemically to a material of low setting and thermal contraction. It should be mechanically strong but have some flexibility to minimise stress concentrations in the bond. The bond must also be resistant to water displacement. The materials must also be non-toxic, as such they must be tested for biocompatibility with enamel (Smith 1975).

Clinical trials both *in vitro* and *in vivo*, have been carried out over the years using various adhesive resins and glass-ionomer cements but, results from such tests are not always in agreement.

The most important considerations studied in the effectiveness of fissure sealants, in laboratory studies and clinical trials are for:

1. Depth of penetration
2. Microleakage
3. Wear resistance
4. Caries reduction
5. Retention (Smith 1975)

Generally it is proven that fissure sealants can have a highly significant effect in the prevention of occlusal caries. Many studies have documented its retention and caries prevention efficacy.

4.1 EXPERIMENTAL RESULTS WITH ADHESIVE RESINS

4.1.1 Laboratory trials

Penetration of sealant

Ideally, any resinous material used to prevent caries in occlusal surfaces should completely fill and seal the entire fissure. The ability of Bis-GMA resins to completely penetrate susceptible pits and fissures depends not only on the configuration of the fissure but greatly on its ability to penetrate into narrow crevices before hardening occurs. The results of a study by Taylor and Gwinnett (1973) reported that wide fissures were more often completely penetrated by Bis-GMA resins that narrow, constricted fissures.

The rate of sealant penetration is a function of the crevice dimension and the penetrativity of the sealant. Penetrativity can be expressed in terms of a penetration coefficient (PC), which is a function of the properties of the sealant:

surface tension

viscosity

contact angle on the capillary wall

Measurements of the PC of Nuva Seal (LD Caulk) at 25°C and 37°C showed that at 37°C, the PC was 2.5 times that at 25°C, this increase being due to a decrease in the viscosity of the sealant at the higher temperature. These results show that the PC is highly temperature dependent. The time required for a sealant to penetrate a specific distance is highly dependent on the PC of the sealant (Fan, Seluk, O'Brien 1975).

Fan, O'Brien and Craig (1979) in further laboratory studies have found that the PC is higher and the contact angle is lower for Delton (Johnson and Johnson) than for Nuva Seal (LD Caulk). These properties result in better wetting and increased penetration of Delton into the teeth which should enhance its clinical performance.

The adhesive bond strength of a sealant to the enamel is influenced by the degree of penetration of polymeric tags into the etched enamel surface. Breakspere and Wilton (1977) reported that to produce a large number of well formed tags, the sealant should, before polymerisation, be brushed into the etched surface. Thus, the length and population of the tags is not dependent upon the viscosity of the unpolymerised sealant, provided that the sealant is brushed into the etched surface.

Powell and Craig (1978) did an *in vitro* investigation of the penetrating efficacy of 2 Bis-GMA products - Nuva Seal (LD Caulk) and Epoxylite 9075 (Lee). They showed that wide fissures were more often completely penetrated by the products than constricted fissures. Thus, the frequency of incomplete penetration of constricted fissures was very high.

The penetration coefficients (PC) and tensile bond strengths of eight pit and fissure sealants, all commercially available, Bis-GMA resins were determined by Wright and Retief (1984). The eight materials studied were Delton (Johnson & Johnson), Delton Tinted pit and fissure system (Johnson &

Johnson), Concise white sealant system (3M), Concise enamel bond system, (3M), Nuva Seal (LD Caulk), Nuva Cote (LD Caulk), Prisma Shield (LD Caulk) and Visio Seal (ESPE Premier). The first four of the above are chemically cured two-component systems. Nuva Seal and Nuva Cote are polymerised by U-V light and Nuva Cote also contains filler particles. Prisma Shield and Visio Seal were the newer visible light cured systems. The penetration coefficients were generally consistent with those reported previously by Fan et al.(1975). Although the penetration coefficients of the eight materials varied significantly, there were no significant differences in the resins' tensile bond strengths to etched enamel. Similar tensile bond strengths were obtained regardless of the materials penetration coefficient value or the presence of filler particles. All the commercials sealants evaluated had flow properties adequate for producing a strong enamel/resin bond.

Microleakage

Sealant materials when placed in pits and fissures, with proper sealing, are expected to isolate such areas of viable enamel from a cariogenic environment. The success of the sealant, therefore, depends on the efficacy of the resin to seal these vulnerable areas and to maintain the seal for prolonged periods.

The sealing ability of the commercially available pit and fissure sealants as well as experimental materials were examined *in vitro* for microleakage in several studies. Dye penetration occurred in all materials tested, but the type of penetration varied between the commercially available pit and fissure sealants and the glass-ionomer cements.

Williams, von Fraunhofer and Winter (1975) studied the microleakage of sealants, determined by dye penetration and zero resistance current measurement studies. The materials consisted of ESPE 717 and 71729 (ESPE), Nuva Seal (LD Caulk), Epoxylite 9075 (Lee) and 2 cements, Poly F and ASPA. The materials were applied to premolars, which were then placed in a solution of 0.1 per cent fluorescent calcium bonding solution for up to 8 weeks.

Penetration occurred in all materials at some point in time but the type of penetration varied between the resins and the cements. With the resins, penetration tended to be along the enamel/sealant interface. In the cements, the body of the material was freely permeable.

A zero resistance ammeter technique was used to measure the galvanic current exhibited by a sheet of steel, when coupled to zinc, coated with the sealant in aqueous chloride medium. Passage of current, meaning a continuous electrolyte pathway between zinc and steel, indicated leakage through and/or around the sealant. These zero resistance current measure studies supported the dye penetration findings.

Jensen and Handleman (1978) compared 6 different fissure sealants: Concise Enamel Bond System (3M), Delton (Johnson & Johnson), Epoxylite 9075 (Lee), Kerr Pit and Fissure Sealant (Kerr/Sybron), Nuva Seal (LD Caulk) and an experimental filled sealant. These sealants were applied to 48 caries free third molars. After a week's storage in water, the specimens were thermocycled at 1 minute intervals for 2 hours at 60 ± 3°C and 8 ± 3°C and then immersed in a 0.25 per cent aqueous solution of basic fuchsia for 24 hours.

Of the 48 specimens, the 8 teeth covered with Epoxylite 9075 had the worst results. Two of these teeth showed total loss of the sealant and penetration of dye into the dentine; the other 6 displayed varying amounts of sealant loss but without dye penetration into the enamel. None of the other specimens showed marginal leakage.

Speiser and Segat (1978) did a similar *in vitro* study on the sealing properties of Delton (Johnson & Johnson), Nuva Seal (LD Caulk), Epoxylite 9075 (Lee), Kerr Pit and Fissure Sealant (Kerr/Sybron) and Concise White Pit and Fissure Sealant (3M) on 175 extracted mandibular and maxillary premolars and molars. The specimens were thermocycled in dye baths of 0.5 per cent basic fuchsia alternatively between 10°C and 70°C for 600 one-minute intervals. All materials exhibited dye penetration. Delton exhibited the least dye penetration. No significant difference in leakage was found between Delton, Nuva Seal and Epoxylite 9075 but Delton differed significantly from Kerr and Concise. Tooth type had no bearing on dye penetration in any resin group.

Sealant Wear

Wear of sealants occurs with time in the oral cavity, and the sealant becomes thinner and wears away due to occlusal and masticatory forces. This could be a result of a combination of factors, including fractures and loss of filler particles, loss of resin matrix, failure of the matrix through cracking and exposure of entrapped bubbles of air.

The wear of three commercial pit and fissure sealants was investigated in an *in vitro* study by Roberts, Powers and Craig (1977). Samples of the sealant materials, Kerr Pit and Fissure Sealant (Kerr/Sybron), Delton Pit and Fissure Sealant (Johnson & Johnson) and Nuva Seal (LD Caulk), were abraded on silicone carbide paper with continuous flushing of water, and their surfaces were scratched by a diamond hemisphere under load. There was no significant difference in the abrasion resistance of the three sealants. However, Nuva Seal had the highest value of surface failure as compared to Delton Pit and Fissure Sealant and Kerr Pit and Fissure Sealant. Kerr Pit and Fissure Sealant is a filled resin, thus it exhibited greater resistance to penetration and surface damage done by the diamond transversing its surface as compared to Delton, an unfilled resin.

The quantitative wear of sealants in vivo was assessed by Jensen, Handelman and Pameijer (1978). They used a tooth replica technique where thirty two caries free permanent premolars and molars were sealed with either Nuva Seal (LD Caulk) or an experimental, filled sealant. Pre- and post-sealant impressions were taken with an elastic impression material. Silver copings were made by electroplating the vinyl-epoxy dies of the immediate post-sealant impressions. At the 7 and 16 month recall visits, new impressions were taken and new dies were made. The pre-sealant dies were then placed in their respective copings. The amount of sealant applied was determined by placing impression material in the coping prior to placement of the pre-sealant dies. Pressure was applied with a C-clamp. The material contained in the space between the die and coping was then weighed. The amount of sealant lost was determined in a similar fashion using the recall dies and their respective copings.

Sealant wear was calculated as the percentage loss of sealant initially applied. The two types of sealants appeared to wear equally. The preliminary evaluation of the data shows that the greatest sealant loss occurred within the first 7 months. The average sealant loss was about 65 per cent from the premolars and about 80 per cent from the molars during this period. The sealant lost from the molar teeth was at a more rapid rate compared to the premolars.

Jensen, Handleman and Perez-Diez (1985) tested four different commercially available sealants:

1. Delton (Johnson & Johnson), a self polymerising, unfilled sealant
2. Kerr (Kerr), a self polymerising filled sealant
3. Nuva Cote (LD Caulk), a U-V light polymerised filled sealant
4. Nuva Seal (LD Caulk), a U-V light polymerised unfilled sealant

These sealants were placed in caries-free permanent premolars and molars for a total of 381 teeth in 53 young participants. The volumetric loss of sealant material was evaluated over a two-year period using a similar tooth replica technique as mentioned earlier. The pattern of progressive sealant loss was measured. The findings of the results are tabulated in Table 2.

Table 2: Volumetric sealant loss in mm^3 by tooth type and material
Source: Jensen, Handelman, Perez-Diez (1985)

Material	Tooth Type	Mean Volume Applied ($mm^3 \pm$ S.E.)	Sealant Loss (± S.E.)				
			1 mo.	6 mo.	12 mo.	18 mo.	24 mo.
Delton	Premolars Molars	8.29(.56) 13.77(.67)	3.57(.39) 6.87(.60)	4.49(.52) 7.39(.51)	4.64(.22) 8.84(.58)	5.13(.55) 9.11(.61)	6.13(.68) 9.88(.74)
Kerr	Premolars Molars	6.06(.32) 14.03(1.11)	3.09(.17) 7.86(.81)	3.57(.17) 8.61(.89)	3.76(.19) 9.47(1.00)	4.14(.25) 10.50(1.08)	4.62(.21) 11.53(1.01)
Nuva-Cote	Premolars Molars	8.78(.59) 15.58(1.27)	5.36(.50) 7.38(.57)	5.73(.53) 9.03(.46)	5.59(.46) 8.91(.67)	6.20(.57) 9.62(.77)	6.37(.54) 10.67(.74)
Nuva-Seal	Premolars Molars	8.09(.60) 15.54(.95)	4.00(.37) 9.06(.58)	4.75(.34) 9.66(.56)	5.45(.53) 10.48(.54)	5.90(.49) 11.39(.69)	6.05(.42) 12.06(1.26)

There were no statistically significant differences in clinical wear rates between filled and unfilled sealants, or between self polymerising and U-V polymerising sealants. However, Delton, a self-polymerising, unfilled sealant, tended to perform better at all times. The greatest amount of sealant loss for both premolars and molars occurred within the first month following sealant application, accounting for more than half of the total sealant loss during the two year study period. The authors concluded that some initial wear is desirable to help re-establish proper occlusion.

There were no patient complaints of tooth or tempero-mandibular joint sensitivity due to increased vertical dimension of the occlusion after sealant application on the occlusal surfaces of the posterior teeth. During the two year study period, only 9 of 381 teeth (2.4 per cent) were judged to be at risk or carious, by the investigator or by the parents' private dentist, requiring resealing or restoration at the 18 or 24 month recalls (Jensen et al. 1985).

The problem of sealant wear is obscure because it is difficult to distinguish between the sealant wear and loss of material due to moisture contamination, inadequate curing or faulty material manipulation. The methods currently used to evaluate clinical performance of fissure sealants fall into two broad categories: qualitative methods and quantitative methods. Both of these methods have a potential for subjective error. An alternative approach, which is independent of mechanical manipulation, is to use a computer to align the surfaces.

Since both qualitative and quantitative information is stored on magnetic disk, it provides a permanent record of wear at a given time and serves as a reference for sequential measurements over time (Conry, Pintado, Douglas 1990).

The study conducted by Conry et al.(1990) showed that all fissure sealants undergo a progressive wear process, which exposes previously covered areas of the occlusal surface. Maxillary teeth exhibited a greater amount of sealant loss than mandibular teeth for all parameters, volume, area and depth.

4.1.2 Clinical trials

The purpose of sealants is to inhibit occlusal decay, as such the success of this treatment is measured by the degree to which treated teeth do not develop occlusal caries. The caries protection provided by sealants is a function of their ability to remain firmly adherent to the tooth surface. Thus, clinical evaluations of sealant performance involve a determination of occlusal caries reduction and their retention on the teeth. Examinations of the results of clinical trials that compared sealed and unsealed teeth is an appropriate way to assess sealant effectiveness.

Sealant effectiveness can be actually evaluated by:

1. the per cent effectiveness, the statistic frequently used in clinical trials to compare the caries rate of sealed and unsealed teeth
2. the per cent of complete sealant retention
3. the per cent of sealed teeth becoming carious and/or restored
4. reapplication rates (Weintraub 1989)

Occlusal Caries Reduction

Clinical trials have traditionally been done using a half-mouth design, that is, the unilateral sealing of homologous pairs of posterior teeth. The double blind design usually preferred in clinical trials cannot be used in the case of fissure sealants. In the half-mouth study design, a pair of caries-free molars of the same tooth type on contralateral sides of the mouth were selected; one member of the pair was sealed, while the other remained unsealed to serve

as a passive control. The results of these studies varied with type of teeth sealed, their morphology and posteruptive age, and the application techniques used (Rock 1975, Weintraub 1989).

In most clinical trials, the sealant has been applied only at the initial visit and then the children are recalled at yearly intervals. At the recall examination, the teeth are visually checked for caries or by radiographs. The treated teeth are also examined for the presence of sealant. If the occlusal surface is completely sealed at the recall visit, it is presumed that the surface is caries-free. Most studies report the results after only one application of sealant, though effectiveness is increased if sealant is repaired or replaced as necessary (Straffon, Dennison, More 1985).

As teeth are evaluated as treatment-control pairs, an index called "net gain" utilises the fate of paired teeth to analyse the treatment effectiveness of sealants. This method recognises that four outcomes are possible for each tooth pair; that is,

1. treated sound and control carious
2. treated carious and control carious
3. treated sound and control sound
4. treated carious and control sound

"Net gain" is the absolute number of treated teeth estimated to have been saved from caries by the sealant treatment. It is calculated by subtracting the

number of treated carious, control sound pairs from the number of treated sound, control carious pairs (Ripa 1985).

The ability of sealants to inhibit caries has also been evaluated by the "per cent effectiveness" method. It is calculated by dividing the net gain by the total number of carious control teeth and multiplying by 100 to obtain a percentage (Ripa 1985).

Table 3 presents the occlusal caries reductions for permanent teeth obtained from various clinical sealant studies. The results are listed according to decreasing order of effectiveness.

Table 3: Occlusal caries reductions from the use of sealants on permanent teeth
Source: Adapted from Ripa 1985

Study (Year)	Type of Permanent Teeth	Polymerisation Method	Percent Occlusal Caries Reduction
	ONE YEAR AFTER SEALANT APPLICATION		
Buonocore 1970	premolars, 1st & 2nd molars	UV	100
Rock 1973	premolars, 1st & 2nd molars	UV	100
	premolars, 1st & 2nd molars	Chem	81
Houpt & Sheykholeslam 1978	1st molars	Chem	91
Bojanini et al 1976	1st molars	Chem	91
Bagramian et al 1976	1st molars	UV	88****
	premolars, 1st 7 2nd molars	UV	79
Charbeneau et al 1977	1st molars	Chem	83
Charbeneau & Dennison 1979	1st molars	Chem	83
Low 1982	premolars, 1st & 2nd molars	UV	82
McCune et al 1973	premolars, 1st & 2nd molars	UV	81-85*
Thylstrup & Poulsen 1976	1st molars	Chem	70
Rock et al 1973	1st molars	Chem	67
Rock 1972	premolars, 1st & 2nd molars	UV	65
Gourley 1974	premolars, 1st & 2nd (?) molars	UV	65
	ONE AND A HALF YEARS AFTER SEALANT APPLICATION		
Meurman et al 1975	1st molars	UV	88
Charbeneau et al 1977	1st molars	Chem	76
	TWO YEARS AFTER SEALANT APPLICATION		
Buonocore 1971	premolars, 1st & 2nd molars	UV	99
Rock 1974	premolars, 1st & 2nd molars	UV	99
	premolars, 1st & 2nd molars	Chem	84
McCune et al 1979	1st molars	Chem	93
Sheykholeslam & Houpt 1978	1st molars	Chem	88
Bagramian et al 1977	premolars, 1st & 2nd molars	UV	77****
	1st molars	UV	74
Low 1982	premolars, 1st & 2nd molars	UV	77
Charbeneau & Dennison 1977	1st molars	Chem	74
Brooks et al 1979	1st molars	Chem	71
	1st molars	UV	38
Horowitz et al 1974	premolars, 1st & 2nd molars	UV	67
Gourley 1975	premolars, 1st & 2nd (?) molars	UV	58
Going et al 1976	premolars, 1st & 2nd molars	UV	55
Higson 1976	1st molars	UV	23
Burt et al 1977	premolars, 1st & 2nd molars	UV	14

Table 3 continued

Study (Year)	Type of Permanent Teeth	Polymerisation Method	Percent Occlusal Caries Reduction
	THREE YEARS AFTER SEALANT APPLICATION		
McCune et al 1979	1st molars	Chem	85
Houpt & Shey 1979	1st molars	Chem	78
Bagramian et al 1978	premolars, 1st 7 2nd molars	UV	73
	1st molars	UV	73
Brooks et al 1979	1st molars	Chem	69
	1st molars	UV	39
Rock 1977	premolars, 1st & 2nd molars	UV	68
Richardson et al 1980	1st molars	Chem	64
Charbeneau & Dennison 1978	1st molars	Chem	64
Rock & Bradnock 1981	1st molars	Chem	36
	FOUR YEARS AFTER SEALANT APPLICATION		
Houpt, Shey 1983	1st molars	Chem	72
Richardson et al 1980	1st molars	Chem	62
Mertz-Fairhurst et al 1981	1st molars	Chem	62**
	1st molars	UV	14**
Charbeneau & Dennison 1979	1st molars	Chem	54
Horowitz et al 1976	premolars, 1st & 2nd molars	UV	45
Gong et al 1977	premolars, 1st & 2nd molars	UV	43
Leake & Martinello 1976	1st molars	UV	22
	FIVE YEARS AFTER SEALANT APPLICATION		
Meurman et al 1978	1st molars	UV	60
Richardson et al 1981	premolars, 1st & 2nd molars	UV	58
Gibson et al 1982	1st molars	Chem	51
Horowitz et al 1979	premolars, 1st & 2nd molars	UV	37
Bagramian 1982	premolars, 1st & 2nd molars	UV	42-17***
	1st molars	UV	32-17***
	SIX YEARS AFTER SEALANT APPLICATION		
Houpt & Shey 1983	1st molars	Chem	56
Mertz-Fairhurst et al 1982	1st molars	Chem	55
		UV	8
	SEVEN YEARS AFTER SEALANT APPLICATION		
Mertz-Fairhurst et al 1984	1st molars	Chem	55
		UV	12

* 2 examiners
** 4-5 years after application
*** retreatments for 5 years; retreatments for 3 years respectively
**** sealant and topical fluoride treatment provided to children in this group, sealants reapplied if lost
UV = ultraviolet light polymerised sealant
Chem = Chemically polymerised sealant

There is a variation in the occlusal caries reductions reported in the 5 year studies. The data in Table 3 shows that per cent effectiveness decreases with number of years since sealant application, however, within each time period there is a wide range of results. By disregarding the particulars of the individual studies and averaging the results on an annual basis, Ripa (1985) found occlusal caries reductions of 82, 68, 65, 43, 36, 40 and 34 per cent from one through seven years after sealant application. Since most of these studies applied sealants only once, the results represent a dramatic reduction in caries on the occlusal surfaces, achieved with a minimum amount of effort.

It is also noted from the table that as the duration of the trials increase, the chemically initiated sealants perform better than the U-V light cured sealants. Studies which directly compared the caries reduction by the two sealant types, reported that a chemically cured sealant provided superior caries protection than the U-V light cured sealant (Mertz-Fairhurst, Fairhurst, Williams, Della-Giustina, Brooks 1984).

Studies by Simonsen (1981b; 1987), produced favourable ten year per cent effectiveness results, based on a comparison group, not a half-mouth design and small sample size. Sixteen pairs of sealed and control sites were compared at the 10 year examination. Eighty four per cent of the pit and fissure sealants were sound after 10 years. After 15 years, in the sealed group of 24 patients, 74 per cent of the pit and fissure surfaces of the permanent first molars were sound. In the matched pair analysis of 16 pairs of patients,

carious or restored surfaces of permanent first molars made up 82.8 per cent of the surfaces in the unsealed group.

Mertz-Fairhurst, Fairhurst, Williams, Della-Guistina, Brooks (1982), in their study concluded that the median effectiveness after one application of sealant declined from 71 per cent after 2 years to 55 per cent after 7 years. This was a 6 year study utilising Delton (Johnson & Johnson).

The results of these long term evaluations strongly suggest that sealants are capable of long term retention and caries prevention.

Table 4 shows the percent effectiveness of sealants when the fluoride status of the community is taken into consideration. The median effectiveness figure for fluoridated communities is better than for fluoride deficient communities after one and two years. This relationship however reverses after three and four years and results are similar for both communities after six years. In addition to the fluoride status and the caries rate in the community, the selection criteria for participants in sealant studies and the exposure of participants to other caries preventive agents also influence the per cent effectiveness.

Table 4: **Per cent effectiveness of sealants by fluoride status of community and length of time since sealant application.**
Source: Adapted from Weintraub (1989)

Fluoride Status	First Author	Number of Years						
		1	2	3	4	5	6	7
NF	Thylstrup (1976, 1978)	69	50					
NF	Gibson (1982)			64	62	51		
NF	Houpt vis. light (1987)	88	87	79	77	67	56	
Median		79	69	72	70	59	56	
F	Charbeneau (1979)	83	74	64	54			
F	McCune (1979)		93	85				
F	Mertz-Fairhurst (1984)		71	69	62		55	55
Median		83	74	69	58		55	55

F = fluoridated
NF = not fluoridated

Sealant Retention

The magnitude of the occlusal caries reduction is a function of the sealant ability to remain firmly adherent to the acid etched tooth. Since significant leakage does occur between the sealant and tooth (William et al. 1975; Speiser, Segat 1978) a sealant is believed to be effective as long as it adheres to the occlusal surface and continuous to act as a physical barrier between caries susceptible pits and fissures and the oral environment. Retention, thus, is a prime determinant of sealant success together with marginal integrity (Mertz-Fairhurst et al. 1984).

The caries reduction studies were abandoned once the efficacy of sealants was positive. It was also shown through the first generation sealant studies that effectiveness was a direct function of sealant retention (Mertz-Fairhurst 1984; Rock 1984). The half-mouth design of studies withholds half of the treatment benefit to the patient, thus sealant studies can no longer ethically use this design (Mertz-Fairhurst et al.1982) Thus, the more recent sealant studies have used a whole mouth design in which all of the teeth indicated in subjects' mouths are treated. Success in fissure sealant programs is now judged on the basis of retention. At recall, examination of treated teeth is done both visually and with the tip of an explorer to determine the presence of the sealant. Only pits and fissures which are completely covered by the sealant are finally considered in most retention studies (Ripa 1985).

Sealant studies also moved towards designs that compared two types of sealant instead of using an unsealed passive control. The retention of occlusal sealants on permanent teeth obtained from numerous clinical studies is tabulated in Table 5. The data is also listed in decreasing order of retention. Sealant retention also demonstrates a wide variability for a given time interval after placement. Most studies show a retention of 70-99 per cent after 1-2 years of sealant application. The average retention figures from one to seven years after sealant application are 80, 71, 58, 51, 43, 54 and 49 per cent respectively. Generally sealants were applied only once to the teeth (Ripa 1985).

Table 5: Retention of occlusal sealants on permanent teeth
Source: Adapted from Ripa (1985)

Study (Year)	Type of Permanent Teeth	Polymerisation Method	Percent Retention Completely Covered Teeth
	ONE YEAR AFTER SEALANT APPLICATION		
Stephen et al 1981	1st molars	UV	100
	1st molars	Chem	99
Buonocore 1970	premolars, 1st & 2nd molars	UV	99
Simonsen 1975	premolars, 1st & 2nd molars	Chem	96
Sveen & Jensen 1984	premolars, 1st & 2nd molars	Chem	96
	premolars, 1st & 2nd molars	V-L	94
Brooks et al 197	1st molars	Chem	95
	1st molars	UV	84
Stephen 1981	premolars, 1st & 2nd molars	UV	95
	premolars, 1st & 2nd molars	UV	90
Li et al 1981	premolars, 1st & 2nd molars	Chem	94
	premolars, 1st & 2nd molars	UV	82
Houpt & Sheykholeslam 1978	1st molars	Chem	94
Stephen et al 1978	1st molars	UV	93
Eidelman et al 1983	1st & 2nd molars	Chem	93
	1st & 2nd molars	Chem	92
Bojanini et al 1976	1st molars	Chem	92
Low 1982	premolars, 1st & 2nd molars	UV	90
Romcke et al 1990	1st molars	Chem	89
McCune et al 1973	premolars, 1st & 2nd molars	UV	88
Ferguson & Ripa 1980	premolars, 1st & 2nd molars	Chem	88
	premolars, 1st & 2nd molars	UV	70
Gourley 1974	premolars, 1st & 2nd (?) molars	UV	87
Rock 1973	premolars, 1st & 2nd molars	UV	86
	premolars, 1st & 2nd molars	Chem	53
Rock et al 1978	premolars, 1st & 2nd molars	Chem	85
	1st molars	Chem	53
Charbeneau et al 1977	1st molars	Chem	79
Charbeneau & Dennison 1979	1st molars	Chem	79
Leske et al/Cons et al 1976	1st molars	UV	77
Rock & Evans 1982	1st molars	Chem	76
	1st molars	V-L	75
Thylstrup & Poulsen 1976	1st molars	Chem	73
Risager & Poulsen 1976	1st molars	UV	69
Harris et al 1976	premolars, 1st & 2nd molars	UV	54
Fuks et al 1982	premolars, 1st & 2nd molars	Chem	60
Cline & Messer 1979	premolars, 1st & 2nd molars	UV	58
Rock 1972	premolars, 1st & 2nd molars	UV	54
Stiles et al 1976	?	UV	51
Whitehurst & Soni 1976	1st & 2nd molars	UV	18
	ONE AND A HALF YEARS AFTER SEALANT APPLICATION		
Li et al 1981	premolars, 1st & 2nd molars	Chem	92
	premolars, 1st & 2nd molars	UV	77
Meurman et al 1975	1st molars	UV	88
Low 1982	premolars, 1st & 2nd molars	UV	81
Charbeneau et al 1977	1st molars	Chem	76
Whitehurst & Soni 1976	1st & 2nd molars	UV	10

Table 5 continued

Study (Year)	Type of Permanent Teeth	Polymerisation Method	Percent Retention Completely Covered Teeth
	TWO YEARS AFTER SEALANT APPLICATION		
Simonsen 1980	premolars, 1st & 2nd molars	Chem	96
Williams et al 1978	premolars, 1st & 2nd molars	Chem	96
	premolars, 1st & 2nd molars	UV	53
Eidelman et al 1983	1st & 2nd molars	Chem	96
	1st & 2nd molars	Chem	88
Ball 1981	premolars, 1st & 2nd molars	Chem	94
Li et al 1981	premolars, 1st & 2nd molars	Chem	92
	premolars, 1st & 2nd molars	UV	78
McCune et al 1979	1st molars	Chem	88
Buonocore 1971	premolars, 1st & 2nd molars	UV	87
Sheykholeslam & Houpt 1978	1st molars	Chem	85
Brooks et al 1979	1st molars	Chem	84
	1st molars	UV	58
Stephen 1981	premolars, 1st & 2nd molars	UV	83
	premolars, 1st & 2nd molars	UV	79
Rock 1974	premolars, 1st & 2nd molars	UV	80
Gourley 1975	premolars, 1st & 2nd (?) molars	UV	78
Horowitz et al 1974	premolars, 1st & 2nd molars	UV	73
Low 1982	premolars, 1st & 2nd molars	UV	72
Charbeneau & Dennison 1979	1st molars	Chem	71
Going et al 1976	premolars, 1st & 2nd molars	UV	69
Richardson et al 1977	premolars, 1st & 2nd molars	UV	61
Poulsen et al 1979	1st molars	Chem	58
Rock 1974	premolars, 1st & 2nd molars	Chem	52
Cline & Messer 1979	premolars, 1st & 2nd molars	UV	52
Leske et al/Cons et al 1976	1st molars	UV	50
Harris et al 1976	premolars, 1st & 2nd molars	UV	45
Burt el al 1977	premolars, 1st & 2nd molars	UV	27
Higson 1976	1st molars	UV	3
	THREE YEARS AFTER SEALANT APPLICATION		
Simonsen 1981	premolars, 1st & 2nd molars	Chem	94
McCune et al 1979	1st molars	Chem	88
Brooks et al 1979	1st molars	Chem	80
	1st molars	UV	60
Houpt & Shey 1979	1st molars	Chem	77
Rock & Bradnock 1981	premolars, 1st & 2nd molars	Chem	77
	1st molars	Chem	41
Richardson et al 1980	1st molars	Chem	75
Anson et al 1982	premolars, 1st & 2nd molars	UV	75
Rock 1977	premolars, 1st & 2nd molars	UV	70
Charbeneau & Dennison 1979	1st molars	Chem	60
Rock & Evans 1983	1st molars	Chem	56
	1st molars	V-L	43
Cline & Messer 1979	premolars, 1st & 2nd molars	UV	41
Harris et al 1976	premolars, 1st & 2nd molars	UV	37
Bagramian et al 1979	premolars, 1st & 2nd molars	UV	37
	1st molars	UV	11
Messer & Cline 1980	premolars, 1st & 2nd molars	UV	34
Leske et al/Cons et al 1976	1st molars	UV	33

Table 5 continued

Study (Year)	Type of Permanent Teeth	Polymerisation Method	Percent Retention Completely Covered Teeth
	FOUR YEARS AFTER SEALANT APPLICATION		
Williams & Winter 1981	premolars, 1st & 2nd molars	Chem	88
	premolars, 1st & 2nd molars	UV	36
Mertz-Fairhurst et al 1981	1st perm. molars	Chem	72*
	1st perm. molars	UV	35*
Richardson et al 1980	1st molars	Chem	69
Charbeneau & Dennison 1979	1st molars	Chem	52
Horowitz et al 1976	premolars, 1st & 2nd molars	UV	50
Going et al 1977	premolars, 1st & 2nd molars	UV	50
Cline & Messer 1979	premolars, 1st & 2nd molars	UV	34
Leake & Martinello	1st molars	UV	22
	FIVE YEARS AFTER SEALANT APPLICATION		
Simonsen 1987	1st molars	V-L	82
Gibson et al 1982	1st molars	Chem	67
Horowitz et al 1977	premolars, 1st & 2nd molars	UV	42
Richardson et al 1981	premolars, 1st & 2nd molars	UV	19
	SIX YEARS AFTER SEALANT APPLICATION		
Mertz-Fairhurst et al 1982	1st molars	Chem	68
	1st molars	UV	37
Houpt & Shey 1983	1st molars	Chem	58
	SEVEN YEARS AFTER SEALANT APPLICATION		
Mertz-Fairhurst et al 1982	1st molars	Chem	66
	1st molars	UV	31
Romcke et al 1990	1st molars	Chem	63
	TEN YEARS AFTER SEALANT APPLICATION		
Simonsen 1987	1st molars	V-L	57
Romcke et al 1990	1st molars	Chem	41
	FIFTEEN YEARS AFTER SEALANT APPLICATION		
Simonsen 1991	1st molars	V-L	28

UV = ultraviolet light polymerized sealant
Chem = chemically polymerized sealant
V-L = visible light polymerized sealant
* 4-5 years after application

Simonsen (1981b) showed that after 3 years, there was complete retention of 94 per cent for 605 teeth studied. Loss of sealant was attributed almost exclusively to a breakdown in the application technique. Simonsen used Concise White Sealant (3M), an auto polymerising agent. Sealant retention was 94 per cent after 5 years, and 84 per cent at 10 years. After 15 years, 27.6 per cent of the teeth had complete retention and 35 per cent of permanent first molars had a partial retention rate of 35 per cent (Simonsen 1991).

Mertz-Fairhurst et al.(1982), did a comparative study with Delton (Johnson & Johnson), a chemically cured resin and Nuva Seal (LD Caulk), a U-V cured sealant. The results showed a complete retention rate of 68 per cent with Delton as compared to a retention rate of 37 per cent with Nuva Seal. The difference was found to be highly significant ($P < 0.001$).

For comparable time periods, chemically cured sealants have a greater longevity in the mouth than U-V cured sealants. This difference is substantiated by the results of a few studies which clinically compared two sealant materials. Mertz-Fairhurst et al.(1982; 1984) and Williams and Winter (1981) did studies which substantiated better retention with chemically initiated sealants than U-V light cured ones.

Rock (1973) found the U-V light initiated sealant to be superior. Stephen (1981) found no difference in retention between a chemically initiated and U-V light initiated sealant. Rock and Evans (1983) found better retention for a chemically cured sealant than a light cured resin.

One probable explanation for the generally lower retention of the U-V light initiated materials than the chemically initiated ones is that the U-V initiated sealants were the first generation Bis-GMA sealants produced. The U-V light used also had deficiencies in its radiation intensity (Ripa 1985).

Sveen and Jensen (1986) conducted a comparative study of a chemically cured sealant, Delton (Johnson & Johnson) and a visible-light cured sealant, Prisma Shield (LD Caulk). They found no significant differences in retention between the sealant types after two years. Wright, Fredman, Plotzke, Feasby (1988) did a similar study comparing a new visible light activated sealant, Helioseal (Vivadent) and Delton (Johnson & Johnson). After an 18 month follow up, they found no significant differences in retention. The retention of autopolymerised and visible light-polymerised Delton (Johnson & Johnson) fissure sealants was compared by Shapira, Fuks, Chosack, Houpt and Eidelman (1990). Sealants were applied to 207 first permanent molars with 304 separate sites in 73 children, 6-8 years old (mean age 6.3 years). After five years, there was complete retention in 59 per cent of the autopolymerised and 48 per cent of the light-polymerised sealants. The resulting 11 per cent difference in retention rates was not statistically significant ($P<0.05$). The

authors concluded that although the expected higher retention rates with light-polymerised sealant did not occur, the convenience in controlling polymerisation warrants the use of the light-cured material.

The primary determinants of success in fissure sealing are satisfactory etching, maintaining a contaminant - free enamel surface, and maintaining a dry field of operation. Contamination of the etched enamel surface before the application of sealant will prevent proper tag formation and thus poor retention. The principal intraoral factors which affect the operator's ability to sufficiently dry a tooth are the position of the tooth in the mouth, and its degree of eruption (Ripa 1985).

Studies have reported better sealant retention on the premolars, which can be more easily isolated, than the permanent molars where the maintenance of a dry field is more difficult (Bagramian, Srivastava, Graves 1979; Sveen, Jensen 1986).

Mitchell and Murray (1987) reported better sealant retention for lower teeth as compared to upper teeth. This may relate to the use of direct vision and lack of adverse gravity flow of the sealant when treating teeth in the maxillary arch. Ripa (1980) has shown that retention rates in mandibular molars are almost twice that of those in the maxilla.

Shapira and Eidelman (1984) presented the results of a study on the retention of sealants after mechanical preparation of a tooth after 3 years following application. The three year follow-up showed a significantly higher retention rate for sealants applied after mechanical preparation in upper molars (P=0.062). The total retention rate for the control group (without mechanical preparation of the fissure) was 81 per cent and this increased to 93 per cent full retention rate in the mechanically enlarged fissures, after thirty months of application. In mandibular molars, no difference in retention was detected as there were high retention rates in both groups. The findings of this study suggested that mechanical preparation is beneficial in achieving full retention for most of the subjects for whom the conventional technique for sealing maxillary molars fails. This procedure widens and deepens the fissure by eliminating organic material and plaque and a very thin layer of enamel, possibly resulting in a thicker layer of sealant. Retention rates for the mechanically prepared teeth was 88 per cent after 6 years (Shapira, Eidelman 1986).

Stephen (1981) found better retention in 8 to 11 year old children compared to 6 and 7 year olds. Rock and Bradnock (1981) also found better retention in 12 years old than 6 to 7 year olds. The younger the child the more difficult it is to maintain moisture control.

Reapplication of sealants

The sealant studies have shown the effectiveness of sealants as a very positive indication for sealants. The retention figures and those of the many clinical studies carried out can be expected to be even more effective where reapplication of any lost material can be a routine procedure. Sealant efficacy depends on sealant retention. Although the initial retention rate of sealants is high, regular control of these surfaces is necessary, at least during the first few years.

Some studies have reapplied sealants where necessary and reported replacement rates. In the Saskatchewan program after 2 years a cumulative rate of 6.6 per cent of 11,237 sealed first molars required resealing: 513 in the first year, 217 in the second year, and 15 in both years. Resealing rates after one year were reported by age. The rate for 5-7 year olds was almost twice as high, 6.2 per cent, as the rate for 8-15 years old, 3.3 per cent (Whyte, Leake, Howley 1987).

Mitchel and Murray (1987) conducted a retrospective survival analysis of 3,017 sealants placed between 1979 - 1981 at the Newcastle Dental Hospital, located in a fluoridated area. Information available through 1984 from 486 patients records revealed that 574 (19 per cent) of these sealants were replacements during this 3 to 5 year period. The median survival time for the sealants was 51 months, but was greater for older than younger children, premolars than molars, mandibular than maxillary teeth and those applied by staff than by students.

Straffon and Dennison (1988) reported clinical evaluation of sealant treatment received by a group of dental school patients, initially aged 6-8 years, for a 7 year period. At the recall appointment after baseline examination, 3.6 per cent of the sealants needed retreatment. The highest retreatment rate occurred at 6 months, when 19.6 per cent of the sealed teeth were retreated. During this cumulative 7 year period, 44 per cent of the sealants were reapplied at least once.

With exception of the high rate of reapplication of sealant shortly after initial placement, reapplication rates follow a trend similar to the rates of development of carious lesions or restorations in studies where sealant is not reapplied. These similarities provide further confidence in the ability of completely retained sealants to prevent decay. They also highlight the need to reapply sealants in this age group, 6-8 years, if the sealant is lost.

4.2 EXPERIMENTAL RESULTS WITH GLASS-IONOMER CEMENTS

In 1974, glass-ionomer cements were introduced after a two year clinical trial by McLean and Wilson. Aspa II (AD International), a glass-ionomer cement was used to seal 279 posterior teeth in patients aged between 9 to 16 years. Out of these, 250 teeth were available for examination after one year. Both clinical and radiographic examinations were made at yearly intervals to establish whether any secondary caries had occurred.

The percentage of fissures that remained fully sealed after 1 year is high (84 per cent). Only 10 per cent of sealants were lost after one year and 6 per cent partially sealed. After 2 years there was a retention of 78 per cent with a 14 per cent total sealant loss. The incidence of occlusal caries was very small and occurred only when the sealant was lost.

These studies lead to the conclusions that firstly glass-ionomer cements were only suitable as fissure sealants where the pit or fissure orifice exceeds 100 micrometers, and also that pits or fissures below 100 micrometers in size could only be treated if cement is overbuilt above the orifice. Early contamination of the sealant by moisture tends to weaken the poly (acrylate) matrix resulting in rapid wear with loss of cement. Therefore cavity varnish was used to protect the sealant.

Williams, Price and Winter (1978) conducted a 2 year clinical trial using ASPA IV (AD International), a glass-ionomer cement, and compared it to Nuva Seal (LD Caulk), an unfilled dimethacrylate resin, and Concise (Johnson & Johnson), a filled dimethacrylate resin. ASPA IV and Nuva Seal were applied to 406 teeth in 216 children of mean age 11.4 years at the time of application. ASPA IV was applied with a 2-mix technique and was protected by varnish. The teeth were conditioned with 50 per cent citric acid for ASPA IV. After 2 years, the results showed that 47 per cent of the patients retained ASPA IV and 12.8 per cent of the pits became carious. Nuva Seal application showed a 54 per cent retention and 16.6 per cent developed caries. The results in 205 patients showed that 96 per cent retained Concise and only 3 per cent had developed caries. The test showed Concise to be significantly better in reducing caries than Nuva Seal or ASPA IV (P=0.001) and ASPA IV and Nuva Seal were not significantly different in their cariostatic properties.

The 4 year results of a clinical trial comparing Concise, Nuva Seal and ASPA were evaluated by Williams and Winter (1981). Concise showed a higher rate of retention (88 per cent) and 8 per cent caries at 4 years. Nuva Seal showed a 36 per cent retention and 19 per cent caries at 4 years. ASPA was similarly compared with Nuva Seal. Despite a high initial loss of ASPA, at the end of 4 years the overall retention rates of the two materials were similar at 36 per cent and 34 per cent for ASPA and Nuva Seal respectively.

When these results are compared with the 2-year results by Williams, Price and Winter (1978), it is evident that there had been an additional loss of 13 per cent and 18 per cent for ASPA and Nuva Seal respectively during the final 2 year period, the resin sealant showing a slightly higher rate of loss than the glass-ionomer cement. Another difference between the two materials is shown in the caries increment scores, with a minute increase in caries incidence for pits sealed with ASPA of only 0.3 per cent from 12.8 per cent at 2 years to 13.1 per cent at 4 years, compared with a 2 per cent increase in the incidence of caries in teeth sealed with Nuva Seal from 17 per cent at 2 years to 19 per cent at 4 years. At 4 years there is a difference of 6 per cent in caries incidence between the two materials Nuva Seal and ASPA, which is statistically significant ($P<0.01$). The results are tabulated in Table 6.

Partial retention of Nuva Seal in many pits may continue to inhibit caries in these sites (Silverstone 1977) whereas with ASPA it is more likely that the high level of leachable fluoride in the glass-ionomer cement has affected the enamel in the region of the pit so as to render it less susceptible to carious attack. The leachable fluoride continues its cariostatic effect for several years after the cement has disappeared macroscopically from the enamel surface. There was also a net gain of 29 pits for ASPA over Nuva Seal and the percentage effectiveness was 31 per cent. Therefore it was concluded that ASPA performed better than Nuva Seal in this study.

Table 6: **Comparison of two clinical trials of two Bis-GMA resins, Nuva Seal and Concise and a glass-ionomer cement, ASPA**
Source: Adapted from Williams and Winter (1981)

Study/Year	Percentage Retention Rates			Percentage Occlusal Caries Occurrence		
	Nuva Seal	Concise	ASPA	Nuva Seal	Concise	ASPA
	TWO YEARS AFTER APPLICATION					
Williams et al 1978	54	96	47	17	3	12.8
	FOUR YEARS AFTER APPLICATION					
Williams et al 1981	36	88	34	19	8	13.1

Craig (1984), preferred glass-ionomer cements for treating newly erupted posterior teeth. These teeth are relatively porous and the fluoride ions released from the cement should help in the maturation and protection of the enamel in the vicinity of the pit and fissure system (Craig 1984).

The caries preventive action of glass-ionomer cement by its fluoride release into the enamel to increase its acid resistance was clinically demonstrated by Shimokobe, Komatsu, Kawakami and Hirota (1986). A glass-ionomer cement specially formulated for sealant and a resin sealant, Delton (Johnson & Johnson) were used to seal either the left or right molars of 222 children. The other molar with no sealant was used as a control. The glass-ionomer cement was applied into fissures after cleaning with brush cones under low speed and with water spray and Delton was applied according to the manufacturer's instructions. Use of varnish to protect against water contamination for the glass-ionomer cement is not mentioned here. The caries incidence of glass-ionomer cement and Delton were 4.9 per cent, 3.6 per cent after 6 months;

14.6 per cent, 10.7 per cent after 12 months; 37.6 per cent, 25.0 per cent after 24 months and 61.1 per cent, 43.2 per cent after 36 months respectively. In any of these periods Delton showed a lower caries incidence. Delton was retained even after 36 months, while the glass-ionomer cement disappeared in 6 months. But the per cent effectiveness of the glass-ionomer cement was 62.8 per cent after 12 months and 43.9 per cent after 24 months. This suggests that the cement has an effect on caries prevention even after it disappeared. The authors have improved the mechanical properties of the cement to prolong its retention period.

Boksman, Grattan, McCutcheon, Plotzke (1987) conducted a clinical study to evaluate the clinical effectiveness of a Bis-GMA fissure sealant, Concise white light-cured sealant (3M) and a glass-ionomer cement, Fuji Ionomer Type III (GC International). During routine dental treatment following the placement of the sealants, it was noted that a significant proportion of the Fuji III was lost between one and three months postplacement. Because of the high early loss and 94 per cent loss rate after 6 months, it was decided to abandon the study. Thus the authors suggested that clinical use of Fuji III glass-ionomer as a fissure sealant is unreliable, however, there may be residual caries protection in the glass-ionomer group even with this high early loss rate.

Another glass-ionomer cement Ketac Fil (ESPE) was applied as a fissure sealant to 115 maxillary and 117 mandibular permanent molars. Only six year old molars were included. This study was carried out under normal operating

conditions for training school dental therapists in Brisbane, Australia. Complete retention rates (93 per cent) after 6 months and 82.5 per cent complete retention after 12 months were compared with those obtained with Bis-GMA resin sealants in other studies (McKenna, Grundy 1987).

The results were compared with the 24 clinical trials where light cured and chemical cured Bis-GMA resins were used as sealants on premolar and molar teeth by Ripa (1982). One year retention rate for the majority of the trials was greater than 80 per cent. The complete retention rate in this survey of 82.5 per cent after twelve months was comparable with the majority rate of those cited by Ripa (1982).

Twenty one of the thirty five teeth where sealant was partly or completely lost were maxillary molars. Sealant was lost from 18 linguo-occlusal fissures compared with only 8 mesial pits on the maxillary molars, in the above study.

Hatibovic-Kofman and Koch (1991) did an *in vivo* and *in vitro* study on the fluoride release from glass-ionomer cement. Three glass-ionomer cements, Vitrebond (ESPE), Ketac Fil (ESPE) and Chem Fil II (Dentsply) were studied. In the *in vivo* study, the 3 glass-ionomer cements were placed in primary teeth in pre-school children. Unstimulated saliva was collected and the fluoride in the saliva was measured before placement of the restorations, immediately after, after 3 weeks, after 6 weeks, and after 1 year.

In the *in vitro* study, test specimens of glass-ionomer cements were placed in deionised water and the release of fluoride was measured weekly for 16 weeks. At week 12, samples were exposed to fluoride toothpaste.

The concentration of fluoride in saliva was 0.04 ppm before placement of the restorations. After three weeks it had increased to 0.8 ppm and the level remained as high a 0.3 ppm even after 1 year. In the *in vitro* study the tested glass-ionomer cements showed a capacity to absorb fluoride from the fluoride toothpaste and then release it. It was concluded by the authors that glass-ionomer cement can act as a rechargeable slow release fluoride device (Hatibovic-Kofman, Koch 1991).

In conclusion, it is felt that when resins are attached to enamel by acid etching techniques, they provide stronger mechanical bonds than the molecular bonds of glass-ionomer cements. The retention rate generally appears to be lower for glass-ionomer cements than for resin sealants. However long term follow-ups have not been reported. Glass-ionomer cements when used as fissure sealants are not successful when placed in fissures that have a small orifice. Although the cement may be applied to such a fissure, it will soon be lost through erosion/abrasion. By contrast, when glass-ionomer cements are placed in patent fissures as sealants they are very successful (McLean, Wilson 1974). The glass-ionomer cements tended to wear away evenly rather than peel away in bulk, as the Bis-GMA resins are prone to.

The long term effectiveness of adhesive resins as a caries preventive agent are more important than short-term effects. Clinical evaluation of sealants have undergone several stages during the past two decades. Variables in study design, in experience, and lack of understanding by early investigators of certain pitfalls in the clinical technique resulted in questionable and conflicting data.

Studies with self-curing sealants were later done followed by the few visible light-cured sealant studies. These produced more encouraging long-term results. Sealant efficacy depends on sealant retention.

The glass-ionomer cements with their superior properties, namely ability to bond chemically to dentine and enamel and active fluoride release into the surrounding enamel, have not been able to match the adhesive resins in their retentive capacity over long-term clinical trials. They, thus remain as alternatives and have not superseded the adhesive resins, chemically cured or light cured as superior fissure sealant materials.